

**T.C.
MARMARA UNIVERSITY
INSTITUTE FOR GRADUATE STUDIES IN
PURE AND APPLIED SCIENCES**

**DETERMINATION OF PARTICULATE MATTER
ELEMENTAL CONCENTRATIONS IN SELECTED
PRIMARY SCHOOLS IN ISTANBUL, TURKEY**

**Dağhan EKMEKCİOĞLU
(Environmental Engineer)**

**THESIS

FOR THE DEGREE OF MASTER OF SCIENCE

IN

ENVIRONMENTAL ENGINEERING PROGRAMME**

**SUPERVISOR
Asst.Prof.Dr. S. Sinan KESKİN**

İSTANBUL 2005

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ÖZET

Bu tez çalışmasında, İstanbul ili, Kadıköy ilçesinde seçilen belirli ilkokullarda iç ortam havasında bulunan asılı parçacık madde kütle konsantrasyonları ile bu parçacıklar içinde bulunan elementlerin konsantrasyonlarının belirlenmesi amaçlanmıştır. Bu çalışma, örnekleme, analiz ve değerlendirme aşamalarından oluşmuştur. Bu kapsamda, beş okulda örnekleme çalışması gerçekleştirilmiş, ardından kütle konsantrasyon değerleri örneklenen birim hava hacmi başına toplanan kütle miktarından belirlenmiştir. Aynı örnekler, nötron aktivasyon analizi tekniği ile analiz edilerek, elementel içerikleri belirlenmiştir. Ayrıca, seçilen bazı örnekler x-ışınları mikroprobuna sahip taramalı elektron mikroskobu ile incelenerek, parçacık morfolojileri ve bu parçacıkların elementel içerikleri belirlenmiştir. Bulunan parçacık madde kütle konsantrasyon değerleri EPA, WHO, ASHRAE gibi çevre kuruluşlarının sınır değerleri ve de Türk Çevre Mevzuatında belirtilen sınır değerler ile karşılaştırılmıştır. Çalışmanın sonucunda, bu sınır değerlerin önemli oranda aşıldığı belirlenmiş, bu durumun olası sağlık etkileri tartışılmıştır. Ayrıca, elementel analiz sonuçları kullanılarak, parçacık maddelerin olası kaynakları ve bunların olası sağlık etkileri tartışılmıştır.

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ABSTRACT

In this thesis study, it is intended to determine the indoor air suspended particulate matter mass and elemental concentrations in some selected primary schools in Kadıköy district of İstanbul. This study includes sampling, analysis, and evaluation stages. In this respect, sampling activities were performed in five schools, then mass concentration values were determined from total collected mass per unit volume of air sampled. Same samples were analyzed by the instrumental neutron activation analysis technique to determine their elemental contents. In addition, some selected samples were analyzed by scanning electron microscope with x-ray microprobe for determination of particulate matter morphology and their elemental contents. Obtained particulate matter mass concentration values were compared to the limit values given by some environmental agencies such as EPA, WHO, ASHRAE, and by limit values in Turkish Environmental Law. As a result of the study, it was found that these limits were exceeded considerably and the possible health consequences were discussed. In addition, using the elemental analysis results, possible sources of the particulates and their possible health consequences were discussed.

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CLAIM FOR ORIGINALITY

In recent years, indoor air quality research has attracted scientists in different countries because of the possible adverse health effects related to indoor air pollutants. These research include particulate matter mass and elemental concentration determinations in fine and coarse fractions as well as determination of gaseous emissions. Particulate matter of inorganic origin not only affects human respiratory system, but also provides the necessary conditions for production of several bacteria that are volatile and create diseases such as headaches, weakness, lung diseases, and asthma. We believe that this study is among few conducted in our country about indoor air quality in public buildings. The results indicated that limit values specified by the worldwide standards were exceeded considerably in most of the primary schools. We believe that some measures might help to reduce the particulate matter concentrations in these buildings.

LIST OF SYMBOLS

PM	: Particulate matter
PM_{2.5}	: Particulate matter of size upmost 2.5 μm
PM₁₀	: Particulate matter of size upmost 10 μm
PM_{0.1}	: Particulate matter of size upmost 0.1 μm (ultra fine particles)
TSP	: Total suspended particulate
ERF	: Exposure response function
DI	: Deionized water
EF	: Enrichment factor

LIST OF ABBREVIATIONS

NAAQS	: US National Ambient Air Quality Standards
ASHRAE	: American Society of Heating Refrigeration and Air Conditioning Engineers
WHO	: World Health Organization
EPA	: Environmental Protection Agency
SEM	: Scanning Electron Microscope

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CHAPTER I

INTRODUCTION

Today, it is a well-known fact that air pollution is a serious and global problem. There are many sources that emit pollutants into the atmosphere and people inhale these pollutants. Industrial plants, power plants, automobiles, and house stacks constitute most of the emission sources. Air pollution has been a concern almost since the early years of the industrial era in the European countries and the USA. Especially after the famous London Episode in 1952, air pollution research has gained great importance. Since then it has been decades that air pollution research has attained increasing interest. Today many techniques for air pollution analysis and control are available and regulations are in affect in many countries around the world.

Air pollution studies can be classified into two groups as outdoor and indoor air pollution with respect to the surrounding environment. In many studies that included both outdoor and indoor air pollution measurements, it has been seen that outdoor and indoor pollutant concentration levels correlate with each other with high correlation coefficients. However, there are cases that considerable amount of air pollution might originate from indoor activities.

Air pollutants are classified as gaseous and particulate in form with respect to their physical states. Some examples for gaseous pollutants can be given as NO_x, SO₂, and volatile organic carbons. Particulates include both liquid and solid forms. They refer to any substance, except pure water, that exists as a liquid or solid in the atmosphere under normal conditions and is of microscopic or submicroscopic size but larger than molecular dimensions. Natural sources such as windborne dust, sea spray, and volcanoes, and anthropogenic sources such as combustion of fuels are the major sources of particulates. While traffic load and stack emissions are the main sources for both gaseous and particulate emissions in urban areas, factory emissions can be considered as the major source in industrial areas.

With the increasing urbanization trend in all around the world, many people spend most of their lives indoors where air quality is different than outdoors. In recent years, there has been a rapid expansion of interest in indoor air quality and its contribution to total human exposure to air pollutants. Different types of emission sources have characteristic elemental composition signatures belong to them. Therefore, elemental composition determination in air pollution research is important both for source identification and specific health hazard assessment.

In this study, particulate matter mass and elemental concentration levels in indoor air environments of certain primary schools have been searched. Primary schools have been chosen because of the higher health risk associated with the young children and the very high number of primary school students getting educated in Turkey. For this purpose, particulate samples were collected on filters from the selected primary schools and those collected samples were analyzed by the instrumental neutron activation analysis technique for their elemental composition determination.

Although there are many examples related to indoor air particulate matter research in European countries, the USA and Japan, we are not aware of a similar study for indoor public environments performed in Turkey within the scientific literature. We believe that this study will contribute to the understanding of indoor air particulate pollution levels and the associated risks for public health.

CHAPTER II

GENERAL BACKGROUND

II.1. PARTICULATE MATTER

The term particulate matter (PM) is used to describe airborne solid particles and/or droplets. Particulates may vary in size, composition, and origin. Several different indicators have been used to characterize ambient particulate matter. Classification by size is quite common because size governs the transport and removal of particles from the air and their deposition within the respiratory system, and is at least partly associated with the chemical composition and sources of particles. Atmospheric particles often are not spherical and have a range of densities. Therefore, their sizes are often described by an “equivalent” diameter of a sphere.

Based on size, particulate matter tends to be divided into three principal groups: coarse, fine and ultra fine particles. The border between the coarse and fine particles usually lies between 1 μm and 2.5 μm , but is usually fixed by convention at 2.5 μm in aerodynamic “equivalent” diameter ($\text{PM}_{2.5}$) for measurement purposes. In an analysis reported in 1979, EPA scientists endorsed the need to measure fine and

coarse particles separately. Based on the availability of a dichotomous sampler with a separation size of 2.5 μm , it is recommended 2.5 μm as the cut-point between fine and coarse particles. Because of the wide use of this cut point, the $\text{PM}_{2.5}$ fraction is frequently referred to as “fine” particles. Fine particles can only be seen with the aid of a microscope. The border between fine and ultrafine particles lies at about 0.1 μm . PM_{10} is used to describe particles with an aerodynamic diameter smaller than 10 μm . The particles contained in the PM_{10} size fraction may reach the upper part of the airways and lung. Smaller particles (in particular $\text{PM}_{2.5}$) penetrate more deeply into the lung and may reach the alveolar region. Ultrafine particles contribute only slightly to PM_{10} mass but may be important from a health point of view because of the large numbers and high surface area. They are produced in large numbers by combustion (especially internal combustion) engines [1]. In the last decade, the concept of “high risk” respirable particles of smaller size, $\text{PM}_{2.5}$, or even “ultrafine” particles $\text{PM}_{0.1}$, has been discussed in research and regulatory means [2-4, 5].

Since the 1980's the concept of particulate matter of diameters less than 10 μm (PM_{10}) has been popular, and several instruments have been developed for measuring concentrations and chemical composition of these particles [5]. The main parameters in the design of samplers are flow rate, impactor size and filter holder. The flow rates are used between 5 liters and 25 liters per minute. In our study for instance, the flow rate is 5 l/min. Impactor size specifies the particulate matter type to be sampled – PM_{10} or $\text{PM}_{2.5}$. The sampler designs also take into account the position and shape. Since the sampling height may change, it must be mountable on a fixed surface for different heights. On the other hand, it must have a holder apparatus to hang it on somewhere such as a tree. The sampler used in this study which is “Airmetrics Minivol Portable Air Sampler” has a proper holder apparatus.

In many studies, elemental composition of particulate matter has also been studied together with mass concentration. Elementary composition is an important parameter for determining the source and characteristics of particulate matter. Many techniques such as X-ray fluorescence (XRF) spectrometry, instrumental neutron activation analysis (INAA), and inductively coupled plasma mass spectroscopy (ICP-MS) can be use for determining elementary composition in particulates.

II.2. SOURCE ESTIMATES

Elemental composition of particulate matter is an important parameter to give information about its source. Although the same element might originate from different types of sources, ratios of various elements in particulate matter will point out the type of the source in general [6].

In general, indoor air pollution is highly affected from outdoor air pollution in public buildings due to the penetration of pollutants from outdoor to indoor. In this study, the sampling sites are primary schools where daily student circulation in and out is very high. For this reason, air penetration from outside environment to inside environment can be considered as highly likely. Since the selected schools are nearby to a major roadway with high traffic load, even particulates from exhaust emissions and worn out tires are expected in indoor air environment.

Depending on the specific source, elemental composition in particulates will be different. For example, there are many groups of elements in PM₁₀ fraction such as (Al, Si, Ti, Ca), (Br, Pb, Cu, Fe), and (Mn, Zn, K) that originate from soil dust, motor vehicles, and industrial processes, respectively [7, 8]. Some elements might have both outdoor and indoor sources. For example, cigarette smoking is an indoor source for zinc [9-11] although it originates mainly from outdoor sources such as fossil fuel combustion [12]. This element is known to exist in very small particles (mostly smaller than 0.5 μm) so it has high penetration values from outdoors. Potassium as another example is dependent mostly on indoor activities, such as smoking and wood burning. It is also a marker for burning organic matter (i.e. cooking) [9, 13].

