Hungarian University of Agriculture and Life Sciences
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Thesis Title:

Assessment of Calcium, Magnesium, Manganese, Lead, and Iron Concentration in Drinking Water Between Gödöllő and other Regions of Hungary

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Abstract

This thesis presents a comparative analyzing of the potential topical elements concentration of Fe, Mg, Pb, Ca and Mn between Gödöllő and 19 cities across Hungary. These elements were selected due to their significant health impact, specially lead, and their implication in infrastructure such as pipes distribution system. The total amount of samples evaluated are 22, where 3 samples were taken from Gödöllő and the rest in other regions. The assessing compliance for water quality will be done by following The World Health Organization water guideline and the Hungarian government water framework.

The methodology included tap water collection from restaurant, public pitches, MATE University dormitory and public places such as train station. The water collection took approximately half year and the water were preserved at 4°C before their analyzing by using Inductively Couple Plasma Optical Emission Spectroscopy (ICP-OES).

The results indicated that Hungary tap water quality are withing the water frame internationally and locally, except for one sample were Fe concentration were above the limit values suggesting that the sensorial experience and acceptability might be affected. Recommendation includes monitoring were all samples reach the limit values, specially for those who Pb concentration reached their maximum level, and an investigation for possible Fe contamination in drinking water..

Contents

1. Introduction

Water is vital for the survival of life forms where we, as human, are very dependable of it every day. The key term for this study is drinking water. According to PhD Frank R. Spellman, it can be defined as the water delivered to the consumer that can be safely used for drinking, cooking, washing and other household application (Spellman, 2018) The provision of drinking water must be safe and acceptable for consumption. To be acceptable, the drinking water must be odorless, tasteless, and colorless (WHO, Guidelines for drinking-water quality: fourth edition incorporating the first and second, 2022). The water quality is our major concern, but the quality of drinking water is very dependable of geological, industrial, water distribution infrastructure and human activities (EEA, 2022), (Banks, 2015). The concentrations of potential topical element such as lead Pb, M, Mg, Fe, and Ca in drinking water can have an impact on public health, and the acceptability of it (odor, color and taste of the drinking water), (Chowdhury, 2016). Elements like lead and Mn when exceeding the limits established by the World Health Organization or locals' regulation, can cause health issues to the consumers, mainly attacking the nervous system (Cotruvo J. , 2019). The Fe does not have toxic effect in drinking water, but higher concentration can affect the sensorial experience like odor, color, and taste (WHO, Iron in Drinking-water Background document for development of WHO Guidelines for Drinking-water Quality, 1996). Ca and Mg are not toxic, but they play an important in water hardness (Kozisek, 2020).

Hungary, as member of the European Union (EU), must follow certain international standard for drinking water established by the EU as a guideline to preserve human health and suggestions made from the world Health Organization (EU, 1998), but they also have their local water framework (Jogtár, 2023). As a current state member, they have adopted strict parameter regarding the different geographical and local condition that can affect the quality of the water between regions. The quality of the water is very dependable of its environment, variable such as geology, human activity, and even the conditions for water distribution.

The most dangerous elements in drinking water for our study are Mn, and lead (Pb), because of its potential threat to public health, having a bigger impact on children. Lead is well known for its effect in the nervous systems. Even low concentration of lead can cause adverse effect on human in long terms. Chronic exposure can be even more fatal, when in extreme cases, can cause death (Jarvis, 2021). In the other hand, Mn is a trace element essential in our body, but at higher concentration, can cause adverse problem, affecting our neurological system, studies in China reported a decreased school performance and neurobehavioral issues in children exposed to high level of Mn (0.241 mg/L) in drinking water. Chronic intake to high levels of Mn in drinking water can lead to neurological symptoms similar to Parkinson's disease (WHO, Manganese in Drinking-water, 2011). Higher concentration of Fe affects the taste, color, and odor of the water. Water containing inorganic Fe is usually yellow or brown color, but may be colorless, and has metallic taste (IDPH, 2010). It has not toxic effect on human, but it can contribute to the corrosion of the pipes (WHO, Iron in Drinking-water Background document for development of WHO Guidelines for Drinking-water Quality, 1996).

Due to the high impact that the water has on the public health, constant monitoring is required. In Hungary, an EU funded programmed revealed that the presence of lead still in drinking water in higher concentration. The samples were taken from tap water in residence in Budapest. The concentration reach level above 60μg/L. This has increased the concerns of the public opinion

(ZSILÁK, 2020). Although the governmental water framework is well aligned with international standards, the variability of geographical position, and the human activity is a contact challenge. Urban areas in different part of the country might present different water concentration for these potential topical elements, due to the geological composition, industrial activity, or the aging of pipes in the infrastructure.

The scope for this study is to analyze the quality of the water of Gödöllő, a city found in the center of Hungary, and compared their chemical concentration for lead (Pb), Mn, Mg, Fe, and Ca in drinking water with 19 cities distributed in the rest of the country. This analysis will be made by following the international water framework set up by the World Health Organization (WHO), and the local governmental water framework, allowing us to identify whether the cities where the samples were taken compliance the parameter or the city with higher risk of water contamination for the public health.

The study not only focus on the contamination of potential topical elements, but also in the water hardness. The presence has implication in sediment accumulation in the pipes, the efficiency in heaters and longevity of domestic device (WHO, Hardness in Drinking-water: Background document for development of, 2011). The water hardness in Hungary is variable, from region where the water is very hard, and others where is moderately hard. The variability of this factor will be projected in a geospatial analysis, where we can have a better understanding on how water hardness, and the potential topical elements of the study are distributed.

The main goal for this study is to make a comparative analysis of the water quality of Gödöllő with the following regions: Pécs, Veszprém, Dunaújváros, Szabadegyháza, Eger, Gyöngyös, Budapest, Miskolc, Fehérgyarmat, Győr, Debrecen, Békéscsaba, Komló, Szombathely, Szekszárd, Kecskemét, Szolnok, Nagykanizsa, and Szeged. The cities were selected in a way that we can cover most of Hungary. With the geospatial analysis, we can evaluate the hardness, presence of the potential topical elements and their compliance with the WHO and local water framework. By analyzing the water concentration of lead Pb, Mn, Mg, Fe, and Ca in drinking water and the geospatial analysis, we can determine areas with higher risk of contamination.

2. Literature Review

The drinking water quality is liked to the well being of the society. Its quality impacts health, economic and social aspects. The equal distribution of safe drinking water in one of the priorities of international organizations such as United Nations, as it is in their Sustainable Development Goal (SDG) target 6 (UN, United Nation: Department of Economic and Social Affairs, 2023). Although the chemical composition of the can varies based on many factors like natural geological activities or anthropogenic activity contaminate the water (Banks, 2015). Therefore, access to high quality drinking water is a constant challenge, that require constant monitoring and regulation to preserve the public health and reduce its social and economical aspect. Although the access to drinking water is one of the main goal for a sustainable future, it is still estimated that around 2 billion people around the world still without access to safely managed drinking water, and 771 million people cannot even access to basic drinking water services (kashiwase, 2023). It is well known that contaminated water and poor sanitation are carries several diseases such as cholera, diarrhea, hepatitis A, dysentery, typhoid and polio (WHO, World Health Organization, 2023), and the poor management of urban, industrial and wastewater contaminates the drinking water of million of people, exposing them to higher concentration of contaminant such as Pb in drinking water, which comes mainly from lead pipes and Pb solder to join pipes and can lead to neurological problems, especially in children, affecting their behavior and intelligence quotient (IQ) (Jarvis, 2021). The World Health Organization published that 1.5 million of death globally were attributed to Pb exposure in 2021 (WHO, World Health Organization, 2024). Consequently, limits values for many aspects, microbiological, chemical, physical, and radiological, where locally and international as the proposal for the WHO established, including potential topical elements such as Ca, Mg, Fe, Mn, and Pb.
The WHO has established limit values for Pb and Mn, which at high dose poses a threat to human health, while for Ca, Mg and Fe, and the water hardness, there is not an established limit values because they do not pose a threat for human health, but it can affect the acceptability for drinking water (WHO, Guidelines for drinking-water quality: fourth edition incorporating the first and second, 2022). Besides the health impact, poor management of drinking water can also lead to social and economic issues. Access to improved water sources and distribution services reduced the time for water gathering, allowing the population to focus more time on other activities and contributing to personal safely since they do not need to travel long distances seeking for water, and they will get sick less, since they will be less expose to contaminant in drinking water (WHO, World Health Organization, 2023). To mention one example of how potential topical elements can contribute to economical loses, we can mention Fe. High concentration of Fe contributes to the corrosion of pipes, which in the long term will affect the taste, color, and odor of the water, impacting the acceptability of the drinking water[1].

2.1 Human Health Impact of Pb, Mn, Fe, Ca and Mg in Drinking Water

Potential topical elements in drinking water is well regulated locally and internationally. Pb and Mn are the most concerning heavy metal in this study due to their impact on human health. Both can damage the nervous system, especially Pb, which even at lower concentration can cause adverse health problem. Those elements have very well documented health effect, causing bigger impact in children.

Pb in Drinking Water

The World Health Organization has identified Pb as one of one of the ten chemicals with major concern for public health, which it is attributed 0.9 billion of death annually and contributes to the 30% of the global burden of developmental intellectually disability of unknow origin (WHO, Iron in Drinking-water Background document for development of WHO Guidelines for Drinking-water Quality, 1996). Pb is associated as a neurotoxin component due to its adverse effect on the neurological system, having a bigger impact on children (Jarvis, 2021), but it has more implication than just that. In drinking water is documented that Pb contamination has implication on kidney problems and can interfere with the production of red blood cells that carry oxygen to all parts of your body. (Spellman, 2018) (Department, 2024). According to the WHO, depending on the concentration of Pb found in drinking water, and the age of the individual, being children the most vulnerable, Pb can have different approached (WHO, World Health Organization, 2023).

High concentration of Pb exposure on children can severely damage the brain and neurological central system, causing coma, convulsions and even death, and children who survive severe Pb exposure from drinking water, may be left with permanent behavior disorders and intellectual problem. Lower concentration of Pb can be unnoticed, but in the long run, the individual who is exposed can have learning disability, and reduced intelligence quotient (IQ), behavioral changes including reduced attention span and increased antisocial (WHO, World Health Organization, 2024) behavior and reduced educational attainment. Pb exposure also causes anemia, hypertension, renal impairment, immunotoxicity and toxicity to the reproductive organs, showing that even lower concentration of Pb has a huge impact on children (WHO, Exposure to lead: a major public health concern, third edition. Preventing disease through healthy environments, 2023). According to the U.S Centers for Disease Control and Prevention, Pb poisoning can lead to reproductive problems, decreased of kidney function, hypertension, and cardiovascular problems in adults, and for pregnant women, stunted growth of the fetus and premature birth (CDC, What are the Possible Health Effects from Lead Exposure, 2023). It is important to mention that Pb is a bioaccumulating element with a half-life of approximately 30 years, being deposited primarily in the bones, and it is not excreted. It can be re-mobilized thought aging, pregnancy, or Ca deficiency (Cotruvo J. , 2019). Actually, the limit value for Pb in drinking water for safe consumption is 10µg/L, with an achievable goal of 5µg/L (WHO, Guidelines for drinking-water quality: fourth edition incorporating the first and second, 2022). Pb is presence naturally on Earth’s crust, mainly as lead sulfide (galena) and found in sedimentary rocks like shale (WHO, Exposure to lead: a major public health concern, third edition. Preventing disease through healthy environments, 2023) (Nagajyoti, 2010). However, it is not the main source of contamination in drinking water. It is main attributed to the corrosion lead-base pipeline, which it can infiltrate the water system, one of the reasons which water must not be corrosive at any level (Spellman, 2018). In Europe, around 0 – 50% of water distribution system, still pipelines (Jarvis, 2021), therefore there are many aspects to consider when investigating water for Pb contamination sources. The WHO established a co-parameter explaining how water chemistry can influence the corrosion of lead-base pipelines and consequently contaminate the water. The combination of elements, such as Fe, Mn, and natural organic matter (NOM) can affect the water distribution system. For the previous example, it is documented by WHO that the combination of these element can accelerates the dissolution of PbO2 scales in pipes supplies with excess of chlorine acting as a reductant (WHO, Lead in drinking-water: health risks, monitoring and corrective actions. Technical brief, 2022).