II.3. REGULATORY BACKGROUND

In 1987, the US National Ambient Air Quality Standards (NAAQS) for particulate matter were revised to use PM₁₀, rather than total suspended particulate (TSP) matter, as the indicator of particulate matter level in air environment [14]. The use of PM₁₀ as an indicator is an example of size-selective sampling based on a

regulatory size cut [14]. This selection was based on health considerations and was intended to focus regulatory concern on those particles small enough to enter the thoracic region. The PM_{2.5} standard, set in 1997, is also an example of size-selective sampling based on a regulatory size cut [15]. The PM_{2.5} standard was based primarily on epidemiological studies using concentrations measured with PM_{2.5} samplers as an exposure index. These samplers were not designed to collect respirable particulates but to collect fine-mode particulates because of their different sources [16] and the increased regulatory concern with those fine-particulates [17].

II.4. LIMIT VALUES

As a consequence of regulatory concern, many environmental organizations have established a series of limit values for particulate matter. Some of these standards are presented below:

1. *WHO Health Guideline:*

PM₁₀: 70 µg/m³ (24 hours)

PM₁₀: 50 µg/m³ (annual mean)

2. *U.S. EPA, National Ambient Air Quality Standards (NAAQS) (1997):*

PM₁₀: 150 µg/m³ (24 hours)

PM₁₀: 50 µg/m³ (annual mean)

PM_{2.5}: 65 µg/m³ (24 hours)

PM_{2.5}: 15 µg/m³ (annual mean)

3. *Turkish Environmental Law (Türk Çevre Kanunu):*

PM₁₀: 300 µg/m³ (24 hours)

PM₁₀: 150 µg/m³ (annual mean)

II.5. HEALTH EFFECTS

It is proved long time ago that particulate matter of size 10 μm to lesser diameters creates or exacerbates health diseases. Recent epidemiological studies have found an association between concentrations of ambient particulate matter, in particular PM_{10} fraction and especially $\text{PM}_{2.5}$ fraction, and adverse health effects [7, 18, 19, 20, 21]. It was found in a study that, the risk of dying for an adult might increase on any given day by less than 1% when the concentration of inhalable particulate matter (PM_{10}) increases by $10 \mu\text{g}/\text{m}^3$ [22]. Although relative risks related to short-term exposures to particulate air pollution seem rather small, the long-term exposure effects might be seriously harmful.

II.5.1 Exposure of Children to Particulate Matter

Children are exposed to particulate matter by inhalation of pollutants in the ambient air environment. Children are particularly sensitive to air pollutants for several reasons. First, children breathe more rapidly than adults, which allow the inhalation of more pollutants per kilogram of body weight. Children spend more time in outdoors, increasing possibility of being exposed to outdoor air pollutants [23]. In addition, school age children will be exposed to high levels of indoor air pollution within the school buildings without good and efficient cleaning procedures.

The various sources of particulate matter result in a wide range of particle sizes, from $\text{PM}_{2.5}$ particles to PM_{10} and greater. Normally, only particles of 5 μm and smaller can clear the nasal passages and get inhaled into the lungs. However, since children tend to mouth breathing, passing the natural defense mechanisms and preventing particles larger than 10 microns from passing through the nose, both $\text{PM}_{2.5}$ and PM_{10} particles are associated with health risks in children. Another important fact is that the defense mechanisms of children are not as strong as that of an adult [19, 20].

II.5.2 Effect of Particulate Matter on Children's Health

Acutely, exposure to particulate matter irritates eyes, ears, nose, throat and lungs. Respiratory symptoms such as coughing, wheezing and shortness of breath may be observed as well. The symptoms vary from person to person and depend on the particular components of the pollutants [21, 22]. Usually the symptoms disappear when exposure stops.

Long-term health effects are unlikely to result from short-term exposures. Children with chronic illnesses however may experience increased symptoms from exposure. For example, children with asthma may experience an asthma exacerbation when exposed to high levels of particulate matter. Studies have shown increased rates of asthma hospitalizations in association with elevated levels of air pollution and proximity to major roadways [21]. Children with heart disease may also experience chest pain and shortness of breath when exposed to particulate matter. Exposure to air pollution during pregnancy has been linked to premature birth, low birth weight, Sudden Infant Death Syndrome (SIDS) and heart defects [23]. These exposures included carbon monoxide and ozone in addition to particulate matter.

Studies on the association between ambient air pollution and health in industrialized countries seem to indicate that even very small changes in particulate pollution affect mortality [18, 19] and morbidity [24, 25] of a population. Some effects of particulate matter on health in short-term and long-term exposures are as follows [26]:

Short Term:

- Lung inflammatory reactions,
- Respiratory symptoms,
- Adverse effects on the cardiovascular system,
- Increase in medication usage,
- Increase in mortality,

Long Term:

- Increase in lower respiratory symptoms,
- Reduction in lung function in children,
- Increase in chronic obstructive pulmonary disease,
- Reduction in lung function in adults,
- Reduction in life expectancy, owing mainly to cardiopulmonary mortality and probably lung cancer,

II.5.3 Exposure Response Function

The Exposure Response Function (ERF) is a calculation method for impacts of various pollutants on human health that has been developed in a study performed in Europe [26]. The unit of Exposure Response Function is cases/yr per person per concentration ($\mu\text{g}/\text{m}^3$). Higher the ERF, higher the danger of a pollutant on a certain disease. In a statistical long-term study, the ERF values of particulate matter on several diseases are found out as follows [26].

Table II.1: Diseases and corresponding ERF's.

Health Endpoint (Disease)	ERF
Long – term or chronic mortality	6.8×10^{-4}
Short – term or acute mortality	6.8×10^{-4}
Chronic Bronchitis (adults)	5.9×10^{-5}
Restricted Activity Days (adults)	3.2×10^{-2}
Asthmatics (adults)	1.7×10^{-1}
Respiratory Hospital Admissions	3.5×10^{-6}
Cerebrovascular Hospital Admissions	8.4×10^{-6}
Congestive Heart Failure (elderly)	4.0×10^{-6}
Bronchitis (children)	6.5×10^{-4}
Chronic cough (children)	8.3×10^{-6}
Asthmatics (children)	3.2×10^{-1}

Unit: cases/yr per person per concentration ($\mu\text{g}/\text{m}^3$)

Asthmatic impacts include bronchodilator usage and incidences of coughing and wheezing.

As seen in Table II.1, asthma, both for elderly and children, is quite a big problem associated with particulate matter.

II.5.4 Effect of Particulate Matter Reduction on Health

The body of evidence on the effects on health of particulate air pollution at levels currently common in Europe has strengthened considerably over the last few years [23]. Both epidemiological and toxicological evidence have contributed to this strengthening. The latter provides new insights into possible mechanisms for the hazardous effects of particulate matter on human health and complements the large body of epidemiological evidence, which shows, for example, consistent associations between daily variations in air pollution and certain health outcomes [24]. One of the crucial questions – both for the scientific community and for policy-makers – is whether these associations are causal and, if so, which agent(s) involved in the air pollution mixture play a crucial role in the effects [24]. Only if relationships are shown to be causal can it be assumed that a reduction in pollution will reduce health effects. The results strongly suggest that it is indeed reasonable to assume that a further reduction in particulate air pollution will lead to health benefits [26]. This is also in line with recent “intervention studies” that have demonstrated health benefits following the reduction of pollution levels under various circumstances.

II.5.5 Populations with High Risk of Health Diseases

A number of groups within the population have potentially higher vulnerability to the effects of exposure to particulate air pollutants. These are those who are innately more susceptible to the effects of exposure to particulate air pollutants than others, those who become more susceptible (for example, as a result of environmental or social factors or personal behavior) and those who are simply exposed to unusually large amounts of air pollutants [25]. Members of the last group are vulnerable by virtue of exposure rather than as a result of individual susceptibility.

Unborn and very young children seem particularly sensitive to some pollutants [23]. Other groups that are more sensitive include the elderly, those with

cardiorespiratory disease, those who are exposed to other toxic materials that add to or interact with air pollutants, and the socioeconomically deprived. When compared with healthy people, those with respiratory disorders (such as asthma or chronic bronchitis) may react more strongly to a given exposure, either as a result of increased responsiveness to a specific dose and/or as a result of a larger internal dose of particulate pollution than in normal individuals exposed to the same concentration [26]. Increased particle deposition and retention have been demonstrated in the airways of people suffering from obstructive lung disease [24].

II.5.6 Levels of Safe Pollution

In the past, the concept of no-effect thresholds played an important role in deriving air quality guidelines. The existence of such thresholds implies no effects of increasing air pollution until a “threshold” concentration is surpassed, at which stage risk rises [25]. Thresholds are in principle an appealing concept that has also been used in defining air quality policies, such as in justifying the numerical value of air quality limit values. Some findings imply that the current WHO air quality guideline for particulate matter of (PM₁₀) 70 µg/m³ as a 24 -hour mean value does not represent a level below which no adverse effects are expected [26]. Consequently, the threshold concept can be considered to be elusive at a population level for these pollutants. This is almost certainly because there are inevitably large differences in individual susceptibilities in large populations [26]. Instead of thresholds, exposure/concentration–response relationships for different health endpoints provide more realistic information for taking effective action to reduce adverse effects on human health.

II.5.7 Sufficiency of Current Limit Values

The recent WHO review reconfirmed that exposure to particulate matter poses a significant risk to human health at concentration levels common in Europe today [24]. Thus, it can be concluded that further reductions in air pollution will have significant health benefits, even in regions where levels are well below current European Union (EU) limit values for particulate matter. Current air quality standards are to a large extent based on the concept of an effect threshold, below which significant health effects are not likely to occur. As stated above, no such threshold is evident for particulate matter. Therefore, even if the limit /target value is not exceeded, significant health impacts, including a substantial reduction in life expectancy, are to be expected [25]. Conversely, a reduction in pollutant concentrations below the current standards should result in health benefits.

II.5.8 Indicators for Assessment and Regulation of Particulate Matter

Many studies have found that PM_{2.5} particles have serious effects on health, such as increases in mortality rates and in emergency hospital admissions for cardiovascular and respiratory reasons [26]. Thus there is good reason to reduce exposure to such particles. PM₁₀ particles seem to have effects on, for example, hospital admissions for respiratory illness, but their effect on mortality is less clear [24].

Nevertheless, there is sufficient concern to consider reducing exposure to PM₁₀ particles as well as to PM_{2.5} particles. However, the two types have different sources and may have different effects, and tend to be poorly correlated in the air [26]. The systematic review therefore recommended that consideration be given to assessing and controlling PM₁₀ as well as PM_{2.5} particulate matter.

II.5.9 Acute and Chronic Effects

The systematic review confirmed that the public health significance of the long-term effects of exposure to particulate matter clearly outweighs that of the short-term effects [26]. Nevertheless, the effects of short-term exposure to particulate matter have been documented in numerous time-series studies, many of them conducted in Europe [26]; these indicated large numbers of outcomes, such as attributable deaths and hospital admissions for cardiovascular and respiratory conditions [26].

II.6. ENRICHMENT FACTOR

The extent to which trace metals exceed natural concentrations is an important indicator of effect of pollution sources in particulate matter. Enrichment of trace metals in particulate matter collected on filters relative to the abundances in a specific media is determined by the Enrichment factor (EF) which is defined as the ratio of the concentration of an element in a sample with respect to its concentration in that specific media.

In the present study, EF was calculated by normalizing the concentration of elements with that of Na and Sc. Thus EF (particulate matter) relative to the crust or sea-salt is defined as:

$$EF(\text{particulate matter}) = (C_X/C_{Sc}) \text{ Particulate Matter} / (C_X/C_{Sc}) \text{ Crust}$$

and

$$EF(\text{particulate matter}) = (C_X/C_{Na}) \text{ Particulate Matter} / (C_X/C_{Sc}) \text{ Sea - Salt}$$

Where;

$(C_X/C_{Sc}) \text{ Particulate Matter} = (\text{Concentration of 'X' / Concentration of 'Sc'}) \text{ particulate matter/Crust,}$

$(C_X/C_{Na}) \text{ Particulate Matter} = (\text{Concentration of 'X' / Concentration of 'Na'}) \text{ particulate matter/Sea - Salt,}$

X = Element.

CHAPTER III

THESIS STUDY

This study has the objective to determine the indoor air quality in various primary schools in terms of particulate matter mass concentrations and their elemental compositions. In relation to this goal, the statement and application of the experimental steps, the obtained results, and the evaluation of those results are presented.

The particulate matter in its nature is found anywhere where inhalable air exists unless it is removed on purpose. Especially important is the PM_{2.5} fraction that penetrates easily through the respiratory system and creates serious health hazards such as asthma. The upper limit for the particle size was chosen 10 µm since the particulate matter of greater size tends to settle down quickly as dust thus does not stay suspended in ambient air for long times. The study includes two main parts:

1. Sampling of the particulate matter in the schools (site study),
2. The analyses of the samples for concentration and elemental composition determination (laboratory study),

The first part of the study includes the selection of certain primary schools, getting the required permissions, preparing the necessary equipment,

placing the sample collection system in the schools, and collecting the samples for laboratory analyses.

The second part of the study includes the preparation and conditioning of the filters and Petri dishes prior to the sampling period, the mass measurements of the empty and filled filters for mass concentration determinations, the preparation of the filter samples for elemental concentration analysis, and the analysis of these samples by the instrumental neutron activation analysis (INAA) technique.

III.1 THE STUDY PLAN

This study was accomplished in three periods. In the first period, the schools were selected, the official permissions were obtained, the equipment was prepared, and the necessary literature survey was performed. Sampling was performed within the second period. Finally, mass concentration determinations, elemental composition measurements, and individual particle characterizations were finished in the last period. The study plan can be presented in tabular form as follows:

Table III.1: The study plan.

Month	Jan.	Feb.	March	April	May	June	July	Aug.	Sep.
Action	Preparation			Sampling		Analysis			

The preparation, sampling, and analysis steps are presented in more detail in the following parts.

III.1.1. Preparation

1. Selection of schools,
2. Getting official permissions,
3. Preparation of Airmetrics Minivol Particulate air sampler,
 - a. Batteries were renewed,
 - b. Tests were performed,

4. Preparation of Petri dishes,
5. Preparation and conditioning of the filters,
6. Construction of the protection cage,

III.1.2. Sampling

7. Starting the site studies,
 - a. Placing the cage and sampling device to the selected school,
 - b. Programming the device for sampling periods,
 - c. Daily regular control of the filters and the system,
 - d. Moving the filled filter to the laboratory while it is in the sampler's impactor head and placing another impactor head with a new empty filter to the sampler on the site,
 - e. Weighing the filled filters and then carefully placing them into their own Petri dishes,
 - f. Each filter was weighed and recorded twice; one just after the sampling period and the other on June 15, 2004 together with all the others,
 - g. The discharged battery was replaced with the charged one every 36 hours of operation,
 - h. Moving the system to another school after completing the sampling in a school,

III.1.3. Analysis

8. Derivation of the mass concentration values for samples,
9. Preparation of the filters for elemental concentration determination by instrumental neutron activation analysis technique,
10. Irradiation of prepared samples by thermal neutrons in the research reactor at the Küçükçekmece Nuclear Research Center,

11. Counting of irradiated samples for gamma spectroscopy analysis and determining the elemental concentrations of the elements with concentrations above detection limits.

III.2. SITE STUDY

III.2.1. Selection of schools

The schools chosen for this study take place near the Fahrettin Kerim Gökay Street around Göztepe district.

1. *Faik Reşit Unat Primary School:* The school is located on the Fahrettin Kerim GÖKAY Street in Ziverbey neighborhood. This street had a heavy traffic load all around the day. The sampling system was placed on the entrance corridor. This corridor has entrances in both sides that were open from 08:00 to 18:00, so it was exposed to air high circulation. This school has a high population of students and many students pass through the corridor within the break periods. The cleaning frequency was at most once in between break periods. The teachers were using chalk on the blackboards. The location of the school is given in Figure C.3.

2. *Mustafa Aykın Primary School:* The school is located on the Gazi Muhtar Paşa Street. This street did not have a heavy traffic load. The sampling system was installed on the first floor that includes four classrooms. There was not a considerable air circulation on the corridor, and the classroom windows seemed to be the main pathway for the air inlet. The floor was being cleaned both during the breaks and lecture hours. The teachers were using chalk on the blackboards. The location of the school is given in Figure C.2.

3. *Melahat Şefizade Primary School:* The school is located on the Şefizade Street. This Street is the second parallel to the Fahrettin Kerim GÖKAY Street. Although it did not have a heavy traffic load, getting influenced from the heavy traffic pollution on the Fahrettin Kerim GÖKAY Street was likely. The sampling

system was installed in a long and wide corridor on the entrance floor. The corridor was open to many classrooms, executive offices, and toilets. The air circulation was considerable since an entrance door and many windows were open. The teachers were using chalk on the blackboards. The location of the school is given in Figure C.1.

4. *Öğretmen Harun Reşit Primary School:* The school is located on the Fahrettin Kerim GÖKAY Street in Göztepe neighborhood. There is a gas station located 100 meters across from the school. The sampling system was installed in a corridor on the first floor. There was not a considerable air circulation on the corridor, and the classroom windows seemed to be the main pathway for the air inlet. The cleaning frequency was at most once in between break periods. The teachers were using chalk on the blackboards. The location of the school is given in Figure C.4.

In summary, there are common properties for all the schools selected such as being located in the same region, chalk and blackboard usage in the classrooms, and same working hours from 08.00 am to 18.00 pm. However, there are also distinct properties such as air circulation patterns from the outdoor environment, distance to the heavy traffic, and cleaning frequency.

The necessary official permissions for the sampling activities were obtained from the National Education Administration of Kadıköy District and the Governor's Office of Kadıköy District.

III.2.2. The Sampling Equipment

a. Airmetrics Minivol® Portable Air Sampler:

This portable air sampler runs with a battery (12 volts, 12 amp-hours, sealed lead acid battery). There are two batteries both of which can supply the necessary power for 48 hours. One battery is used at a time and the other one is used as a replacement for the discharged one. The suction flow rate of the pump is 5 l/min (the default and the optimum) with an uncertainty of $\pm 5\%$. Air enters

through a suction head which houses size limiting PM₁₀ and PM_{2.5} impactors in it. Placing only the PM₁₀ impactor in the head results in the PM₁₀ sample collection while using both impactors results in the PM_{2.5} sample collection.

The time intervals for sample collection are programmable on the sampler's electronic control unit. The programming can be performed weekly from Monday to Sunday to start and stop any time of the day. Total of six separate programming can be entered. The sampler has a cumulative flow counter to follow the total time that the sampler operated. Some pictures of the sampler and its parts are given in Figures A.1, 2, 3, 4, 5, 6 and 7.

b. Mettler Toledo® MX5 Balance:

This electronic balance has the measurement sensitivity of 1 µg. It has an uncertainty of ± 2 µg. The balance has a closed measurement chamber to prevent air disturbance around the sample. The pictures of the balance are given in Figures A.9 and 10.

III.2.3. The Sample Collection

In the sample collection phase, the Gelman&Sciences 47 mm Teflon® filters with 2 µm pore size were used. One filter at a time was placed in the sampler air entrance head. This preparation of the head was done in the clean room before getting into the sampling site. Total of 16 filters were used in the study. The sampling schedule is presented in Table III.2. After collection, each sample filter was brought back to the clean room in the head for weighing and storage. They were stored in pre-cleaned and labeled Petri dishes. The picture of a Petri dish is given in Figure A.8. During these preparation steps, clean room wearing including a dust-repellent laboratory coat, a bonnet, a mouth holder, overshoes, and powder-free latex gloves were used to prevent filters from contamination.

The sampler was placed in a protection cage during the collection. This cage (60x60x80 cm in size) had a wooden body that was encircled by a large mesh-sized (1 cm x 1 cm) plastic material. The use of metals was avoided not to cause elemental contamination to the samples. The cage was used to prevent children to touch the sampler during the collection phase. The picture of the cage is given in Figure A.13. The sampler's height was adjusted so that, the air entrance through the head would be at about 1.2 meters above the ground thinking that it would be representative for students' average height.

Table III.2: Sample collection schedule

Filter	Date	School	PM	Sampling Period [h]	Volume [m³]
1	27.04.2004	F. R. U.	10	8 (weekday)	2.4
2	28.04.2004	F. R. U.	2.5	8 (weekday)	2.4
3	29.04.2004	F. R. U.	10	8 (weekday)	2.4
4	30.04.2004	F. R. U.	2.5	8 (weekday)	2.4
5	01-02.05.2004	F. R. U.	2.5	24 (weekend)	7.2
6	03-04-05.05.2004	F. R. U.	2.5	20.5 (weekday)	6.15
7	06-07-10.05.2004	M. A.	2.5	22 (weekday)	6.6
8	08-09.05.2004	M. A.	10	24 (weekend)	7.2
9	11-12.05.2004	M. A.	10	16 (weekday)	4.8
10	15-16.05.2004	M. Ş.	2.5	24 (weekend)	7.2
11	17-18.05.2004	M. Ş.	10	16 (weekday)	4.8
12	20-21.05.2004	M. Ş.	2.5	16 (weekday)	4.8
13	24-25-26.05.2004	Ö. H. R.	2.5	18 (weekday)	5.4
14	27-28.05.2004	Ö. H. R.	10	15.25 (weekday)	4.575
15	29-30.05.2004	Ö. H. R.	2.5	24 (weekend)	7.2
16	Blank				

• All the sampling in weekdays was performed within 10.⁰⁰ – 18.⁰⁰

• F. R. U.: Faik Reşit UNAT, M. A.: Mustafa AYKIN, M. Ş.: Melahat ŞEFİZADE, Ö. H. R.: Öğretmen Harun REŞİT.

III.3. LABORATORY STUDY

This phase of the study includes the preparation of sample filters and their protecting Petri dishes, the measurements of filter weights for mass concentration determination, and finally gamma spectroscopy analysis of the filters by the instrumental neutron activation analysis technique for elemental concentration determination.

III.3.1. Preparation of Filters and Petri Dishes

Before starting the site study, the sample filters were prepared in a clean room within our laboratory. These filters were stored in Petri dishes (Gelman&Sciences® brand) to prevent them from contamination before and after the sampling stages. The Petri dishes were labeled from 1 to 16 and they were kept in the clean room except during the sampling stage. Since the mass of particulate matter collected on filters is less than 1 mg/filter, it is quite important to store sample filters in contamination-free conditions.

Prior to the sampling, filter weights were measured by the Mettler Toledo MX5 balance in the clean room. Following this, the filters were kept in a laminar flow bench in the clean room under low flow condition for 24 hours. During this time, their protecting Petri dishes were kept open to bring the filters into equilibrium with the surrounding environment that had a temperature and relative humidity of 20 ± 1 °C and 50 ± 5 %, respectively. After this conditioning period, the filter weights were measured again. This conditioning step was repeated for the following 24-hour period and filter weights were measured third time at the end. Since the second and third measurement results were very close to each other, the filters were conditioned properly.