Mn in Drinking Water

The difference between Pb and Mn is that Pb has no function in our body. Mn is a trace element important for the function of our nervous system, it supports our immune system, and help to regulate the sugar blood level (WHO, Evaluation of Certain Food Additive and Contaminant, 2011). It is well documented that Mn airborne fumes exposure led to neurological condition similar to Parkinson’s disease, but there is a controversy whether oral ingestion can lead to the same condition. Although The World Health Organization states that oral intake of Mn is the least toxic (WHO, Manganese in Drinking-water, 2011), but several studies conducted at high concentration of Mn in public water supplies showed that there was negative effect on human health. A study in Japan suggested that high concentration of Mn in water can bring adverse health affect after 16 cases were reported for Mn contamination in drinking water, where 2 cases were fatal and once committed suicide (Kawamura, 1941). According to the WHO, the concentration was poorly quantified because people were also expose to high concentration of Zinc. Either way, The WHO established a limits value of 400µg/L base on tolerable daily intake (TDI) concluding that there is not sufficient quantitative data to set toxic limit values for Mn (WHO, Manganese in Drinking-water, 2011).

A study in Bangladesh suggested a correlation between the intake of Mn-contaminated water and behavioral problems. The study focused on children aged 8-11years old who were exposed to a mean concentration of Mn (889.2µg/L), and median concentration 649.5µg/L, suggesting a correlation to behavioral problems such as: anxiety, depression, aggression, and attention problem (Khan, 2011). However, the standard deviation was 783.7µg/L, suggesting that there was a high variability in the results, where children were expose to high Mn concentration, and others to lower Mn concentration. Another study focused on children in Canada suggested that high concentration intake of Mn in drinking water can lead to Intellectual impairment where 6.2 points differences in IQ were found between the lowest and highest Mn quantities. According to Minnesota Department of health, this health condition affects adults and children (Department, 2024). Although Mn contamination may not lead to condition similar to Parkinson’s disease, different studies has concluded that exist a correlation between behavioral problem and intellectual impairment, and long-term exposure to Mn-contaminated water for concentration that exceeded way more than 400µg/L established by WHO.

Fe in Drinking Water

According to WHO, there is no toxic limit value below acceptability levels (0.3 mg/L), but it does influence the organoleptic properties (the taste, odor, and color) (WHO, Guidelines for drinking-water quality: fourth edition incorporating the first and second, 2022). Concentration below 0.3mg/L are considered unnoticeable in drinking water, and higher concentration promotes undesirable bacterial growth (“Iron bacteria) in distribution system, resulting in the deposition of a slimy coating on the piping (WHO, Iron in Drinking-water Background document for development of WHO Guidelines for Drinking-water Quality, 1996). This outcome has been linked with lead leachate from lead-base pipeline.

Several risks assessment made in Bangladesh suggest that high concentration of Fe can lead to cardiovascular problems and diabetes (Ghosh, 2020) (Rahman, 2021), however no case for Fe poisoning were reported and both element Fe, and Mn were considered together as contaminants and not separately. This can suggest that the combination of both element, Mn, and Fe, can pose a threat at elevated concentration levels (>0.3mg/L).

Ca and Mg in Drinking Water

These heavy metals are important trace element which play an important role in our health (Standing Committee on the Scientific Evaluation of Dietary References Intakes, 1997). Therefore, there is no toxic limit values establish by WHO or Hungarian government (WHO, Guidelines for drinking-water quality: fourth edition incorporating the first and second, 2022) (Jogtár, 2023). Instead, some studies suggest the benefits of Ca and Mg intake, considering water as part of our dietary Ca and Mg intake (WHO, Calcium and Mangensium in Drinking water, Public health significant, 2009). Hight Ca intake results in reduced risk of kidney stones, and in combination with Mg, sodium and potassium brings some cardiac benefits (Cotruvo D. J., 2018). When it comes to water, both elements play a more complex role. Usually both heavy metals are used to measure water harness. Water hardness is commonly defined as the sum of the polyvalent cations dissolved in the water (Spellman, 2018).

$$Hardness\ (°dH\ CaO_3) = (\frac{[Ca^{2+}]mg/L}{20}) + (\frac{[Mg^{2+}]mg/L}{12})$$

There is a controversy whether the hardness of the water influences the public health. Documented investigations in Taiwan have found a correlation between various diseases such as: coronary mortality, gastrointestinal tract cancers, cerebrovascular disease, and the water hardness (WHO, Calcium and Mangensium in Drinking water, Public health significant, 2009) but the information about the concentration of Ca and Mg where not provided. The World health organization sees water hardness as an important contributor in diet for marginal for Ca and Mg intake. A report published by the University of Calcutta, evaluated the potential health impacts of hard water. In the report, several diseases were linked to hard water, documenting an inverse relationship between water hardness and cardiovascular disease, but it also indicates a negative association between various cancers like gastric, colon, rectal, pancreatic, esophageal and ovarian cancers, and the water hardness (Sengupta, 2013). Regardless of the debate whether there is health risk, studies are still conducted and WHO considered that there is not sufficient data to determine health limit values for hardness (WHO, Hardness in Drinking-water: Background document for development of, 2011)

Hardness is mostly expressed as Ca carbonate ($CaCO_3$) equivalent per liter, but it can also be expressed and calcium oxide concentration (CaO) by the unit measure °dH. The WHO considered that concentration below 60 mg/l (0.00 – 3.37°dH) is considered as soft; 60–120 mg/l (3.38 – 6.74°dH), moderately hard; 120–180 mg/l (6.75 – 10.11), hard; and more than 180 mg/l (≥ 10.12°dH), very hard (WHO, Hardness in Drinking-water: Background document for development of, 2011).

2.2 Importance of potential topical elements evaluation in drinking water

We call heavy metal to those elements with atomic weight between 63. And 200.5, and specific gravity greater than 4.0 (Spellman, 2018). The evaluation of heavy metal in drinking water is a public concern topic, especially for Pb. in Hungary elevated level of Pb were documented after an EU funded program analyzed the tap water chemistry in Budapest (ZSILÁK, 2020). No Pb poisoning cases were reported. An investigation conducted in Pakistan showed elevated level of Pb in drinking water (0.21ppm in piped water, 0.64ppm in hand pump water, and 0.37 in tanker water) (ZSILÁK, 2020). Although no case was reported, the investigation highlighted the significant health risk for kidney damage, hypertension, and other toxic effects. Not everyone is aware of the taste, odor, color or health impact of water in their health, although the water is contaminated. In the District Vehari, Pakistan people reported water borne diseases, but the survey showed poor awareness regarding water quality. Besides, the people didn't complain about water or asked to get their water tested. The investigation documented that waterborne diseases not related to microbial contamination were found (Khalid, 2018). This suggest that there is an unknow source of contamination affecting the population, and a significant number of people are unaware.

Hungary, as a member state of EU (euro, n.d.), is compromised to international standard and suggestion made by WHO. The relevance of the evaluation of heavy metal in drinking water is to preserved public health, and people with limited knowledge about water quality. The WHO sees water as a right, and valuable source that should be accessible in quantity, and quality (WHO, World Health Organization, 2023).

2.3 International and national water framework

To preserver the public health when drinking water, limits values for toxic potential topical elements has been set. Every country has their own water framework, and the limit values might be different due to geological differences and human activities. The compliance of these standard are important to established a concept ang guideline about what water quality is, focusing on the prevention of waterborne diseases and guarantee a safe water source to drink, and use for daily day task as cleaning, cooking, bathing, etc. This section will present the standard limit values established by WHO and Hungarian government.

2.3.1 Normative for drinking water quality established by WHO and Hungarian Government.

The World Health Organization has established limit values for several microbial, chemistry, physical and radiological properties as a guide to preserved public health consumption and usage, based on research and investigation perform globally. The updated version is the guidelines for drinking water quality Published in 2022. The same way, Hungarian government has published their own limits values.in this study our main concern are the potential topical elements, specifically Ca, Mg, Fe, Mn, and Pb. The Hungarian water framework is more stringent than WHO, when it comes to Fe, and Mn (Jogtár, 2023). It is important to mention than WHO established limits values as a global target, as it is mentioned in the SDG 6 by the United Nations (UN, sdg6data.org, n.d.). Although there are limit values set up by international organizations, it does not interfere with the sovereign of country to rule and manage their own water resources.

- The World Health Organization: a limit value of 10µg/L is recommended as guideline for Pb. It is important to mention that there is nontoxic concentration know for Pb in drinking water since even lower concentration can lead to adverse health effect and new target values are being considered for the next update, reducing the concentration to 5µg/L (WHO, Exposure to lead: a major public health concern, third edition. Preventing disease through healthy environments, 2023). For Mn, the limit value is 400µg/L (WHO, Exposure to lead: a major public health concern, third edition. Preventing disease through healthy environments, 2023). The suggested value for Fe is 300µg/L since below that concentration, Fe is unnoticeable (WHO, Exposure to lead: a major public health concern, third edition. Preventing disease through healthy environments, 2023). And for Ca and Mn, there is no toxic concentration values for both element and the water hardness (WHO, Guidelines for drinking-water quality: fourth edition incorporating the first and second, 2022).
- Hungarian government: the Hungarian drinking water guidelines are similar to the value established by WHO. Being more stringent with Mn, with a concentration limit value of 50µg/L, and Fe with a limit value of 200µg/L. by 2036, the Hungarian government has targeted limit value of 5µg/L for Pb. And when it comes to Ca and Mg, no limit value has been established for the elements and for the water hardness.

2.3.2 Importance of their compliance

The compliance of the water limit for potential topical elements is important not only because of the public health, but because their important is more complex than just that, involving cultural, sustainability economic, and social aspect. As we have mentioned before, Fe play a crucial role in acceptability. Higher concentration can modify the sensorial experience changing the consumer perspective, which could lead to complains and the use of potentially unsafe water sources (WHO, Guidelines for drinking-water quality: fourth edition incorporating the first and second, 2022). Havin accessible clean drinking water allowed people to invest their time in other activities rather than water gathering, exposing themselves to risk when traveling, and it also means more human power to develop the area (WHO, World Health Organization, 2023). In the case of Hungary, where water gathering is not needed, it means that the population will get sick less, reducing the economic impact for medical expenses and days off, and possible long term permanent health issues.

We can also mention that having safe drinking water increases the reliability of the population toward their government, strengthening the trust for local and international people.

3. Methodology

3.1 Sampling collection

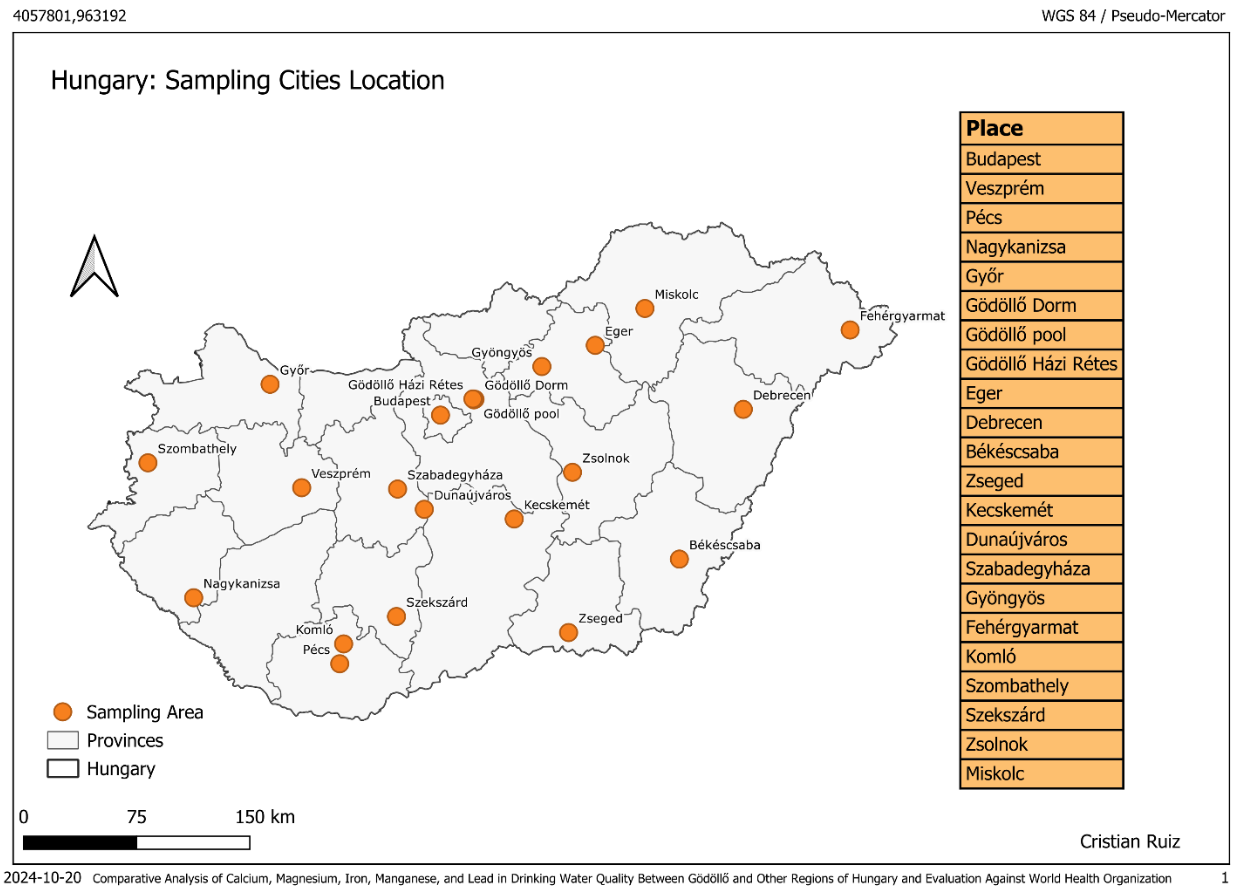


Figure 3.1.1

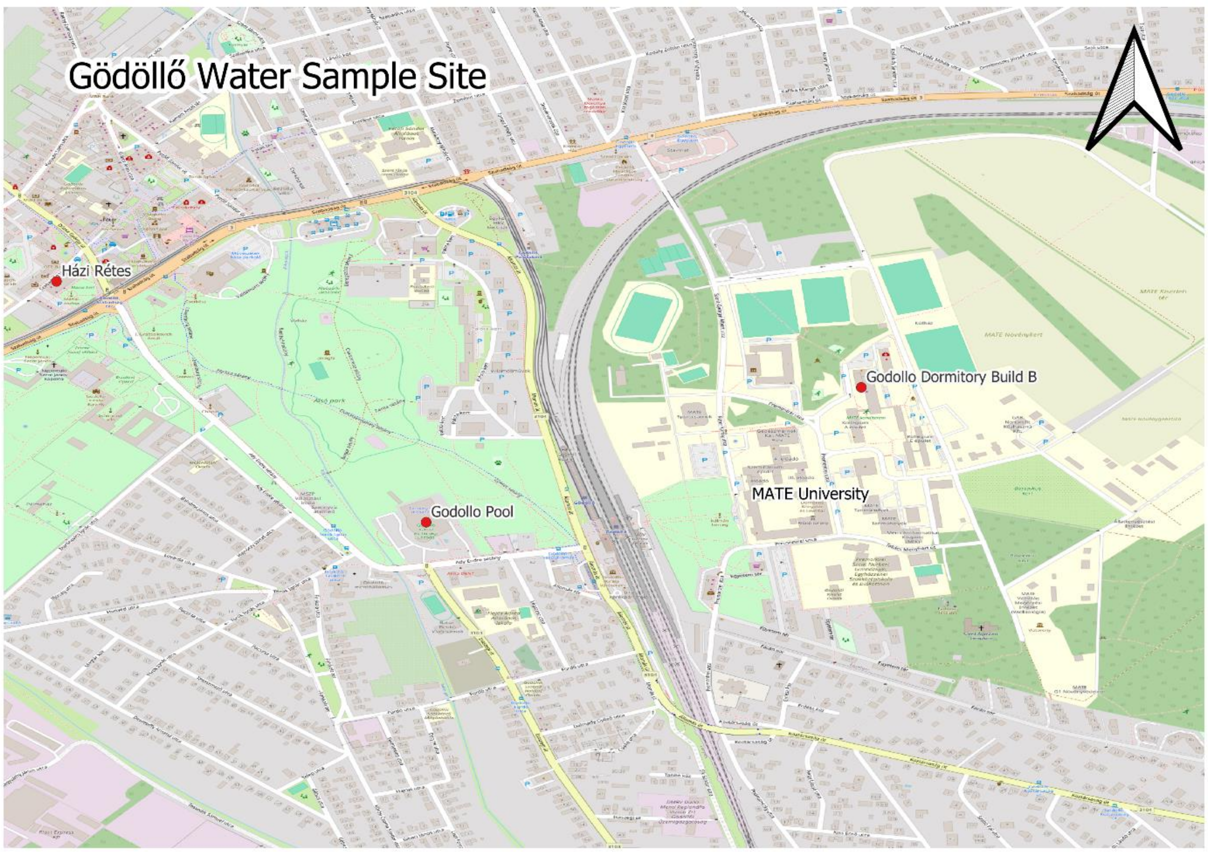
Date	Place
3/13/2024	Budapest 1078 Nefelejcs
3/19/2024	Gyöngyös
3/25/2024	Dormitory Building B Gödöllő
4/7/2024	Miskolc
4/10/2024	Gödöllő Pool
4/10/2024	Gödöllő Házi rétes
4/12/2024	Eger

Date	Place
5/20/2024	Fehérgyarmat
5/21/2024	Győr
6/21/2024	Debrecen
6/21/2024	Kecskemét
6/21/2024	Szolnok
6/21/2024	Szeged
7/2/2024	Békéscsaba

4/23/2024	Pécs	7/10/2024	Komló
5/3/2024	Veszprém	7/15/2024	Szombathely
5/6/2024	Dunaújváros	8/5/2024	Szekszárd
5/17/2024	Szabadegyháza	9/9/2024	Nagykanizsa

Table 3.1

For the following study, 22 samples of water were collected from different cities across Hungary: Pécs, Veszprém, Dunaújváros, Szabadegyháza, Eger, Gyöngyös, Budapest, Miskolc, Gödöllő, Fehérgyarmat, Győr, Debrecen, Békéscsaba, Komló, Szombathely, Szekszárd, Kecskemét, Szolnok, Nagykanizsa, and Szeged. From Gödöllő we analyzed 3 samples, and the rest was just 1 sample per city. The samples were obtained in a period between March and September 2024, with the main goal to cover most of the Hungarian country considering the differences between the geographical position of the cities and urban areas. The samples cover the north, south, west, east, and center of Hungary.



In Gödöllő, 3 samples were extracted and then georeferenced in a detailed map of the city, showing the exact location where the samples were taken.
The samples were collected in urban areas such as:

- Restaurants
- Public water fountains such as Kecskemét train station.

- Public bathroom
- Residence area

All samples were contained in a plastic container, provided by the laboratory of the university through my thesis supervisor. To preserve the quality of the samples, they were refrigerated immediately at 4 ° Celsius after collection until the day for the measurements to prevent possibles chemical alteration before the analysis.

3.2 Heavy Metals Analysis

The concentration's analysis for potential topical elements (Ca, Mg, Mn, Fe, and Pb) in the drinking water was performed on September 18th, 2024, using the inductively coupled plasma – optical emission spectrometry technique (ICP – OES). A very sensitive method for metal detection and quantification.

The analysis was performed under the supervision of my thesis advisor, using the following equipment in the laboratory:

- Instrument: Agilent 5800 ICP-OES

Figure 3.1.2

I was not personally participating in the sampling analysis, but my supervisor sent the raw data with values such as Standard Deviation (SD), and Relative Standard deviation (%RSD). This suggest that the analysis was performed by doing the necessary repetition to guarantee the accuracy of the results.

3.3 Software

For the results, many Programs and tools were used for analyzing and visualization for the data:

- Microsoft Excel and Google Colab (Python) were mainly used for data processing. Python were used for mathematical operation to calculate the water hardness, and excel to store the raw data and create the csv file for QGIS, where all the information related to coordinates (latitude and longitude), potential topical elements concentration and cities were processed.
- QGIS was used for mapping. A shape file (.shp) for Hungary was downloaded from the internet with the province division. By using quick OMS Standards, and csv file previously done in excel, I was able to identify the location in the map where the samples were taken. Two maps were created, one for better visualization of how much was cover in the country and the other is a detailed map about Gödöllő that shows the exact location were the three water samples were taken.

- Google Colab (R) was mainly used to for data visualization. All graph charts were done by coding.

3.4 Standards Compliance

The concentration those five heavy metals were evaluated and compared following their compliance with World Health Organization and with the Hungarian's standards. The evaluation was done directly by comparing the result and the standards to determine whether the water samples meet the expected quality internationally and locally.

3.5 Hardness Calculation

For Gödöllő hardness determination, we took the mean value of the three samples. To calculate hardness for all samples, the math operation was done in Google Colab with Python Kernel. All values were written in a excel sheets along with the city coordinates, then it was converted into a CSV file for QGIS mapping. With the harness values, and location of the place, I was able to create a graduated map that shows their harness classification. The codes used will be attached in the annex. The unity used for water hardness is °dH, which 1 °dH is equivalent to to 10 mg/L of CaCO3 and 1 mg/L of Ca is equivalent to 20 mg/L. 1 mg/L of Mg is equivalent to 12 mg/L of CaCO3.
The Python codes follows the following mathematical operation.

$$Hardness\ (°dH\ CaO_3) = (\frac{[Ca^{2+}]mg/L}{20}) + (\frac{[Mg^{2+}]mg/L}{12})$$

Where:

- 20 = number used for Ca convertion to °dH.
- [Ca] = Calcium concentration in water (mg/L)
- 12 = number used for Mg convertion to °dH
- [Mg] = Magnesium concentration in water (mg/L)

4. Results

4.1 Results for Gödöllő Water Samples.

Three water samples from Gödöllő were analyzed, taken from different places inside the area, including one bakery, the dormitory building B and Gödöllő pool. The elements evaluated were Ca, Mg, Mn, Fe, and Pb.