These weighted empty filters were kept in pre-cleaned Petri dishes until the sampling. The Petri dishes were acid washed and dried in the laminar flow bench. They were soaked in a solution of 65% nitric acid in deionized (DI) water (1:4 volume ratio) for 24 hours. After that they were rinsed with DI water and dried in the laminar flow bench.

III.3.2. Determination of Filter Mass Concentrations

The following procedure was used during a sampling stage:

- (1) The air entrance head-1 of the Airmetrics Minivol Sampler was cleaned with alcohol.
- (2) A pre-weighed empty filter was placed into the head-1.
- (3) The head-1 was placed into a clean polyethylene bag to safely carry to the sampling site.
- (4) The head-2 that already stands on the sampler was replaced by the head-1 for the next sample collection period.
- (5) The head-2 with a full filter in it was placed in the bag and brought back to the clean room.
- (6) The filter in the head-2 was taken out and placed into its labeled Petri dish.
- (7) The filter was conditioned in the laminar flow bench for 24 hours as explained above.
- (8) The filter was weighed and then kept in its Petri dish until the final weighing.
- (9) The head-2 was cleaned with alcohol.

After all sixteen samples collected, the final weighing was performed for all filters on June 15, 2004. The final net particulate matter mass values were determined from the empty and full filter weight measurements. Afterwards, filter mass concentrations were determined by dividing mass values to the pre-recorded air flow volume values.

III.3.3. Elemental Composition Analysis

The elemental composition analysis of filters was performed at the Küçükçekmece Nuclear Research Center. The instrumental neutron activation analysis technique was utilized for this purpose. The pre-cut filters were irradiated by thermal neutrons within the reactor for two hours. The nuclear reactions between thermal neutrons and nuclei of different elements in the particulate matter produce radioactive isotopes that emit gamma rays at specific energies. These irradiated samples were counted twice in a gamma-ray detector,

one for short-lived elements and the other for long-lived elements. Obtained gamma ray spectra were compared by the spectrum of a reference material to determine the elemental concentrations in the filter particulate matter. The gamma spectroscopy system is given in Figure A.20 and 21.

III.3.4. Additional Study in Fenerbahçe High School

In March and April 2005, an additional study is performed in Private Fenerbahçe high school. Private Fenerbahçe high school takes place in Kayışdağı, on a tranquil street where no heavy traffic or industries take place. In this study, the sampler system is placed in a classroom instead of the main corridor. In this study, less particulate pollution is expected to be found than that of the other four schools. This is why the floor cleaning is quite good, the rush in break times is low and the system takes place in the class instead of corridor. The sampling operations are done between 08.00 am and 18.00 pm. The frequency of floor cleaning of the classes is as much as twice a day. Teachers use chalk on blackboard. The place of the school can be seen in Figure C.6.

CHAPTER IV

RESULTS

IV.1. MASS CONCENTRATIONS

IV.1.1. State Schools

In this section, particulate matter mass concentration values are determined from the measured filter weights and total air volumes passed through the filters. The sampling details for four state schools are presented in Table IV.1 and Table IV.2.

Table IV.1: Sample collection schedule

Filter	Date	School	Time
1	27.04.2004	Faik Reşit UNAT İÖÖ	weekday
2	28.04.2004	Faik Reşit UNAT İÖÖ	weekday
3	29.04.2004	Faik Reşit UNAT İÖÖ	weekday
4	30.04.2004	Faik Reşit UNAT İÖÖ	weekday
5	01-02.05.2004	Faik Reşit UNAT İÖÖ	weekend
6	03-04-05.05.2004	Faik Reşit UNAT İÖÖ	weekday
7	06-07-10.05.2004	Mustafa AYKIN İÖÖ	weekday
8	08-09.05.2004	Mustafa AYKIN İÖÖ	weekend
9	11-12.05.2004	Mustafa AYKIN İÖÖ	weekday
10	15-16.05.2004	Melahat ŞEFİZADE İÖÖ	weekend
11	17-18.05.2004	Melahat ŞEFİZADE İÖÖ	weekday
12	20-21.05.2004	Melahat ŞEFİZADE İÖÖ	weekday
13	24-25-26.05.2004	Öğretmen Harun Reşit İÖÖ	weekday
14	27-28.05.2004	Öğretmen Harun Reşit İÖÖ	weekday
15	29-30.05.2004	Öğretmen Harun Reşit İÖÖ	weekend

- All the sampling in weekdays was performed within 10.⁰⁰ – 18.⁰⁰
- F. R. U.: Faik Reşit UNAT, M. A.: Mustafa AYKIN, M. Ş.: Melahat ŞEFİZADE, Ö. H. R.: Öğretmen Harun REŞİT.

Table IV.2: Sample collection durations and total air volumes.

Filter No	Sampling Duration [h]	Total Air Volume Sampled [m³]
1	8	2.4 ± 0.12
2	8	2.4 ± 0.12
3	8	2.4 ± 0.12
4	8	2.4 ± 0.12
5	24	7.2 ± 0.36
6	20.5	6.15 ± 0.31
7	22	6.6 ± 0.33
8	24	7.2 ± 0.36
9	16	4.8 ± 0.24
10	24	7.2 ± 0.36
11	16	4.8 ± 0.24
12	16	4.8 ± 0.24
13	18	5.4 ± 0.27
14	15.25	4.575 ± 0.23
15	24	7.2 ± 0.36

Table IV.3: Filter weight measurement results.

	Filter mass [mg]			Particulate Matter Mass [mg]	
	(1)	(2)	(3)	(4)	(5)
Filter No					
1	172.496	173.063	173.025	0.567	0.529
2	167.520	167.755	167.742	0.235	0.222
3	160.162	160.872	160.842	0.710	0.680
4	171.533	171.752	171.761	0.219	0.228
5	165.930	166.350	166.312	0.420	0.382
6	175.664	176.171	176.154	0.507	0.490
7	171.957	172.370	172.355	0.413	0.398
8	180.021	180.540	180.492	0.519	0.471
9	182.230	183.110	183.085	0.880	0.855
10	177.150	177.650	177.624	0.500	0.474
11	168.233	169.525	169.600	1.292	1.367
12	161.426	161.670	161.651	0.244	0.225
13	168.361	168.620	168.594	0.259	0.233
14	177.028	177.651	177.614	0.623	0.586
15	180.870	181.102	181.108	0.232	0.238

- (1) Conditioned empty filters.
- (2) Twenty-four hours after each sampling.
- (3) Final weighing on June 15, 2004.
- (4) Particulate matter mass collected [(2)-(1)]
- (5) Particulate matter mass collected [(3)-(1)]

The total mass of the particulate matter on each filter is taken as the arithmetic average of the columns (4) and (5) in Table IV.3. Therefore, the corresponding indoor air particulate matter mass concentration values for each filter is calculated by the following formulas

$$\text{Total mass (mg)} = \frac{(4) + (5)}{2} \quad (\text{IV.1})$$

$$\text{Indoor conc. (}\mu\text{g/m}^3\text{)} = \frac{\text{Total Mass (mg)} * 1000 (\mu\text{g/mg)}}{\text{Time (h)} \times 60 (\text{min/h}) \times \text{Air flow rate (5 l/min)} / 1000 (\text{l/m}^3)} \quad (\text{IV.2})$$

Table IV.4: Total particulate mass and concentration values.

Filter No	PM	Total mass [mg]	Mass concentration [µg/m³]
1	10	0.548	228.33 ± 11.45
2	2.5	0.228	95.21 ± 4.83
3	10	0.695	289.58 ± 14.5
4	2.5	0.224	93.13 ± 4.73
5	2.5	0.401	55.69 ± 2.80
6	2.5	0.499	81.06 ± 4.07
7	2.5	0.406	61.44 ± 3.09
8	10	0.495	68.75 ± 3.45
9	10	0.868	180.73 ± 9.05
10	2.5	0.487	67.64 ± 3.93
11	10	1.330	276.98 ± 13.86
12	2.5	0.235	48.85 ± 2.48
13	2.5	0.246	45.56 ± 2.31
14	10	0.605	132.13 ± 6.62
15	2.5	0.235	32.64 ± 1.66

IV.1.2. Private Fenerbahçe High School

A total of six samples were collected in this part of the study. Not only PM₁₀ and PM_{2.5} samples, but also total suspended particulate (TSP) samples were collected. The results of this study are given in Tables IV.5, IV.6, IV.7, and IV.8.

Table IV.5: Sample collection schedule.

Filter No	Date	PM	Time
17	19-20.03.2005 26-27.03.2005	2.5	Weekend
18	19-20.03.2005 26-27.03.2005	10	Weekend
19	21-25.03.2005	2.5	Weekday
20	21-25.03.2005	10	Weekday
21	28.03-01.04.2005	TSP	Weekday
22	02-03.04.2005	TSP	Weekend

Table IV.6: Sample collection durations and total air volumes.

Filter No	Sampling Duration [h]	Total Air Volume Sampled [m³]
17	30	9 ± 0.45
18	35.3	10.59 ± 0.53
19	38.1	11.43 ± 0.57
20	41.8	12.54 ± 0.63
21	32	9.6 ± 0.48
22	16	4.8 ± 0.24

Table IV.7: Filter weight measurement results.

Filter No	Empty Weight (1)	08.04.2005 (2)	12.04.2005 (3)	(2) - (1)	(3) - (1)
17	167,690	168,008	167,996	0,318	0,306
18	158,740	159,028	159,042	0,288	0,302
19	157,145	157,300	157,294	0,155	0,149
20	161,222	162,245	162,280	1,023	1,058
21	166,038	167,855	167,885	1,817	1,847
22	158,584	158,876	158,886	0,292	0,302

- (1) Conditioned empty filters.
 (2) Weight measured on April 8 2005.
 (3) Weight measured on April 12 2005.

Table IV.8: Total particulate mass and concentration values.

Filter No	PM	Total Mass (mg)	Mass concentration [µg/m3]
17	2.5	0,312	34.67 ± 1.75
18	10	0,295	27.86 ± 1.41
19	2.5	0,152	13.30 ± 0.69
20	10	1,040	82.97 ± 4.15
21	TSP	1,832	190.83 ± 9.54
22	TSP	0,297	61.87 ± 3.12

Elemental composition analyses were not performed for these samples. However, the EDS spectra were collected for single particles during scanning electron microscopy analyses and they are given in Appendix B.

IV.2. ELEMENTAL ANALYSIS

The elemental analyses results for state schools are given in Table IV.9.