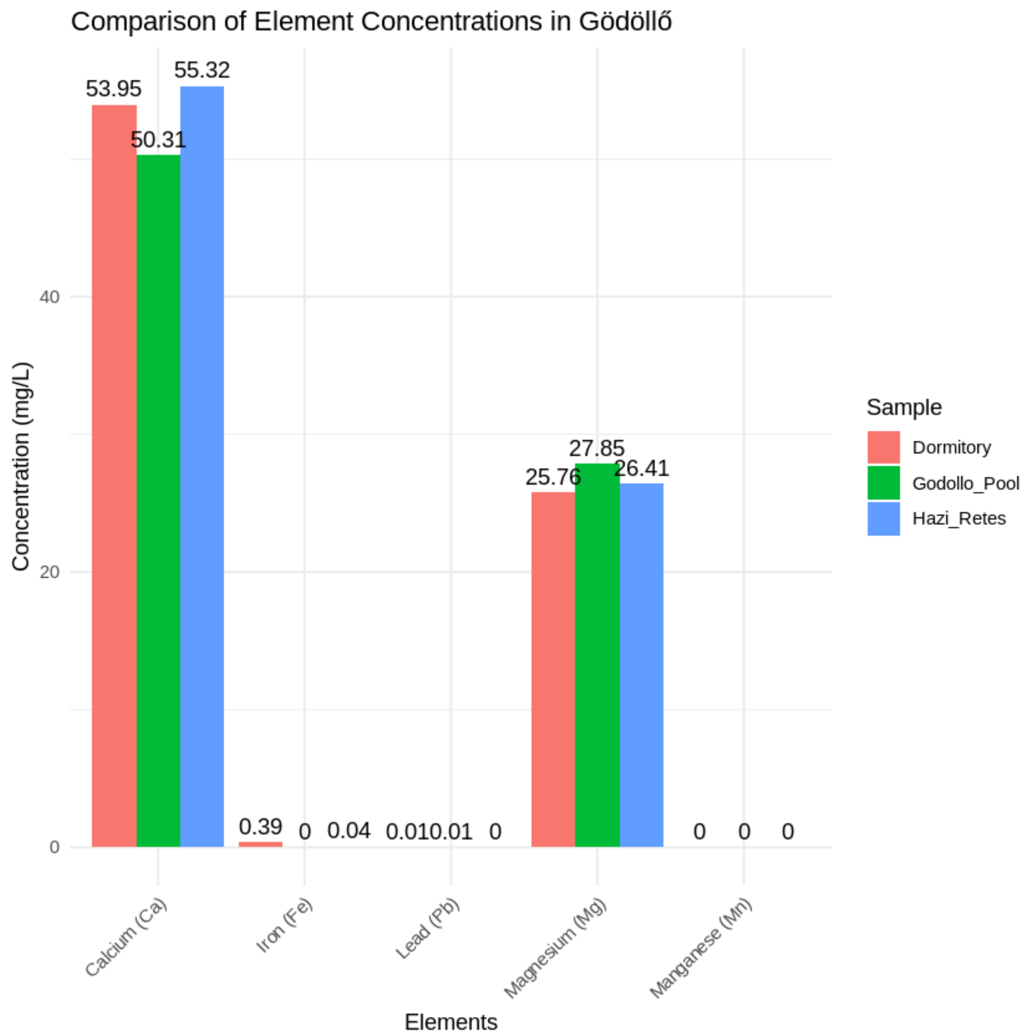


Figure 4.1.1

We can see concentration in drinking water of Ca, Mg, Mn, Fe, and Pb for each place where the samples were taken in Gödöllő. Cero means that they are under detection limits.

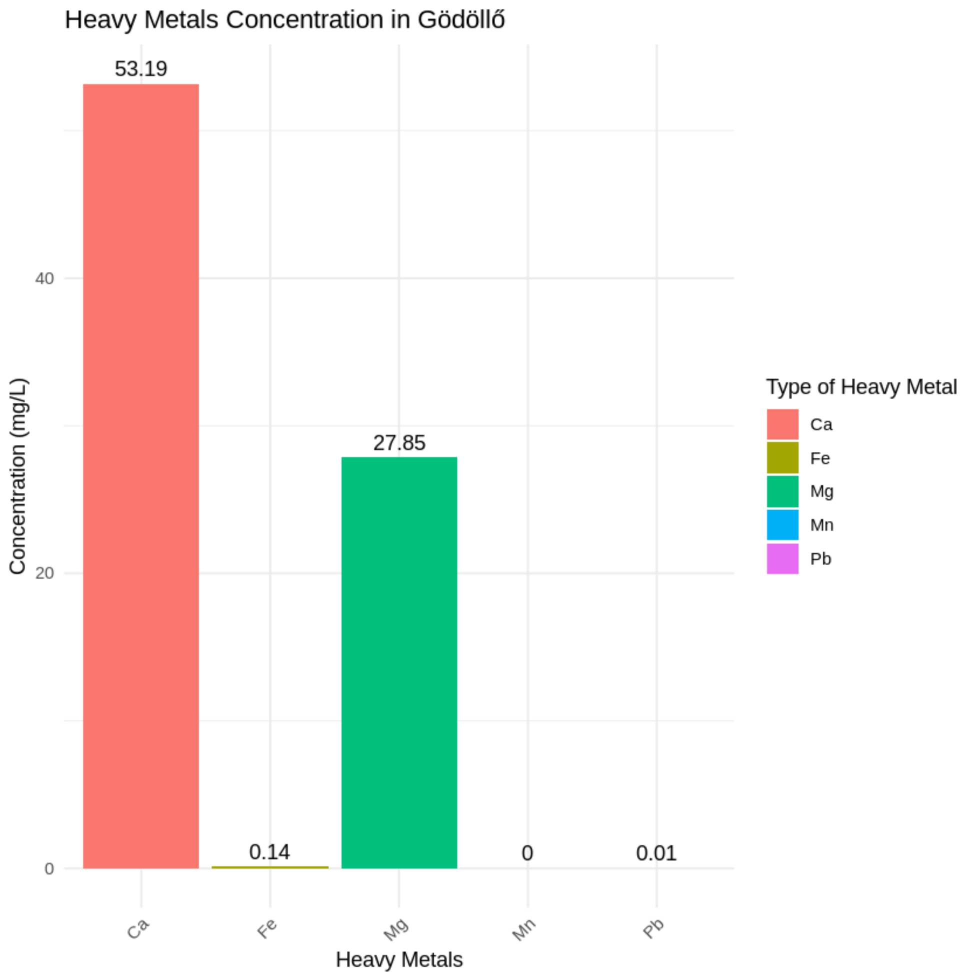


Figure 4.1.2

The mean values concentration in drinking water for Ca, Mg, Fe, Mn, and Pb, where the only element under detection limit was Mn, which suggest it was not detected in our samples.

4.2 Concentration Values for Other Regions and Comparison with Gödöllő

To evaluate the differences between Gödöllő and the other regions of Hungary, the concentration for the same elements were measure in samples taken from 19 different cities across the country. The results are shown in the following tables:

Calcium

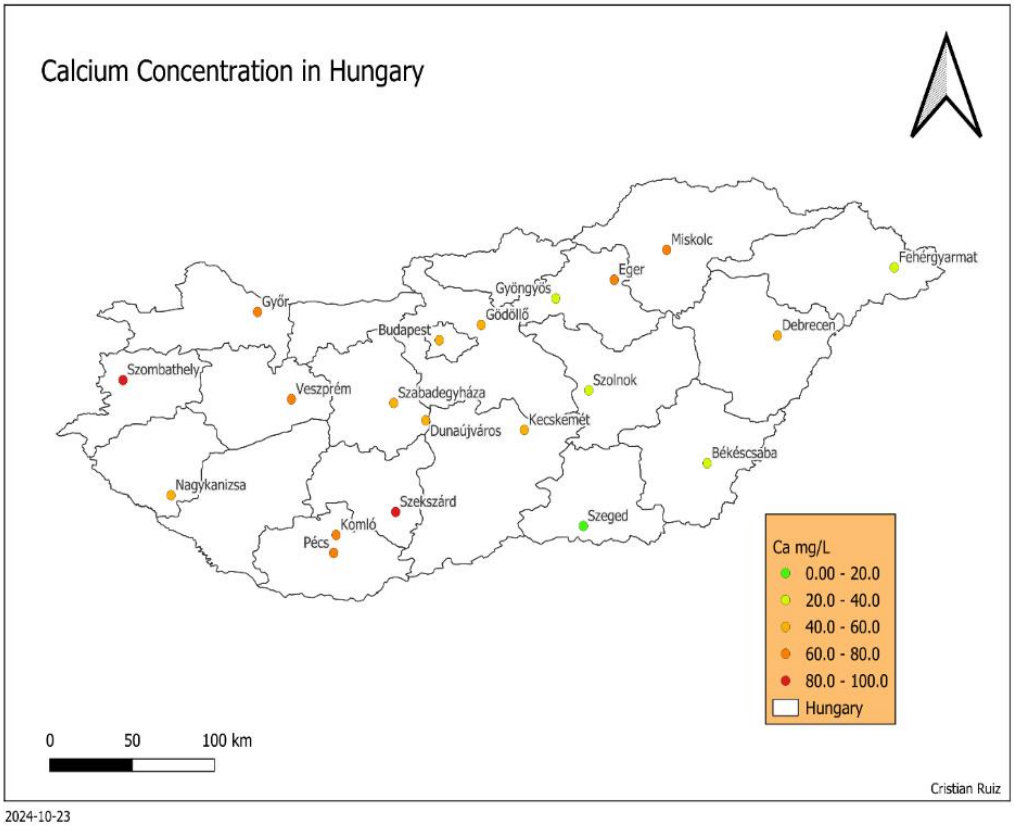


Figure 4.2.1

The Ca concentration in our samples with major dominance ranges from 40mg/L to 80mg/L, having more presence in the west side of the country.

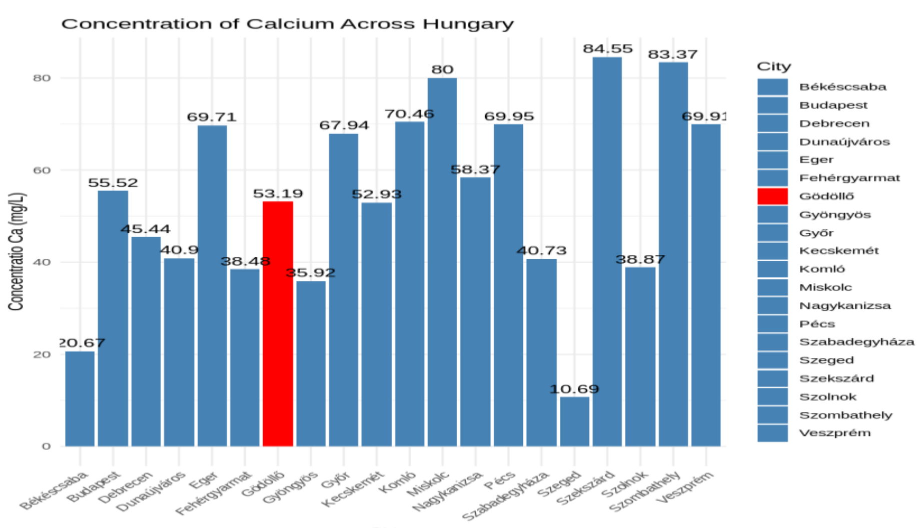


Figure 4.2.2

Compared with the rest of the samples, Gödöllő does not have neither the higher nor the lowest concentration. Gödöllő was highlighted in red for better visualization.

Magnesium Results

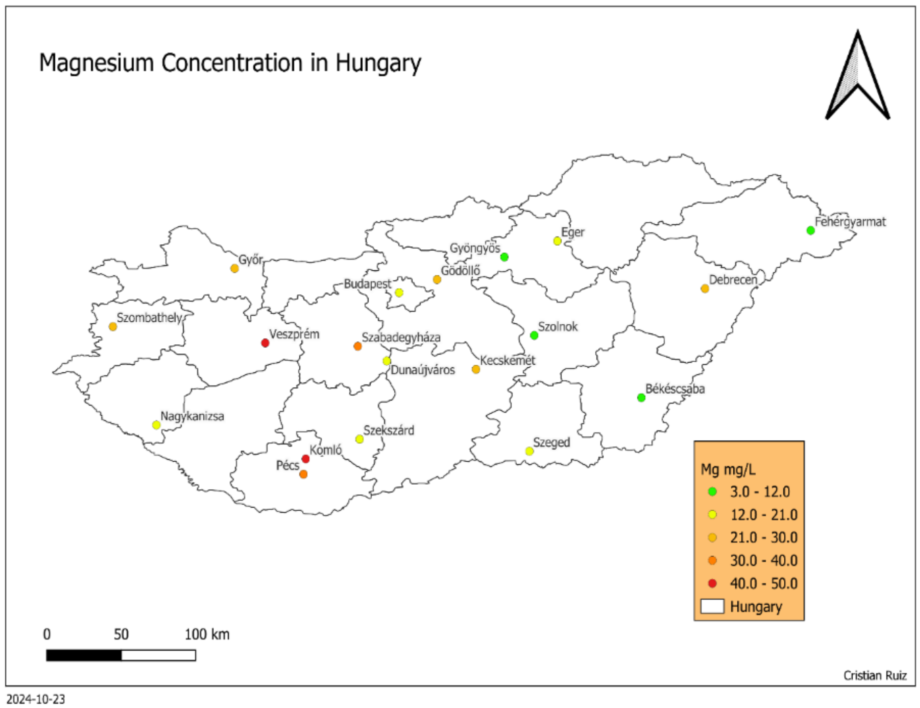


Figure 4.2.3

The concentration of Mg in drinking water showed higher variability regarding its geographical distribution. Just two samples exceeded 40.0mg/L.

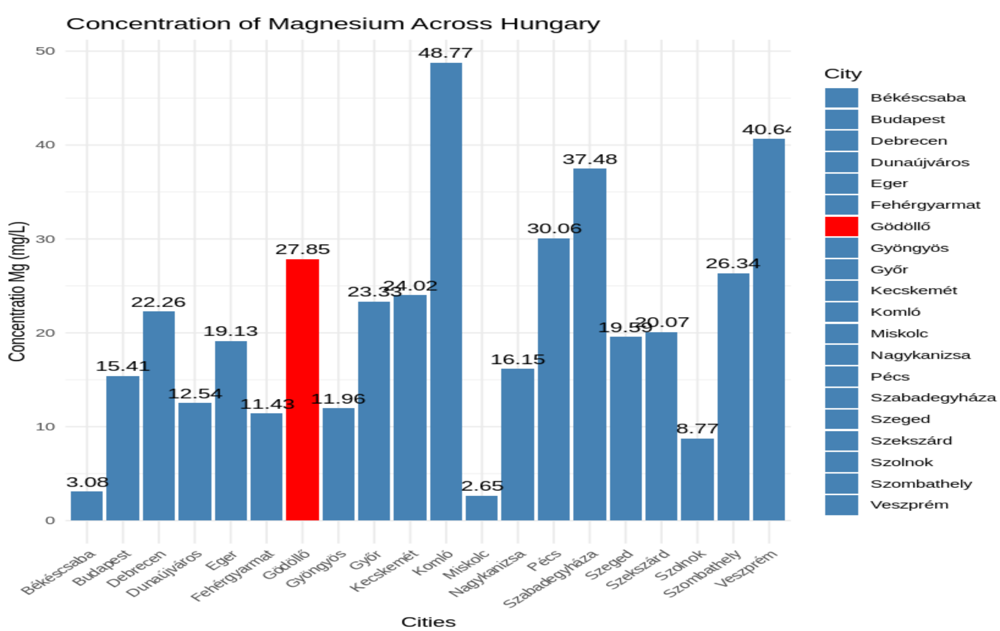


Figure 4.2.4

Gödöllő is on the top 5 cities with higher Mg concentration, being Komló the city with the highest concentration.

When it comes to Ca and Mg, Gödöllő does not have either the highest or lowest concentration. We can analyze cases like Miskolc, where we can see one of the highest concentrations of Ca (80.00µg/L), but at the same time the lowest concentration of Mg (2.65 µg/L). Ca and Mg does not represent risk for human health in drinking water but combine plays an important role for water hardness.

Iron Results

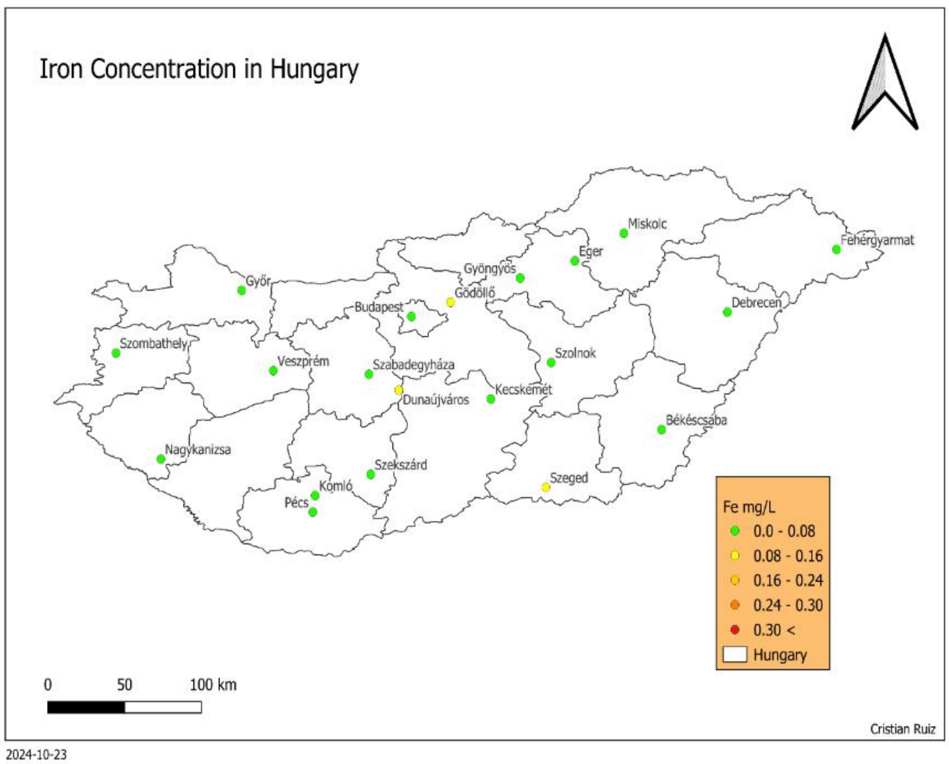


Figure 4.2.5

There was no Fe contamination presented in the map. All values are within the values established by WHO, and the Hungarian government, but it is important to mention that the concentration in Gödöllő is the mean value. The dormitory showed higher concentration of Fe that exceeded the Hungarian and WHO suggested values.

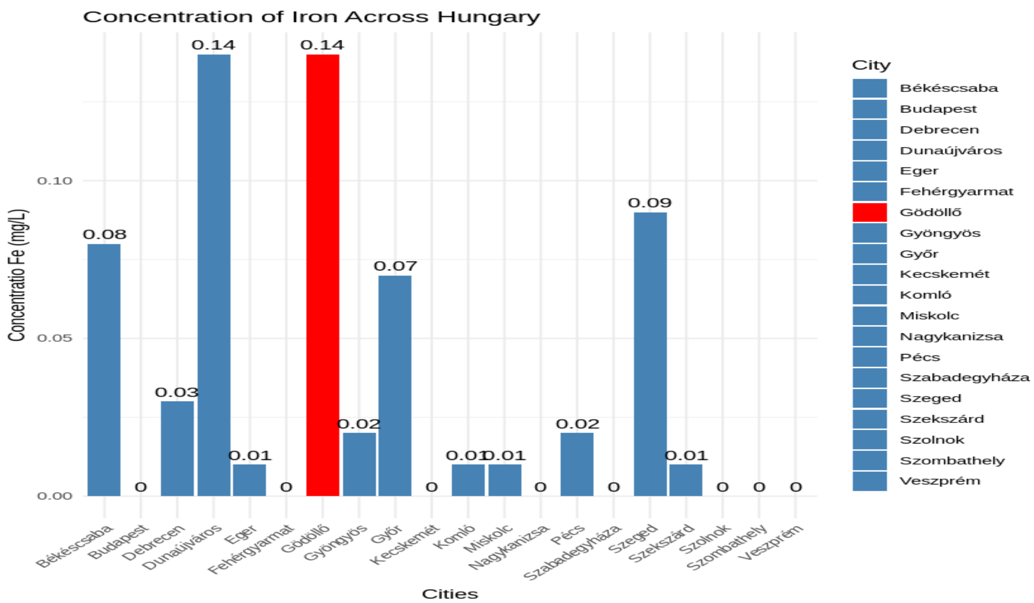


Figure 4.2.6

Gödöllő showed the highest concentration of Iron, alongside Dunaújváros, but none exceeded tha suggested values. In other regions Fe was under detection limit (0.00mg/L).

After analyzing the data, we can see that the values for Fe, specifically from the dorm, are very elevated compared with the rest of the sample (0.39ppm). The other two samples taken in Gödöllő showed lower concentration of the same element. The results suggest a possible local problem about water quality in the dormitory. After comparing with the rest of the samples, the Fe concentration is significantly elevated. It is important to mention that elevated level of Fe can affects the color, smell, and flavor of the water, having a metallic taste that can be unpleasing for consumers.

Mn Results

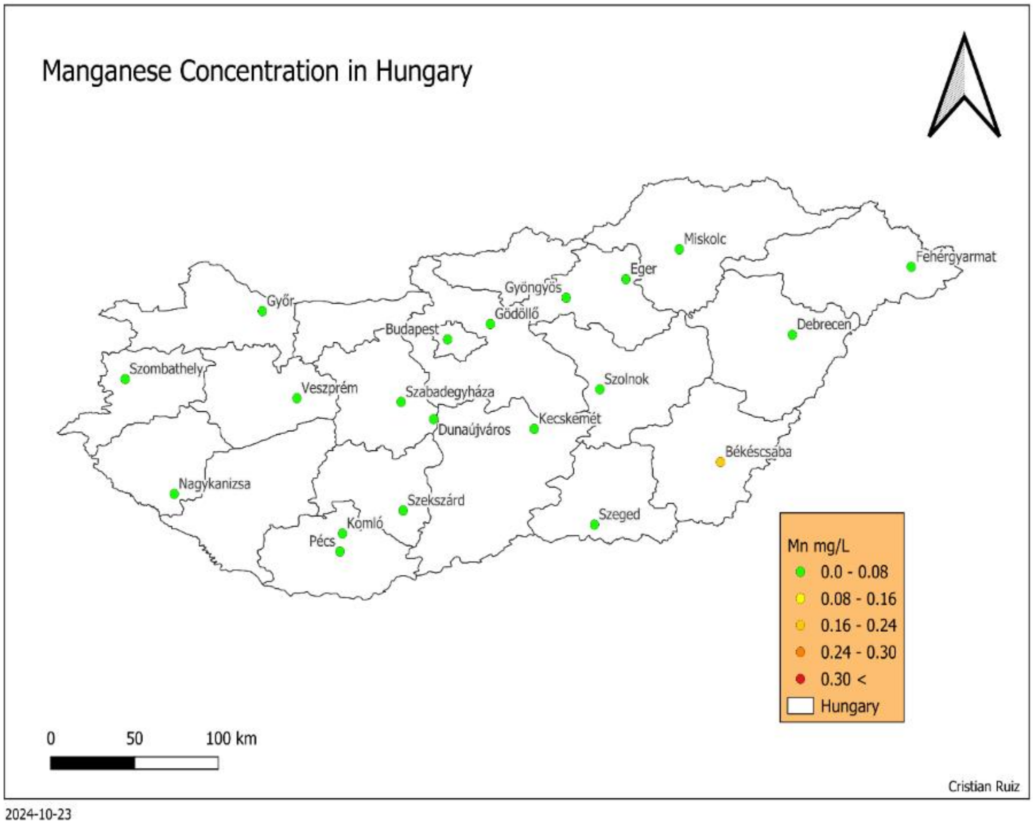


Figure 4.2.7

None of the simples exceeded the 0.08mg/L, but Békéscsaba, where reached the limit value established by the Hungarian Government, but still below WHO concentration limit values for drinking water.

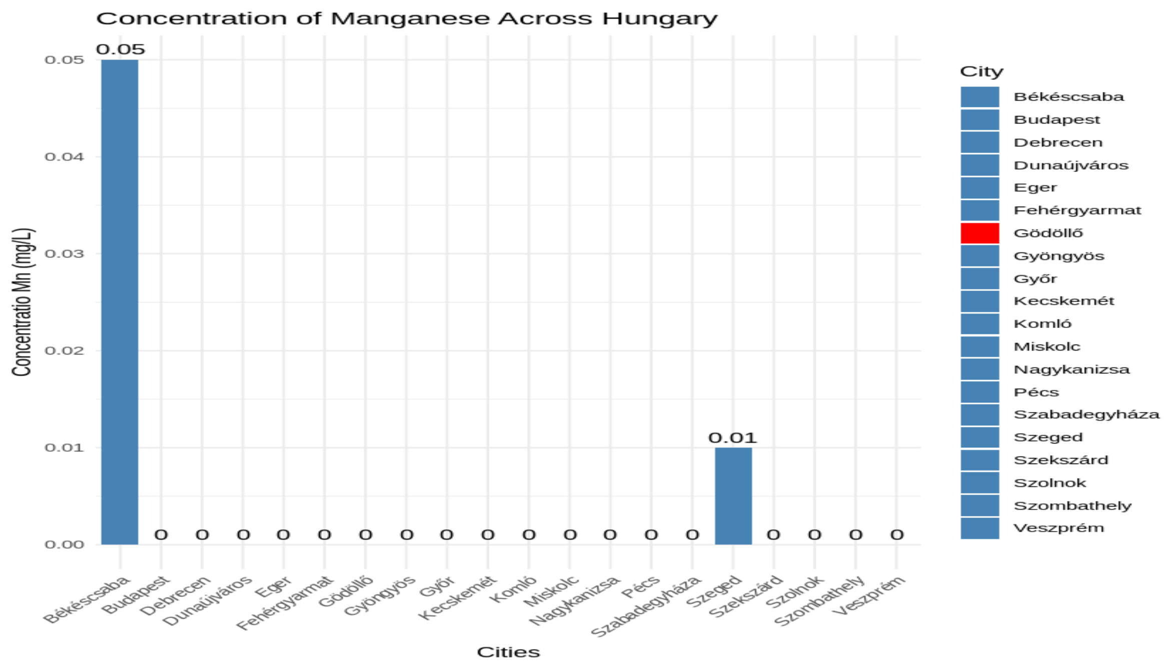


Figure 4.2.8

In the graph, we can see that Mn were not detected, but in Békéscsaba and Gödöllő. Only Békéscsaba reached the limit values established by the Hungarian Government in drinking water, and Gödöllő was below those values.