Table IV.9: Elemental analysis results in $\mu\text{g}/\text{m}^3$

Filter No	Na	K	Sc	Cr	Zn
1	3.28 ± 0.23				
2	3.36 ± 0.04		0.0001 ± 0.0001		0.18 ± 0.13
3	3.30 ± 0.23				
4	3.64 ± 0.26				
5	1.24 ± 0.09				
6	1.02 ± 0.01				
7	1.55 ± 0.11	0.69 ± 0.48			
8	1.24 ± 0.09				
9	0.78 ± 0.06	1.29 ± 0.40	0.0009 ± 0.0007		0.13 ± 0.06
10	0.34 ± 0.03	0.29 ± 0.19	0.0002 ± 0.0001		
11	0.57 ± 0.03	0.78 ± 0.19	0.0002 ± 0.0001		0.065 ± 0.04
12	0.15 ± 0.01				0.19 ± 0.08
13	0.23 ± 0.02				0.08 ± 0.03
14	1.55 ± 0.08	1.64 ± 0.29	0.0044 ± 0.0001		0.06 ± 0.06
15	0.11 ± 0.01			0.021 ± 0.001	

Table IV.9: Continued

Filter No	As	Br	Sb	La
1		0.028 ± 0.007		
2		0.038 ± 0.021		
3	0.0047 ± 0.0024	0.023 ± 0.005		
4		0.015 ± 0.004		
5		0.011 ± 0.003		
6	0.0002 ± 0.0001	0.010 ± 0.006		
7		0.011 ± 0.004		
8		0.008 ± 0.002		
9	0.0023 ± 0.0008	0.012 ± 0.003	0.0098 ± 0.0038	0.0017 ± 0.00063
10	0.0013 ± 0.0005	0.008 ± 0.002		
11	0.0017 ± 0.0008	0.006 ± 0.001		0.0007 ± 0.00021
12	0.0013 ± 0.0007	0.004 ± 0.001	0.0063 ± 0.0033	
13		0.007 ± 0.001		0.0006 ± 0.00028
14	0.0033 ± 0.0012	0.013 ± 0.001	0.0164 ± 0.0046	0.0037 ± 0.00085
15	0.0007 ± 0.0004	0.007 ± 0.002		0.0003 ± 0.00019

CHAPTER V

DISCUSSION

As seen in Table V.1, most of the indoor particulate matter mass concentration values are well above the limits of WHO and EPA. Since the annual limits indicated by Turkish Environmental Law are approximately three times those of WHO and EPA, 25% of the obtained concentrations are below the limits and the others exceed the limits by two factor. Parameters affecting the indoor particulate matter mass concentration values are penetration from the outdoor environment, effectiveness of the cleaning procedures, ventilation of the indoor environment, and materials used indoor.

Possible causes of the above limit particulate matter mass concentrations may be listed as follows:

1. Since the selected state schools are nearby to a crowded street, high particulate matter pollution from the traffic might affect the indoor environment through penetration from outside.
2. Because of the high student population in those buildings, daylong activities might increase suspended particulate matter indoor.

3. The frequency and effectiveness of the cleaning procedures together with a proper ventilation are also determining factors on indoor ambient particulate concentrations.

As seen in the same table, the measured concentration values in Fenerbahçe High School are well below those of the state schools. The reason for this situation is likely to be the location of the school which is far from the high traffic area, and also better cleaning and ventilation procedures. In this school, the measured concentration values are all below the Turkish Environmental Law limits, whereas only 50% of the results are below the limits of EPA and WHO.

V.1. POSSIBLE SOURCES

Source attribution and apportionment are important in pollution studies. Source composition and receptor site measurements are the required information for these studies. In recent years, detailed information about the composition of many sources has been obtained. In these studies, certain signature elements were determined type of sources. Some of these elements are summarized as follows:

Sodium (Na): Sodium is an abundantly found element in nature. It is found in almost all rural and urban dust [6].

Lanthanum (La): Lanthanum is used at petroleum refineries [28].

Cerium (Ce): Cerium is used at petroleum refineries and automobile catalysts [28].

Molybdenum (Mo): Molybdenum is used in automobile catalysts [28].

Iron (Fe) and Barium (Ba): These are elements commonly found in brake wear dust [29].

Antimony (Sb): Antimony is commonly found in brake wear dust and is emitted as a result of high temperature sources.

Copper (Cu): The existence of Copper suggests a local high temperature source and it is an indicative of a high-temperature non-ferrous metal smelter [30].

Lead (Pb): The existence Lead suggests a local high temperature source [30].

Zinc (Zn): Zinc is indicative of a high-temperature non-ferrous metal smelter. [31, 32]

Since the number of samples used in this study is limited, using statistical tools for source attribution and apportionment is not possible. However, some general comments are possible from the measured elemental concentrations and EDS analysis of samples. As seen in Figures D1-8 in Appendix D, mainly sea salt element such as sodium, crustle elements scandium and lanthanum, motor vehicle emission related elements bromine and antimony and industrial pollution related elements zinc, arsenic, were obtained from the neutron activation analysis results.

We performed scanning electron microscopy analysis together with elemental determination by EDS. As seen in Figures B.1-14 in Appendix B, coarse, fine, and TSP particulate collection are successful on the filters. Also, from the same figures it can be seen that there are different type of particles with certain morphological properties. The results of the EDS analysis on individual PM₁₀ particulates are presented in Figure B.15-18 in Appendix B. As can be seen, these particulates mainly include aluminum, silisium and calcium which are soil related elements. The similar analysis for PM_{2.5} particulate matter has been performed and the results are presented in Figures B.20-23. As seen from the results, marine and crustle related elements have similar concentrations.

Table V.1: Comparison of the indoor concentration values with that of the standards.

Filter	Type	Indoor Concentration ($\mu\text{g}/\text{m}^3$)	WHO health guideline (PM_{10}: $50 \mu\text{g}/\text{m}^3$)	U.S. EPA ($\text{PM}_{2.5}$: $15 \mu\text{g}/\text{m}^3$) ($\text{PM}_{10}$: $50 \mu\text{g}/\text{m}^3$)	Turkish Environmental Law (PM_{10}: $150 \mu\text{g}/\text{m}^3$)
1	PM_{10}	228.33	AL	AL	AL
2	$\text{PM}_{2.5}$	95.21	NA	AL	NA
3	PM_{10}	289.58	AL	AL	AL
4	$\text{PM}_{2.5}$	93.13	NA	AL	NA
5	$\text{PM}_{2.5}$	55.69	NA	AL	NA
6	$\text{PM}_{2.5}$	81.06	NA	AL	NA
7	$\text{PM}_{2.5}$	61.44	NA	AL	NA
8	PM_{10}	68.75	AL	AL	BL
9	PM_{10}	180.73	AL	AL	AL
10	$\text{PM}_{2.5}$	67.64	NA	AL	NA
11	PM_{10}	276.98	AL	AL	AL
12	$\text{PM}_{2.5}$	48.85	NA	AL	NA
13	$\text{PM}_{2.5}$	45.56	NA	AL	NA
14	PM_{10}	132.13	AL	AL	BL
15	$\text{PM}_{2.5}$	32.64	NA	AL	NA
17	$\text{PM}_{2.5}$	34,67	NA	AL	NA
18	PM_{10}	27,86	BL	BL	BL
19	$\text{PM}_{2.5}$	13,30	NA	BL	NA
20	PM_{10}	82,97	AL	AL	BL
21	TSP	190,83	NA	NA	NA
22	TSP	61,87	NA	NA	NA

AL: Above limit

BL: Below Limit

NA: Not Applicable

The most significant sources of $PM_{2.5}$ are:

1. Secondary PM formation,
2. Diesel driven traffic,
3. Paved road dust,
4. Meat charbroiling,
5. Wood burning,
6. Petrol driven traffic.

[33]

V.2. HEALTH EFFECTS

As a matter of fact, health effects of the particulate matter are expected to be high especially in terms of asthma. Also from symptoms point of view, exposure to particulate matter irritate the eyes, ears, nose, throat and lungs. Also children with chronic illnesses are widely affected from particulate pollution. [34, 35]

Today, it is not known which element(s) in particulate pollution adversely affects human health, which illnesses do they create or exacerbate. The only researches performed are on the basis of size and source affects. For instance, it can be said that $PM_{2.5}$ is important for it can penetrate through lungs when inhaled. On the other hand, evaporative cooling or fossil fuel burning is researched on its own as examples of source contributions to health effects. [34, 35]

V.3. INDOOR OUTDOOR CORRELATION

The outdoor concentration values for PM_{10} are daily measured and recorded by the municipality of Istanbul and published in its official web site. The given values of PM_{10} are for the Kadıköy district. These values are given in Table V.2.

As seen in Table V.2, outdoor and indoor values are quite different. One reason for these outdoor measurements will not represent the high concentration values within the traffic in Kadıköy. In addition, student activities in the buildings might create high particulate concentrations as measured.

Table V.2: PM₁₀ outdoor and indoor correlations.

Filter	Date	Day	PM ₁₀ Outdoor (µg/m ³)	PM ₁₀ Indoor (µg/m ³)
1	27.04.2004	Tuesday	24	228.33
3	29.04.2004	Thursday	130	289.58
11	17.05.2004	Monday	39	276.98
	18.05.2004	Tuesday	41	
14	27.05.2004	Thursday	30	132.13
	28.05.2004	Friday	24	

V.4. ENRICHMENT FACTORS

Table V.3: Enrichment Factors with respect to Sodium.

Filter	K	Sc	Zn	As	Br	Sb	La
1					1,38		
2		5877	561578		1,80		
3				5051	1,12		
4					0,67		
5					1,47		
6				571	1,60		
7	12,40				1,10		
8					0,99		
9	46,25	299845	1789191	10532	2,40	262511	76599
10	23,52	128396		13969	3,90		
11	38,18	90182	1189631	10677	1,56		45571
12			13121846	30822	3,98	856164	
13			3537532		4,76		96604
14	29,34	740247	429343	7535	1,29	219761	85393
15				22436	10,24		96154

Enrichment factors in Tables V.3 and V.4, indicate that As, Sb and Zn are highly enriched with respect to both soil and sea-salt. Therefore, they should have some other sources releasing them to the environment and possible sources are motor vehicle emissions and industrial emissions around the city.

At the same time our ppm concentration values indicate that As, and Zn are mostly in fine particulate matter as expected.

Table V.4: Enrichment Factors with respect to Scandium.

Filter	Na	K	Zn	As	Br	Sb	La
1							
2	41,77032		751,22		4545,45		
3							
4							
5							
6							
7							
8							
9	0,81870	1,54	46,91	32,35	118,72	1228,76	1,38
10	1,91193	1,83		100,21	450,79		
11	2,72209	4,22	103,71	109,04	256,29		2,74
12							
13							
14	0,33162	0,40	4,56	9,38	25,91	416,67	0,63
15							

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APPENDIX A

PHOTOGRAPHS



Figure A.1: Airmetrics Minivol Portable Air sampler. Each part separately shown: Two batteries, the main block, two battery cases and two filter heads.



Figure A.2: Airmetrics Minivol Portable Air sampler. The parts are joined to form the block.



Figure A.3: The Program Control Unit of the Airmetrics Minivol Portable Air sampler. (The flow meter, programmable timer and the flow adjustment units)

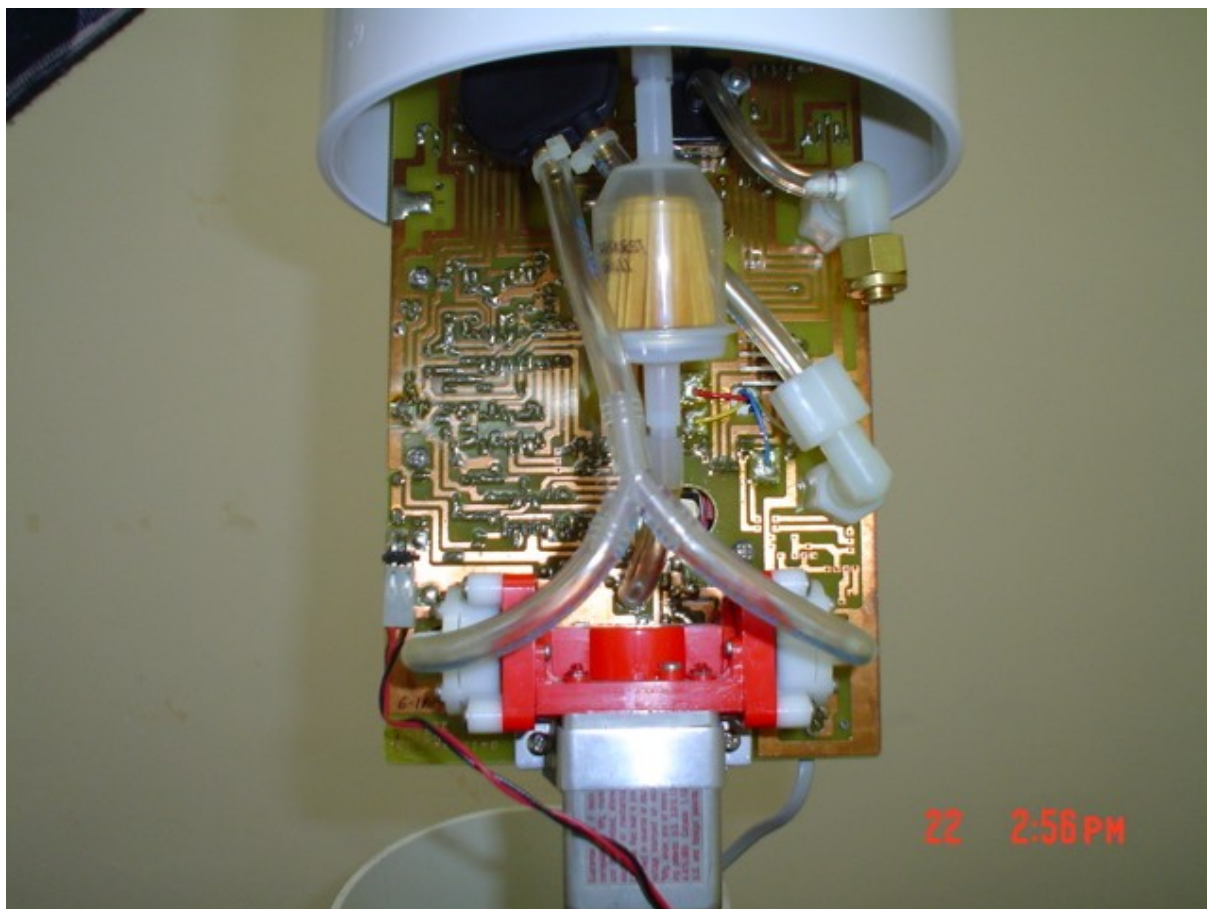


Figure A.4: The pump module of Airmetrics Minivol Portable Air sampler.



Figure A.5: The filter head of Airmetrics Minivol Portable Air sampler.

1. Coarse particulate matter impactor
2. Fine particulate matter impactor
3. Filter holder assembly



Figure A.6: The filter holder assembly



Figure A.7: Coarse and fine particulate matter impactors.



Figure A.8: The Petri dish



Figure A.9: The micro balance (Mettler Toledo)



Figure A.10: The clean hood.



Figure A.11: The clean room.

All the studies are performed with lab coat, powder free latex gloves, mouth holder and bonnet.



Figure A.12: The protection cage for Airmetrics Minivol Portable Air Sampler



Figure A.13: The system placed in the entrance corridor of the school F. R. Unat.



Figure A.14: The system placed in the entrance corridor of the school F. R. Unat. (counter view of Figure A.13)



Figure A.15: The system placed in the entrance corridor of the school M. Şefizade.



Figure A.16: The system placed in the entrance corridor of the school M. Şefizade. (counter view of Figure A.15)



Figure A.17: The system placed in the first floor corridor of the school M. Aykın.



Figure A.18: The system placed in the first floor corridor of the school Ö. H. Reşit.



Figure A.19: The system placed in the first floor corridor of the school Ö. H. Reşit.



Figure A.20: The Neutron Activation system.



Figure A.21: The Neutron Activation system. (inside the neutron bombarding tank)



Figure A.22: The system placed in a classroom of Fenerbahçe high school.

APPENDIX B

SEM FIGURES

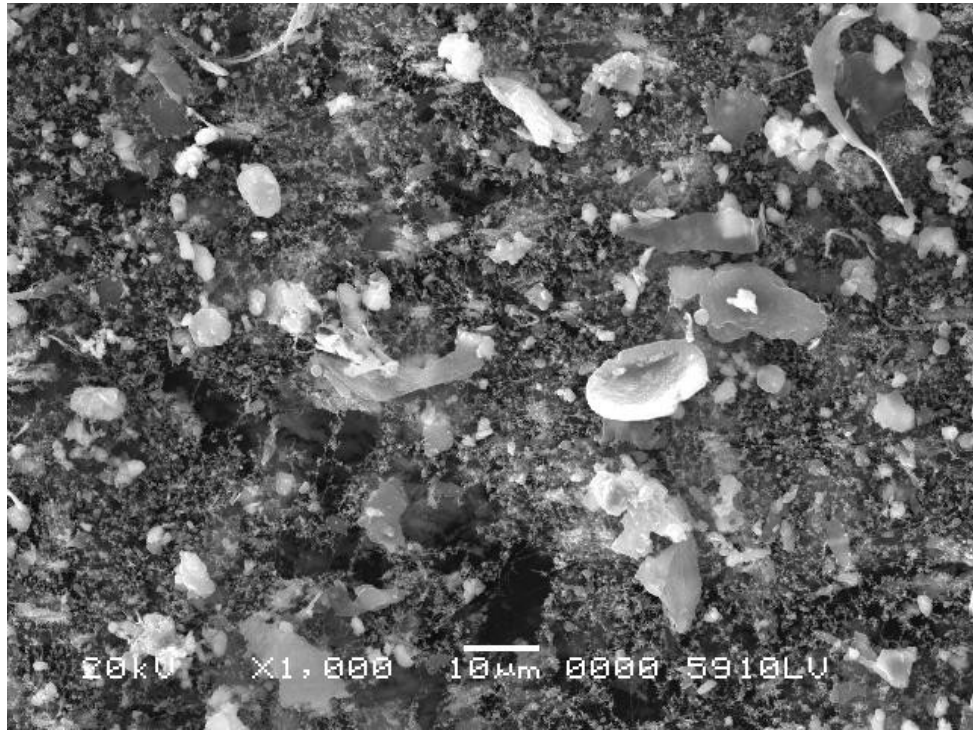


Figure B.1: A view of coarse fraction filter from Fenerbahçe high school.



Figure B.2: A view of coarse fraction filter from Fenerbahçe high school.

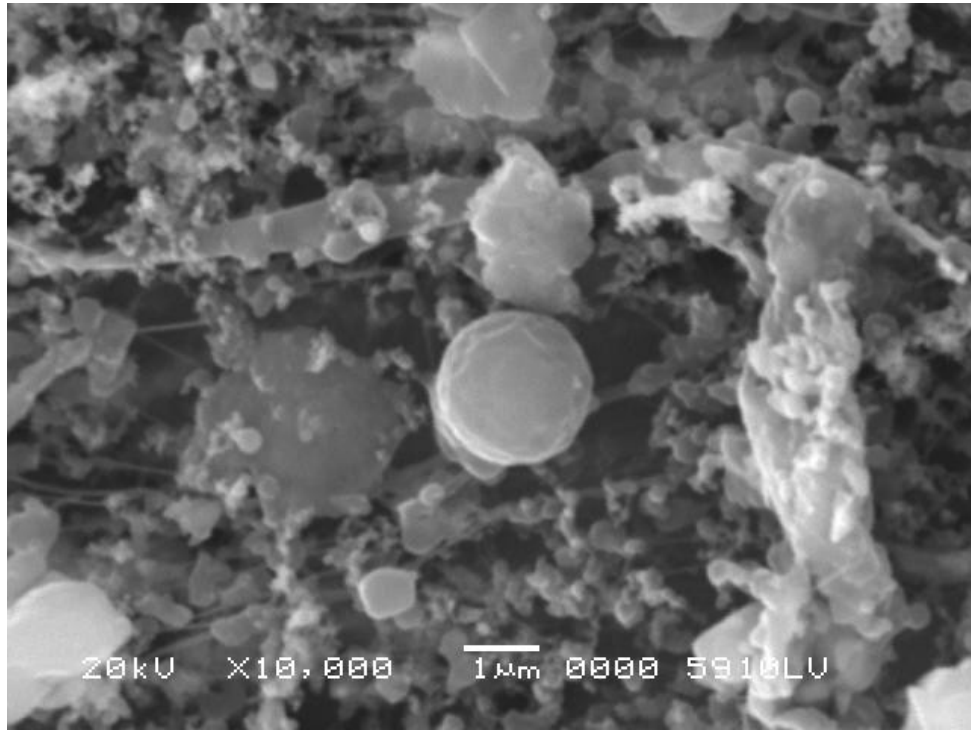


Figure B.3: A view of coarse fraction filter from Fenerbahçe high school.

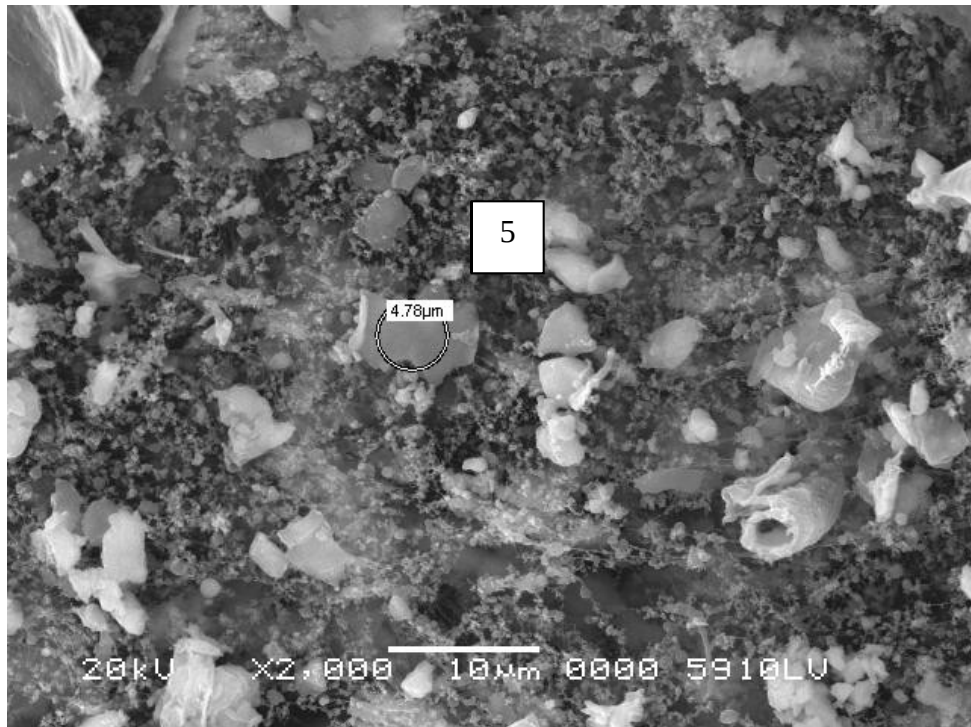


Figure B.4: A view of coarse fraction filter from Fenerbahçe high school.