Pb Results

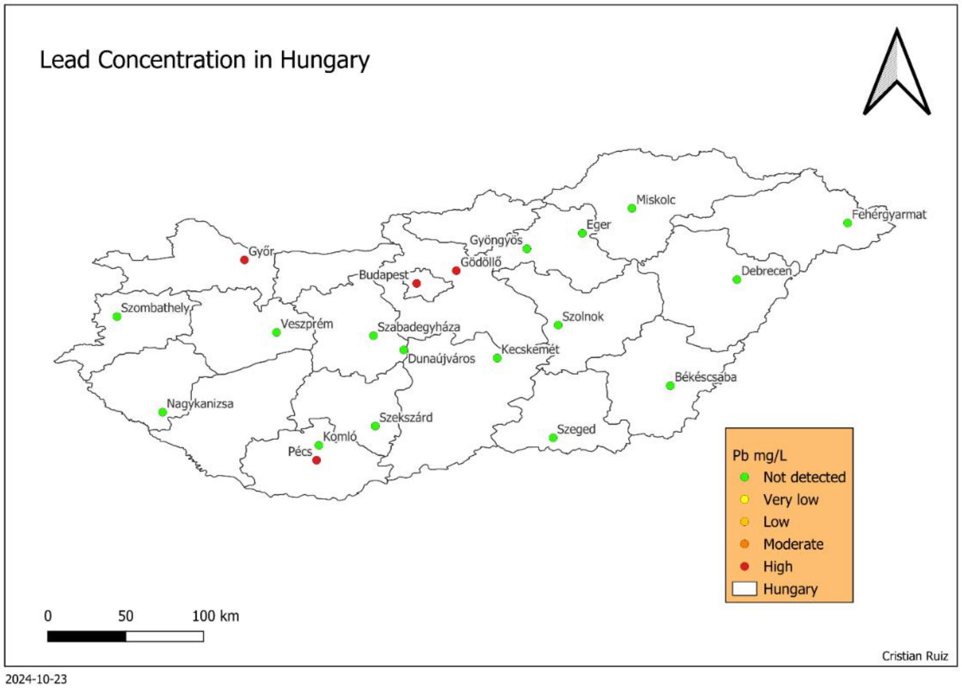


Figure 4.2.9

Four cities reached the limit concentration values for Pb. In the other samples was not detected.

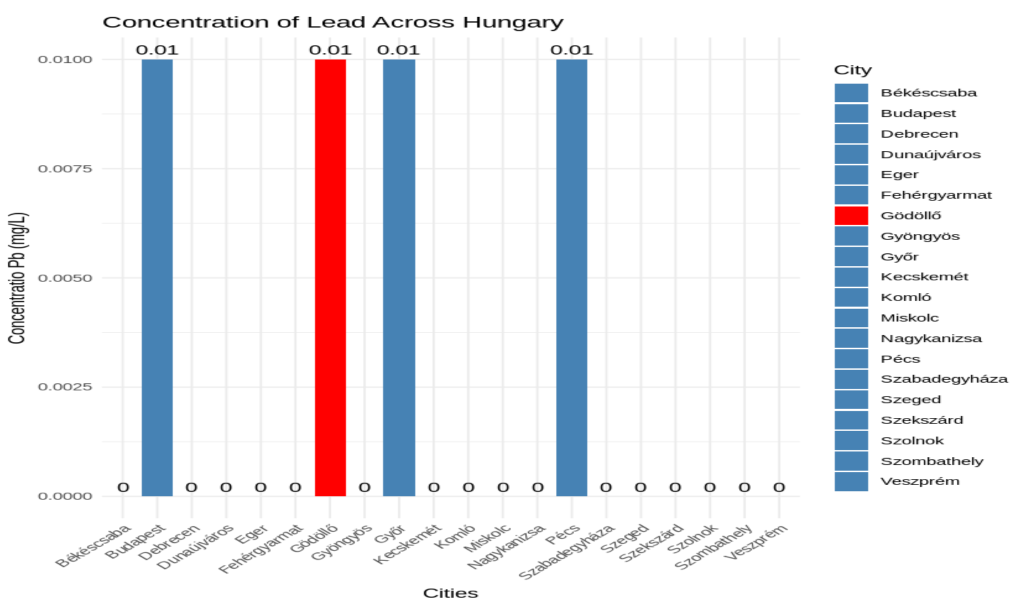


Figure 4.2.10

We can notice that Pb is within the limit values established by WHO, and Hungary (10µg/L) but Hungary set a goal to 5µg/L for 2036.

In Gödöllő, the water samples met the maximum value allowed for Pb compared to other cities where the concentration was higher. The city that showed higher Pb concentration are: Pécs, Budapest, and Győr, where the results showed concentration at 0.01ppm (10µg/L). Finding cities with higher Pb concentration is crucial to accomplish the goal to reduce Pb concentration in drinking water by 2036.
One of the samples taken in Gödöllő, specifically the one taken at Házi rétes, showed %RSD value of 81.76%, which shows a great variability between measurements. This could be a hint for precision problem of the analysis or fluctuation in the levels of contamination.
When it comes to Ca and Mg, Gödöllő does not have either the highest or lowest concentration. We can analyze cases like Miskolc, where we can see one of the highest concentrations of Ca (80.00µg/L), but at the same time the lowest concentration of Mg (2.65 µg/L). Ca and Mg does not represent risk for human health in drinking water but combine plays an important role for water hardness.

4.3 Heavy Metals Compliance for WHO, and Hungarian Standards.

The references used as guidelines to decide the quality of the water are the standards established by the WHO, and the Hungarian government regulation.

Standard limits as per WHO and Hungarian guidelnes (mg/L)		
Parameters	Concentration (WHO)	Concentratio (Hungary)
Ca	No limit value	No limit value
Mg	No limit value	No limit value
Fe	0.3	0.2
Pb	0.01	0.01
Mn	0.04	0.05

Figure 4.3.1

4.3.1 Compliance for World Health Organization and Hungarian Standards

4.3.1.1 Lead

The World Health Organization established a limit value of 10µg/L (0.01mg/L) for Pb in drinking water. All the samples taken in Gödöllő stayed withing this limit. Regarding the rest of Hungary, cities like Pécs, Budapest, and Győr showed limits of 10µg/L, which still within the

WHO limit values for Pb. The remaining cities showed values of 0.00mg/L (0.00ppm), showing positive results for the international standard since those values are very low.
The actual limit value for Pb is 10µg/L in Hungary, like the values set up by the WHO. All concentration for Pb in the water samples are withing this water framework, but Hungary has set a goal to reduce the Pb concentration in drinking water to 5µg/L by 2036. Therefore, identifying the cities with concentration higher than that is crucial. In our study we identify 4 cities: Pécs, Gödöllő, Budapest, and Győr with concentration of 10µg/L.

4.3.1.2 Iron

The World Health Organization established a limit value of 300µg/L (0.3mg/L) for Fe, the sample taken in Gödöllő, especially the one taken at the dormitory Building B, exceeded these values with a concentration of 0.39mg/L. This might affect the sensorial quality of the water, resulting in undesirable metallic taste or color change. The rest of the samples, including the remaining two samples in Gödöllő, showed very low concentration of Fe, like in Budapest, where the concentration was 0.00mg/L.
The actual limit value for Feis 200µg/L in Hungary, stricter than the values set by the WHO. All concentration for Pb in the water samples, Gödöllő included, are below this water framework, but the dormitory building B in Gödöllő, where values exceeded by 0.39mg/L. Very high concentration compared with the rest of the cities, and the remaining two samples taken in the same city and suggests that it might affect the sensorial experience when drinking water in the building.

4.3.1.3 Manganese

The World Health Organization established a limit value of 400µg/L (0.4mg/L) for Mn. The data showed no harmful concentration of this potential topical elements in none of the water samples. All the concentration values were below 0.05mg/L.
The actual limit value for Feis 50µg/L in Hungary, stricter than the values set by the WHO. All concentration for Pb in the water samples, Gödöllő included, are Below this water framework, but one sample taken in Békéscsaba, which reached exactly that level of concentration 0.05mg/L.

4.4 Water Hardness in Hungary

According to the WHO, $CaCO_3$ concentrations in drinking water below 60 mg/l is generally considered as soft; 60–120 mg/l, moderately hard; 120–180 mg/l, hard; and more than 180 mg/l, very hard. In the following table we classify the hardness of water per samples:

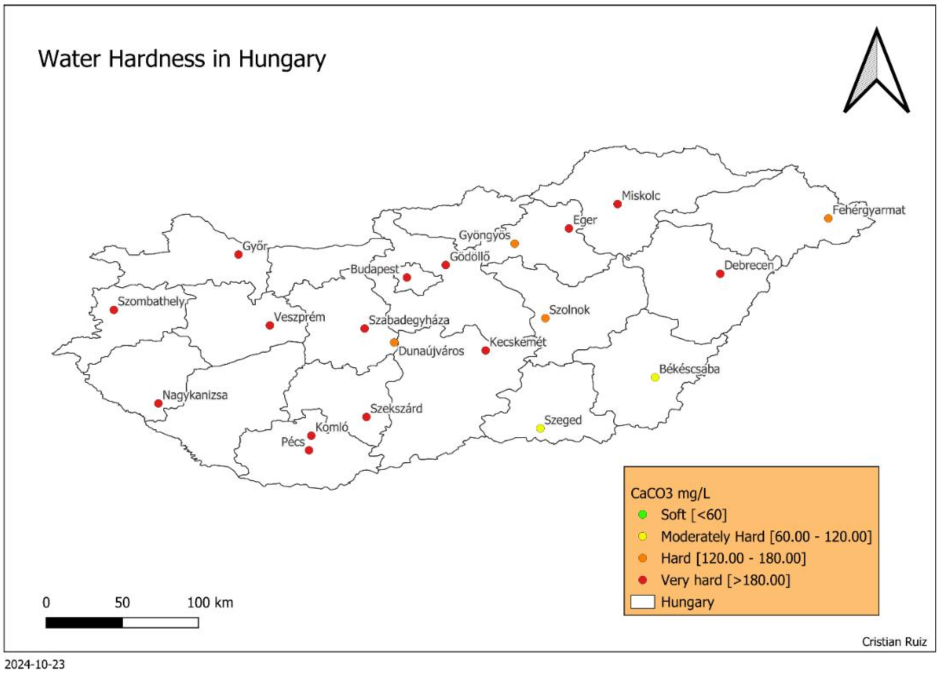


Figure 4.4.1

CaCO3 concentration in drinking water samples across Hungary

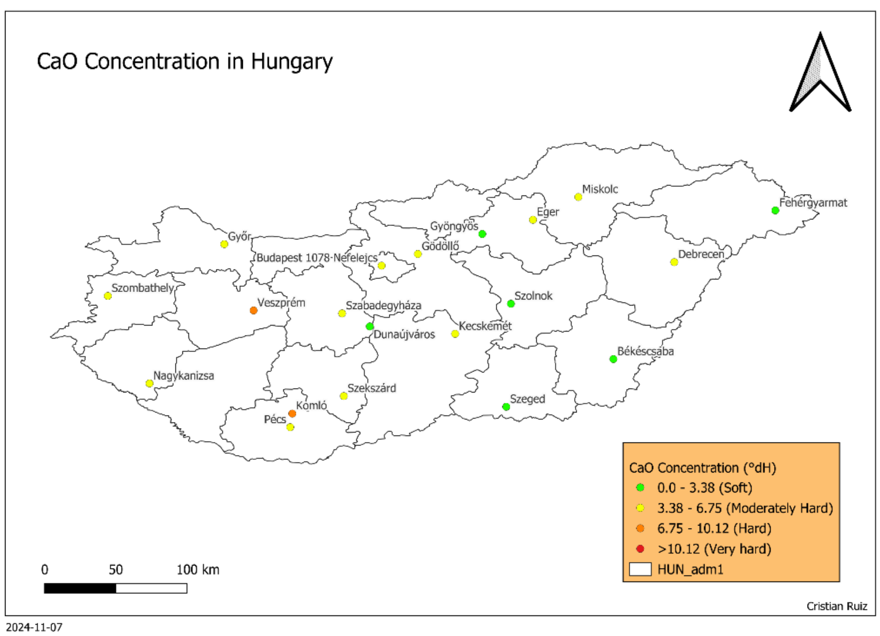


Figure 4.4.2

CaO concentration in drinking water sampes across Hungary

The analysis of Ca and Mg concentration allowed us to classify the water hardness in different regions of Hungary. It was observed significant differences in water hardness. In our samples, it was found moderately hard, hard, and very hard water when using the WHO unit ($CaCO_3$ mg/L), but when using CaO concentrations (°dH) very hard water was not detected, and moderately hard water has a bigger presence across the country.

In Gödöllő, the water is moderately hard (242.34 mg/L), but their concentration of $CaCO_3$ is not the highest compared with the west region of the country, where concentration of 376.11 mg/L were found. However, compared with Szeged (106.92 mg/L) and Békéscsaba (64.30 mg/L), Gödöllő showed way higher concentration.

West Region

The West of Hungary showed a predominant very hard water. The samples collected in those regions demonstrated high consistency of Ca and Mg concentration, placed that area as the most affected by water hardness in the whole country.

Central Region

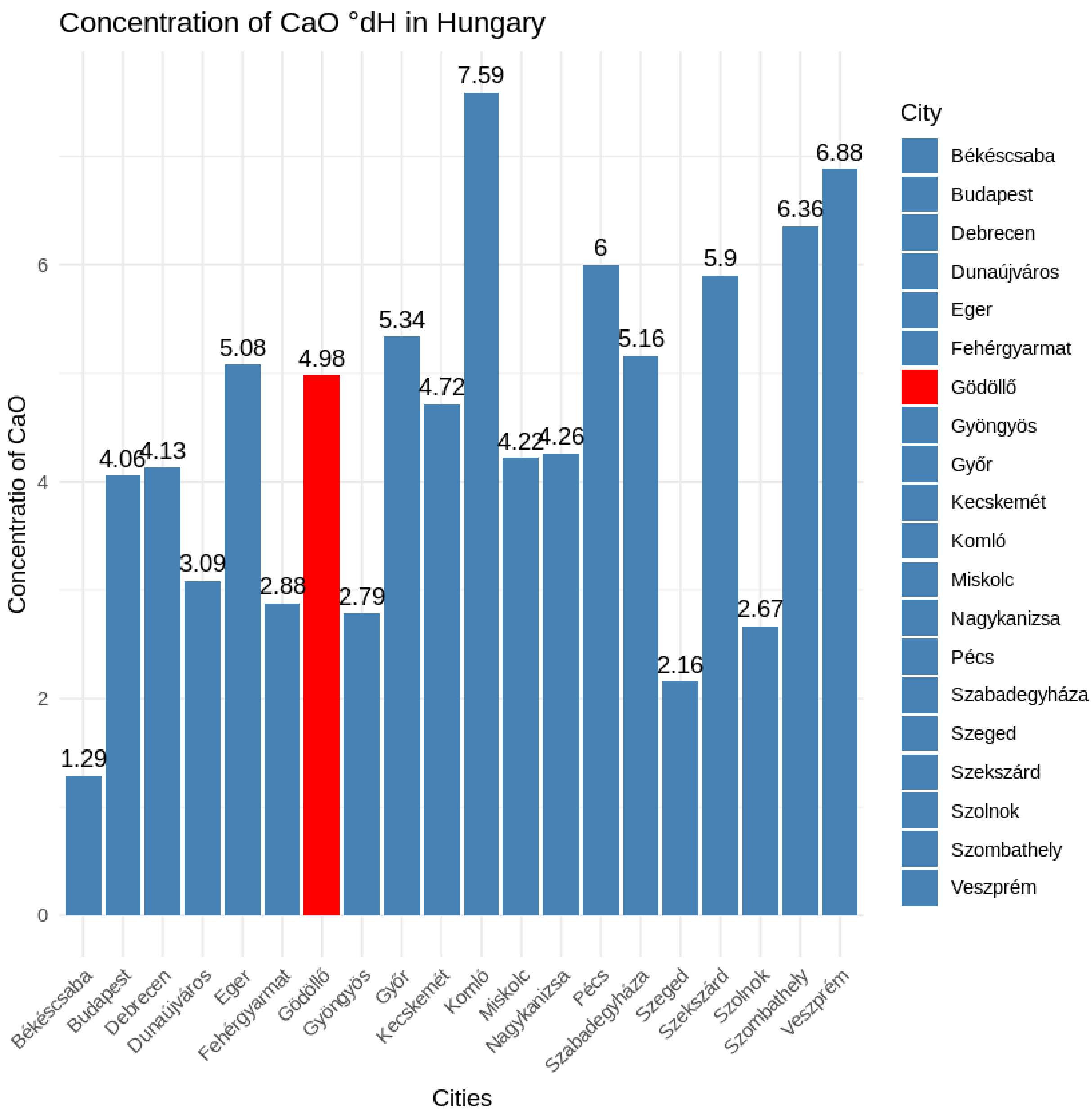
In the Center of Hungary, there was a major variability for water hardness. Some cities showed very hard water, meanwhile other showed just hard water. This suggest that there is a heterogenic distribution of the mineral in this region.

North Region

In the North of Hungary, all water samples were categorized as very hard water, but Gyöngyös, where the water was classified as hard. This patter suggests very concentration of Ca and Mg in the region, but Gyöngyös.

East Region

In the East Region of Hungary, showed a higher variability for all the samples. Where we can find moderately hard, hard, and very hard water.by clustering the samples, we can notice that in the east center, there is predominant high concentration of Ca and Mg (Eger, Miskolc, and Debrecen). The southeast showed the lowest concentration, clarifying the water as moderately hard water, being Békéscsaba (64.30 mg/L) the city with lowest concentration among all the samples. This suggests that southeast is the area less affected for water hardness. Far east was classified.



When it comes to CaO concentration, the classification changes. Komló and Veszprém are the only cities classified as very hard water. The country is mostly impacted by moderately hard water and soft water. Gödöllő is classified as moderately hard water. Békéscsaba is the city with the lowest concentration of CaO.

4.5 Variability of the Results (SD and %RSD)

The metrics used to calculate the variability of the results the Standard Deviation (SD) and the Relative Standard Deviation (%RSD). The data was provided during the analyzing during the laboratory.
According to the data collected, the water samples for Ca, Fe, Mg, Mn and Pb showed SD of less than 1, showing very high consistency during the measurement. The %RSD values of the same

elements were extremely low for Ca, Mg, and Fe. This means that there was no variability during the measurements of the elements, increasing the reliability of the samples, but for Mn and Pb, there were. First, for the samples showing Pb concentration of 0.01 mg/L, the %RSD values did not exceed 15%. This means those samples were reliable, but those with concentration of 0.00 mg/L showed %RSD values higher than 2000%. These fluctuations could be attributed to the sensibility of the equipment when working with samples showing very low concentration of a given element. And for Mn, concentration higher than 0.00 mg/L showed very low %RSD values, but for some samples, the %RSD were high for concentration of 0.00 mg/L. Not all %RSD values with Mg concentration of 0.00 mg/L were high, since many samples showed very low percentage, showing the reliability of the measurement, but in some other samples with same concentration were higher. Just like with Pb, this could be attribute to the sensibility of the equipment when working with very low concentration of a given element.

5. Conclusion

The water analysis of the 22 samples, focus on Gödöllő, has given us a clear vision about the concentration of the potential topical elements, their compliance with international and local water framework, and the variability of the water hardness in different regions of the country. The 22 samples fulfilled all the limits values established by the World Health Organization (WHO), and the Hungarian government. There was only one exception, the concentration of Fe taken in the dormitory building B exceeded the limit values established by the WHO (0.3 mg/L), and local government (0.2 mg/L). this result emphasized the necessity to monitor the water quality of the infrastructure of the dorm and surroundings areas in Gödöllő. Regarding Pb, no samples exceeded the limits values (10µg/L) established by WHO, and Hungarian government, but it is important to highlight that the Hungarian government has set a goal, which consist on establishing new limit values for Pb (5µg) by 2036. Although the concentration fulfilled the parameter, cities like Pécs, Budapest, Gödöllő and Győr registered concentration close to the limit value (10µg/L), which indicates the necessity to monitor this element in these cities. Regarding the variability of the results, when it comes to Fe, the variability was seen in 3 different cities for having higher concentration compared with the rest of the samples, standing out Gödöllő, Dunaújváros and Szeged. Although the mean value for Fe concentration for Gödöllő stays withing the water frameworks, the student dormitory is the exception.
The analysis for Mn showed a geographical variability, being Békéscsaba the city with the highest concentration (0.05 mg/L) of Mn among all the samples. Although the concentration does not exceed the concentration established by WHO, it is very close to the limit value established by the Hungarian government (0.05 mg/L). Therefore, it's important to monitor the water quality for this element in that specific area. The variability suggests that the water quality can fluctuate based on local or distribution conditions. The analysis of the water hardness showed high geographical variability of Ca, and Mg among regions. the west and north of Hungary was characterized by predominant very hard water, which can affect the distribution system by sediment accumulation in the pipes and might have implications on electro domestic devices. The southeast of the country, specifically Békéscsaba, and Szeged showed moderately hard water, suggesting less incident related to water hardness.
In this study we have not evaluated the health effect of water hardness in public health, but it is known that it affects the efficiency of heater, increasing the price for maintenance. This is relevant aspect to take in consideration for future studies since it can affect the quality of the water distribution system and the domestic infrastructure.
This study has identified key areas that might benefit futures studies and continuous monitoring. given that four cities, Gödöllő included, showed Pb concentration of 10µg/L, it is important to regularly monitor the level of Pb in those areas, especially if Hungary want to face the goal of setting limit values of 5µg/L for Pb by 2036. The higher concentration of Fe in the student dormitory makes us wonder whether there is a contamination problem in the water distribution system of the building. Identifying places with higher concentration of Fe, can help to attend, and prevent possible future problems.