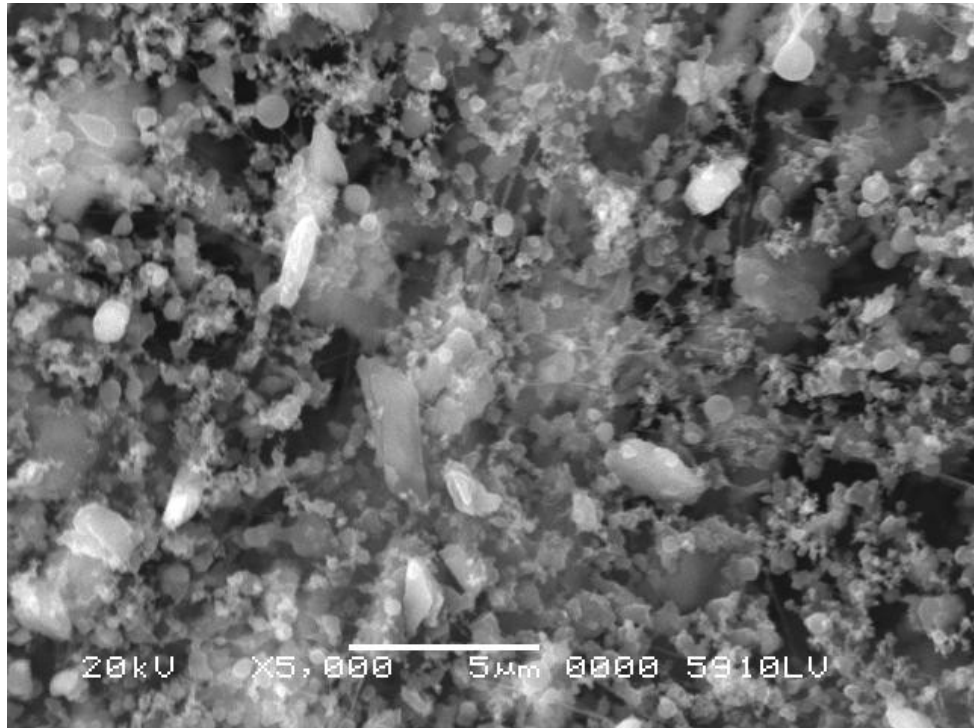


Figure B.5: A view of fine fraction filter from Fenerbahçe high school.

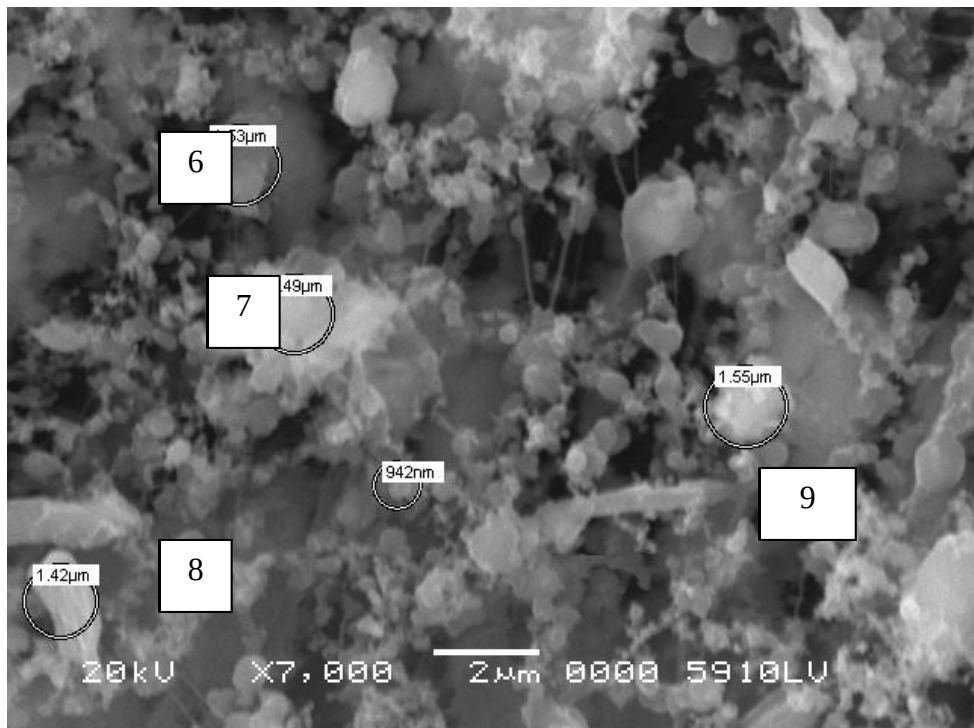


Figure B.6: A view of fine fraction filter from Fenerbahçe high school.

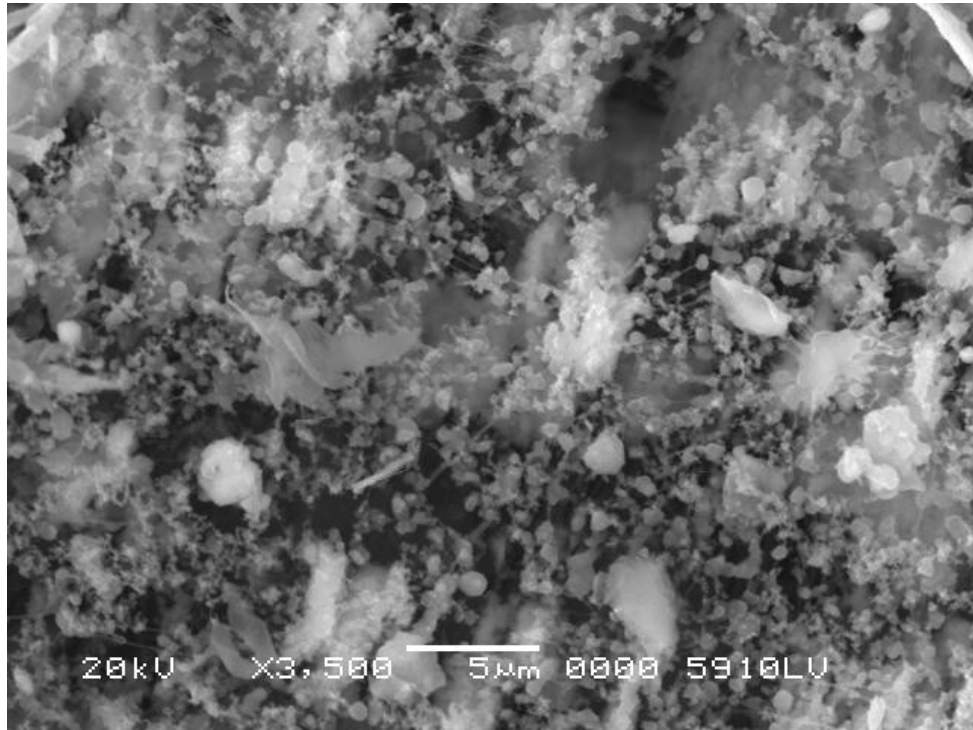


Figure B.7: A view of fine fraction filter from Fenerbahçe high school.

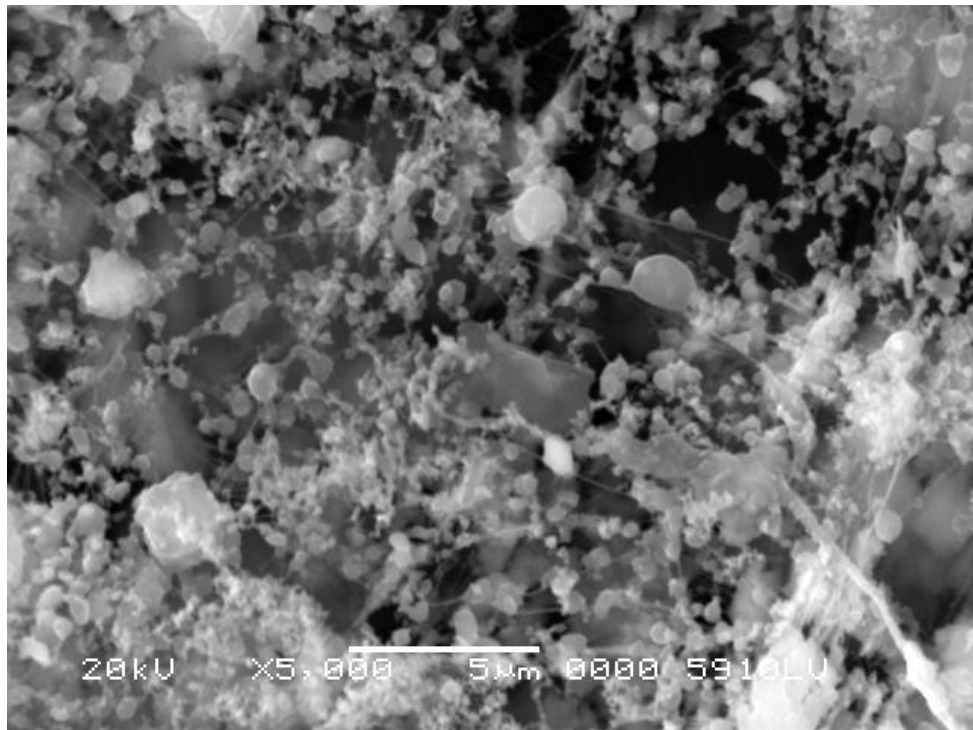


Figure B.8: A view of fine fraction filter from Fenerbahçe high school.

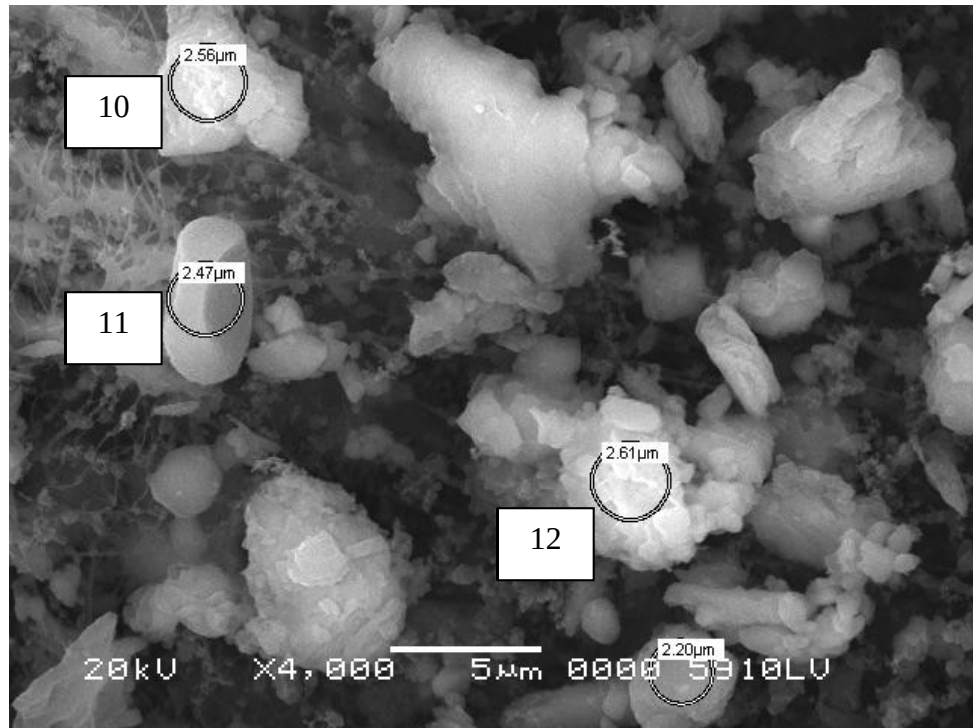


Figure B.9: A view of total suspended particle filter from Fenerbahçe high school.