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7. ANNEX

7.1 Raw data

Potential Topical Element Concentration - Gödöllő

Gödöllő Sampling Site	Element Label	Concentration Mg/L	Concentration SD	Concentration %RSD
Gödöllő Pool	Ca	50.31	0.21	0.43
Gödöllő Pool	Fe	0.00	0.00	2.78
Gödöllő Pool	Mg	27.85	0.10	0.34
Gödöllő Pool	Mn	0.00	0.00	2.43
Gödöllő Pool	Pb	0.01	0.00	9.54
Dormitory Building B Gödöllő	Ca	53.95	0.11	0.21
Dormitory Building B Gödöllő	Fe	0.39	0.00	0.29
Dormitory Building B Gödöllő	Mg	25.76	0.06	0.23
Dormitory Building B Gödöllő	Mn	0.00	0.00	0.87
Dormitory Building B Gödöllő	Pb	0.01	0.00	9.68
Gödöllő Házi rétes	Ca	55.32	0.06	0.10
Gödöllő Házi rétes	Fe	0.04	0.00	0.78
Gödöllő Házi rétes	Mg	26.41	0.04	0.16
Gödöllő Házi rétes	Mn	0.00	0.00	0.26
Gödöllő Házi rétes	Pb	0.00	0.00	81.76

Calcium Concentration

City	Concentration Mg/L	Concentration SD	Concentration %RSD
Pécs	69.95	0.26	0.37
Veszprém	69.91	0.40	0.57
Dunaújváros	40.90	0.23	0.56
Szabadegyháza	40.73	0.10	0.24
Eger	69.71	0.48	0.69
Gyöngyös	35.92	0.10	0.27
Budapest	55.52	0.12	0.21
Miskolc	80.00	0.16	0.20
Fehérgyarmat	38.48	0.09	0.24
Győr	67.94	0.35	0.51
Debrecen	45.44	0.08	0.18
Békéscsaba	20.67	0.01	0.03
Komló	70.46	0.12	0.17
Szombathely	83.37	0.23	0.27
Szekszárd	84.55	0.24	0.28
Kecskemét	52.93	0.18	0.34
Szolnok	38.87	0.12	0.31
Nagykanizsa	58.37	0.20	0.34
Szeged	10.69	0.02	0.19
Gödöllő (Mean Value)	53.19		

Magnesium Concentration

City	Concentration mg/L	Concentration SD	Concentration %RSD
Pécs	30.06	0.26	0.37
Veszprém	40.64	0.40	0.57
Dunaújváros	12.54	0.23	0.56
Szabadegyháza	37.48	0.10	0.24
Eger	19.13	0.48	0.69
Gyöngyös	11.96	0.10	0.27
Budapest	15.41	0.12	0.21
Miskolc	2.65	0.16	0.20
Fehérgyarmat	11.43	0.09	0.24
Győr	23.33	0.35	0.51
Debrecen	22.26	0.08	0.18
Békéscsaba	3.08	0.01	0.03
Komló	48.77	0.12	0.17
Szombathely	26.34	0.23	0.27
Szekszárd	20.07	0.24	0.28
Kecskemét	24.92	0.18	0.34
Szolnok	8.77	0.12	0.31
Nagykanizsa	16.15	0.20	0.34
Szeged	19.56	0.02	0.19
Gödöllő mean value	27.85		

Iron Concentration

City	Concentration Mg/L	Concentration SD	Concentration %RSD
Pécs	0.02	0.00	0.36
Veszprém	0.00	0.00	1.95
Dunaújváros	0.14	0.00	0.55
Szabadegyháza	0.00	0.00	0.92
Eger	0.01	0.00	2.87
Gyöngyös	0.02	0.00	0.78
Budapest 1078 Nefelejcs	0.00	0.00	3.99
Miskolc	0.01	0.00	1.97
Fehérgyarmat	0.00	0.00	3.08
Győr	0.07	0.00	0.42
Debrecen	0.03	0.00	0.58
Békéscsaba	0.08	0.00	0.74
Komló	0.01	0.00	3.44
Szombathely	0.00	0.00	5.14
Szekszárd	0.01	0.00	2.78
Kecskemét	0.00	0.00	4.76
Szolnok	0.00	0.00	2.88
Nagykanizsa	0.00	0.00	3
Szeged	0.09	0.00	0.12
Gödöllő (Mean Value)	0.14		

Manganese Concentration

City	Concentration Mg/L	Concentration SD	Concentration %RSD
Pécs	0.00	0.00	3.29
Veszprém	0.00	0.00	1.42
Dunaújváros	0.00	0.00	0.84
Szabadegyháza	0.00	0.00	11.41
Eger	0.00	0.00	3.92
Gyöngyös	0.00	0.00	0.93
Budapest 1078 Nefelejcs	0.00	0.00	0.6
Miskolc	0.00	0.00	23.40
Fehérgyarmat	0.00	0.00	7.66
Győr	0.01	0.00	0.5
Debrecen	0.00	0.00	2.28
Békéscsaba	0.05	0.00	0.16
Komló	0.00	0.00	57.35
Szombathely	0.00	0.00	2.77
Szekszárd	0.00	0.00	6.29
Kecskemét	0.00	0.00	3.56
Szolnok	0.00	0.00	3.91
Nagykanizsa	0.00	0.00	11.99
Szeged	0.01	0.00	0.2
Gödöllő (Mean Value)	0.00		

Lead Concentration

City	Concentration Mg/L	Concentration SD	Concentration %RSD
Pécs	0.01	0.00	10.92
Veszprém	0.00	0.00	66.49
Dunaújváros	0.00	0.00	178.05
Szabadegyháza	0.00	0.00	100.86
Eger	0.00	0.00	42.51
Gyöngyös	0.00	0.00	38.39
Budapest 1078 Nefelejcs	0.01	0.00	6.27
Miskolc	0.00	0.00	102.41
Fehérgyarmat	0.00	0.00	222.25
Győr	0.01	0.00	15
Debrecen	0.00	0.00	26.48
Békéscsaba	0.00	0.00	217.84
Komló	0.00	0.00	95.2
Szombathely	0.00	0.00	42.49
Szekszárd	0.00	0.00	28.35
Kecskemét	0.00	0.00	43.07
Szolnok	0.00	0.00	37.86
Nagykanizsa	0.00	0.00	43.42
Szeged	0.00	0.00	2720.76
Gödöllő (Mean Value)	0.01		

7.2 Water Hardness Concentration

Ciudad	Ca mg/L	Mg mg/L	Hardness °dH	Hardness mg/L
Gödöllő	53.19	27.85	4.98	242.34
Pécs	69.95	30.06	6.00	298.12
Veszprém	69.91	40.64	6.88	341.4
Dunaújváros	40.9	12.54	3.09	255.49
Szabadegyháza	40.73	37.48	5.16	153.66
Eger	69.71	19.13	5.08	252.71
Gyöngyös	35.92	11.96	2.79	138.84
Budapest	55.52	15.41	4.06	201.98
Miskolc	80	2.65	4.22	210.87
Fehérgyarmat	38.48	11.43	2.88	143.06
Győr	67.94	23.33	5.34	265.5
Debrecen	45.44	22.26	4.13	204.87
Békéscsaba	20.67	3.08	1.29	64.3
Komló	70.46	48.77	7.59	376.11
Szombathely	83.37	26.34	6.36	316.42
Szekszárd	84.55	20.07	5.90	293.66
Kecskemét	52.93	24.92	4.72	234.5
Szolnok	38.87	8.77	2.67	133.13
Nagykanizsa	58.37	16.15	4.26	212.14
Szeged	10.69	19.56	2.16	106.92

7.3 Python Codes

HARDNESS CALCULATION

```
[ ] def calculate_hardness(ca_concentration, mg_concentration):
        coef_ca = 2.5
        coef_mg = 4.1
        hardness = (coef_ca * ca_concentration) + (coef_mg * mg_concentration)
        return hardness

    def classify_hardness(hardness):
        if hardness < 60:
            return "soft"
        elif 60 <= hardness < 120:
            return "moderately hard"
        elif 120 <= hardness < 180:
            return "hard"
        else:
            return "very hard"

    if __name__ == "__main__":
        try:
            ca_concentration = float(input("Enter the concentration of Ca (mg/L): "))
            mg_concentration = float(input("Enter the concentration of Mg (mg/L): "))
            total_hardness = calculate_hardness(ca_concentration, mg_concentration)
            hardness_type = classify_hardness(total_hardness)
            print(f"The total hardness of the water is: {total_hardness:.2f} mg/L of CaCO3, which is considered {hardness_type}.")
        except ValueError:
            print("Please enter a valid numeric value.")
```

Figure 7.2.1

7.4 R Codes

```
library(ggplot2)

# Data frame
data <- data.frame(
  Metal = c('Ca', 'Mg', 'Fe', 'Mn', 'Pb'),
  Concentracion = c(53.19, 27.85, 0.14, 0.00, 0.01)  # Concentrations mg/L
)

# graph Bars
ggplot(data, aes(x = Metal, y = Concentracion, fill = Metal)) +
  geom_bar(stat = "identity") +
  labs(title = "Heavy Metals Concentration in Gödöllő",
       x = "Heavy Metals",
       y = "Concentration (mg/L)",
       fill = "Type of Heavy Metal") +
  theme_minimal() +
  theme(axis.text.x = element_text(angle = 45, hjust = 1)) +
  geom_text(aes(label = Concentracion), vjust = -0.5)
```

Figure 7.3.1 Bar graph codes for Gödöllő

```r
# necessary libraries
library(ggplot2)
library(reshape2)

# data frame with the concentration data in Gödöllő
data <- data.frame(
  Element = c('Calcium (Ca)', 'Magnesium (Mg)', 'Iron (Fe)', 'Manganese (Mn)', 'Lead (Pb)'),
  Dormitory = c(53.95, 25.76, 0.39, 0.00, 0.01),
  Godollo_Pool = c(50.31, 27.85, 0.00, 0.00, 0.01),
  Hazi_Retes = c(55.32, 26.41, 0.04, 0.00, 0.00)
)

# Convert the data frame to long format
data_long <- melt(data, id.vars = "Element", variable.name = "Sample", value.name = "Concentration")

# Create a bar chart
ggplot(data_long, aes(x = Element, y = Concentration, fill = Sample)) +
  geom_bar(stat = "identity", position = position_dodge()) +
  labs(title = "Comparison of Element Concentrations in Gödöllő",
       x = "Elements",
       y = "Concentration (mg/L)",
       fill = "Sample") +
  theme_minimal() +
  theme(axis.text.x = element_text(angle = 45, hjust = 1)) +
  geom_text(aes(label = Concentration), position = position_dodge(0.9), vjust = -0.5)
```
Figure 7.3.2 data frame with the concentration data in Gödöllő

```r
library(ggplot2)

# data frame for calcium
data <- data.frame(
  Ciudad = c('Pécs', 'Veszprém', 'Dunaújváros', 'Szabadegyháza', 'Eger',
             'Gyöngyös', 'Budapest', 'Miskolc', 'Fehérgyarmat', 'Győr',
             'Debrecen', 'Békéscsaba', 'Komló', 'Szombathely', 'Szekszárd',
             'Kecskemét', 'Szolnok', 'Nagykanizsa', 'Szeged', 'Gödöllő'),
  Concentracion_Ca = c(69.95, 69.91, 40.90, 40.73, 69.71,
                       35.92, 55.52, 80.00, 38.48, 67.94,
                       45.44, 20.67, 70.46, 83.37, 84.55,
                       52.93, 38.87, 58.37, 10.69, 53.19)
)

# bar graph
ggplot(data, aes(x = Ciudad, y = Concentracion_Ca)) +
  geom_bar(aes(fill = Ciudad), stat = "identity") +
  labs(title = "Concentration of Calcium Across Hungary",
       x = "Cities",
       y = "Concentratio Ca (mg/L)") +
  theme_minimal() +
  theme(axis.text.x = element_text(angle = 45, hjust = 1)) +
  geom_text(aes(label = Concentracion_Ca), vjust = -0.5) +
  scale_fill_manual(values = c("Pécs" = "steelblue",
                               "Veszprém" = "steelblue",
                               "Dunaújváros" = "steelblue",
                               "Szabadegyháza" = "steelblue",
                               "Eger" = "steelblue",
                               "Gyöngyös" = "steelblue",
                               "Budapest" = "steelblue",
                               "Miskolc" = "steelblue",
                               "Fehérgyarmat" = "steelblue",
                               "Győr" = "steelblue",
                               "Debrecen" = "steelblue",
                               "Békéscsaba" = "steelblue",
                               "Komló" = "steelblue",
                               "Szombathely" = "steelblue",
                               "Szekszárd" = "steelblue",
                               "Kecskemét" = "steelblue",
                               "Szolnok" = "steelblue",
                               "Nagykanizsa" = "steelblue",
                               "Szeged" = "steelblue",
                               "Gödöllő" = "red")) +
  guides(fill = guide_legend(title = "City"))
```

Figure 7.3.3 Bar graph codes for Gödöllő and samples across hungary