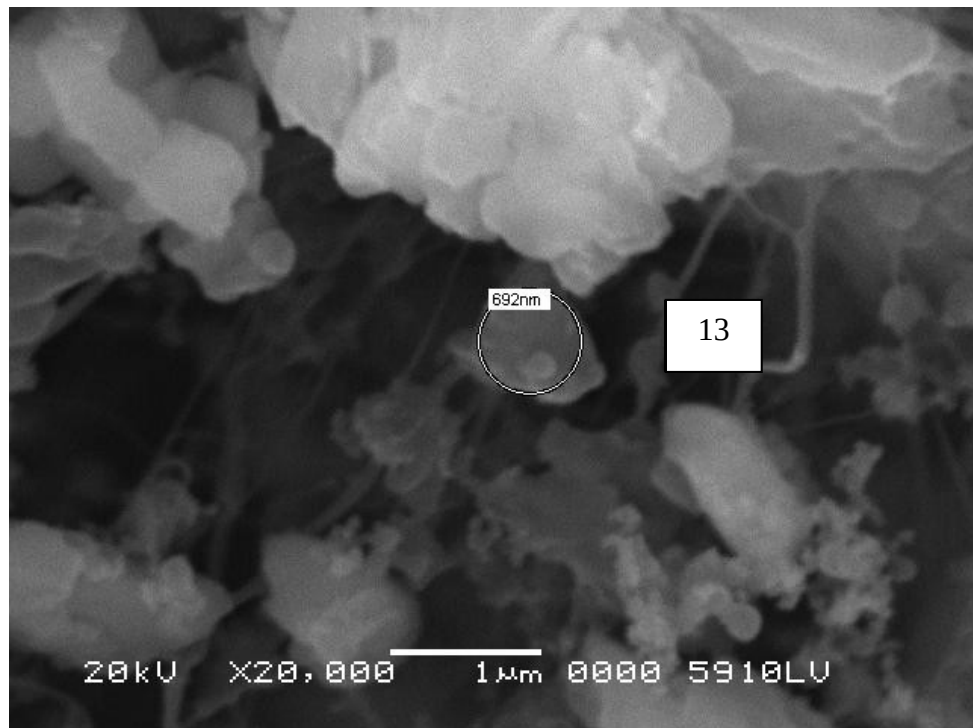


Figure B.10: A view of total suspended particle filter from Fenerbahçe high school.

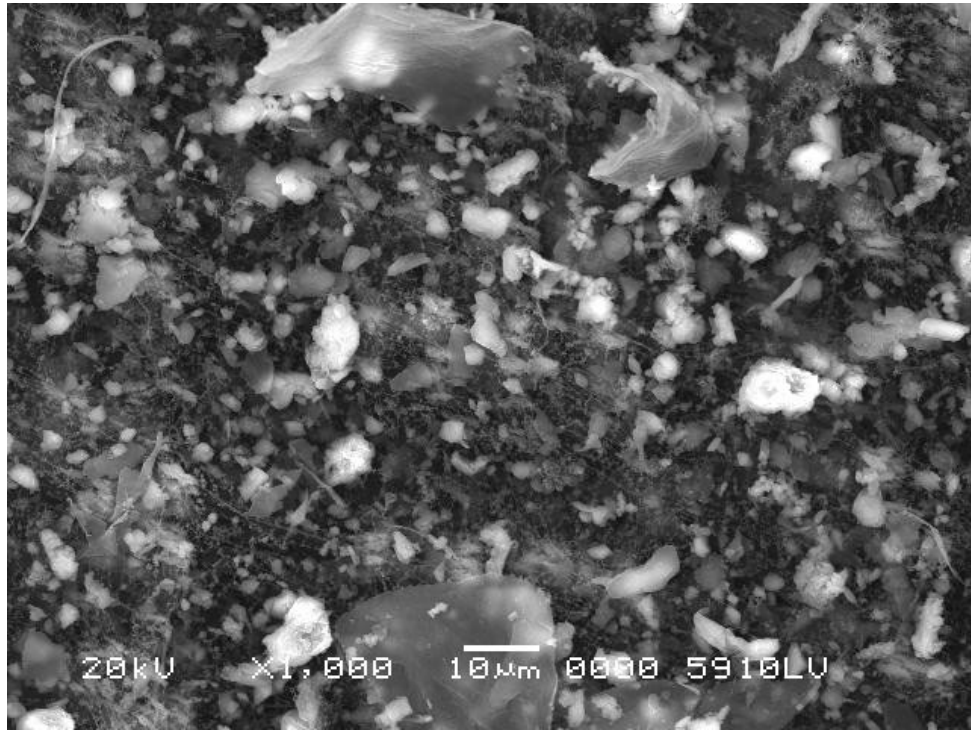


Figure B.11: A view of total suspended particle filter from Fenerbahçe high school.

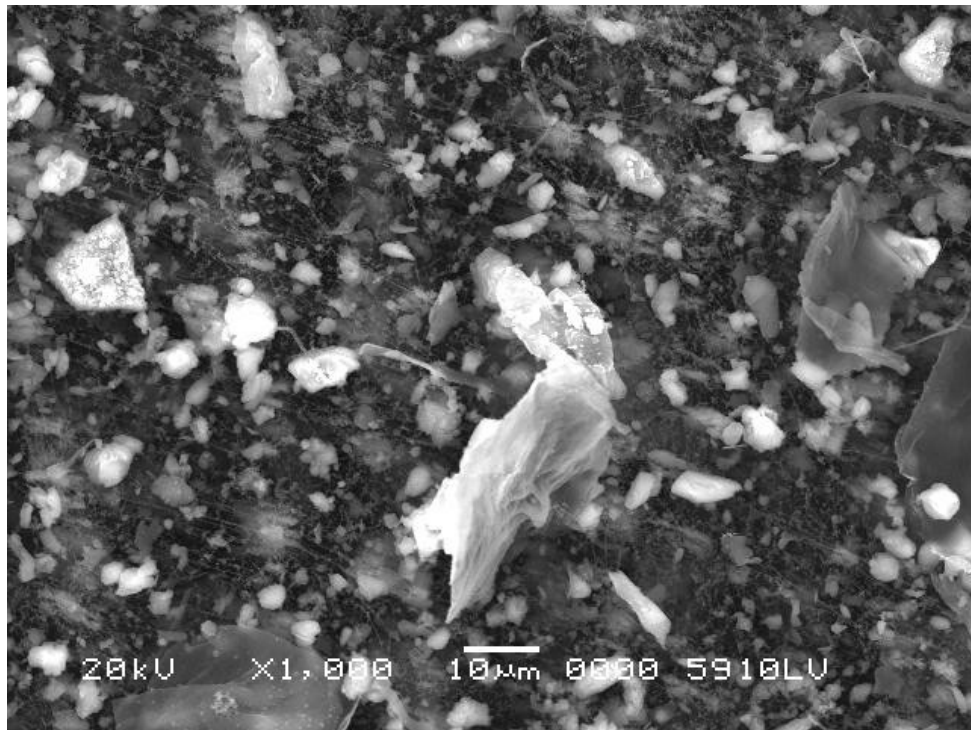


Figure B.12: A view of total suspended particle filter from Fenerbahçe high school.

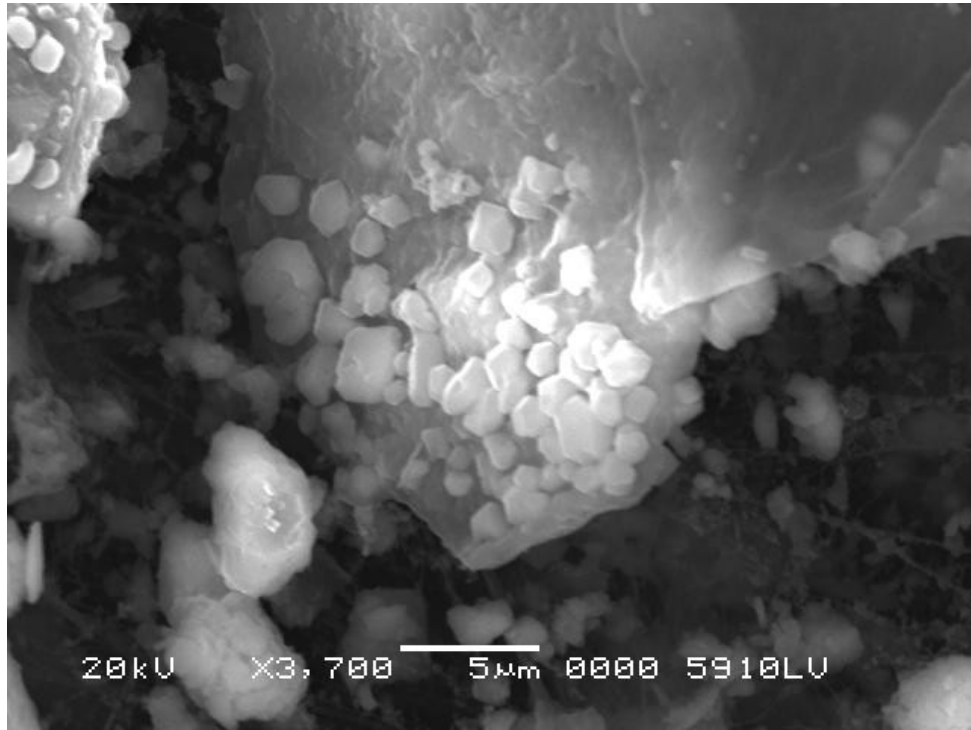


Figure B.13: A view of total suspended particle filter from Fenerbahçe high school.

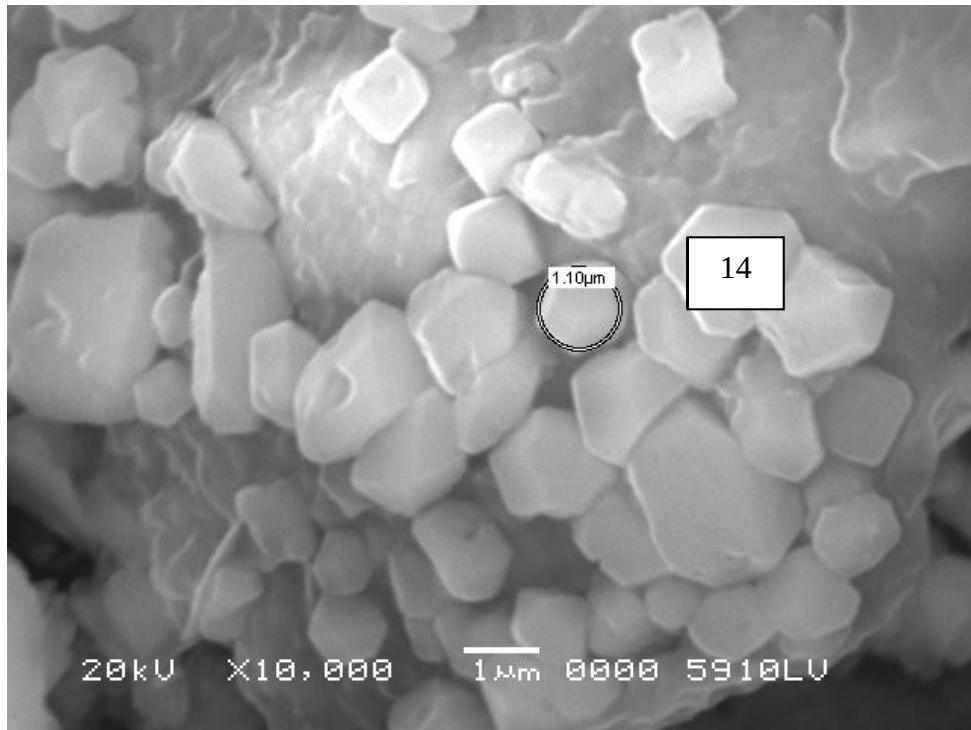
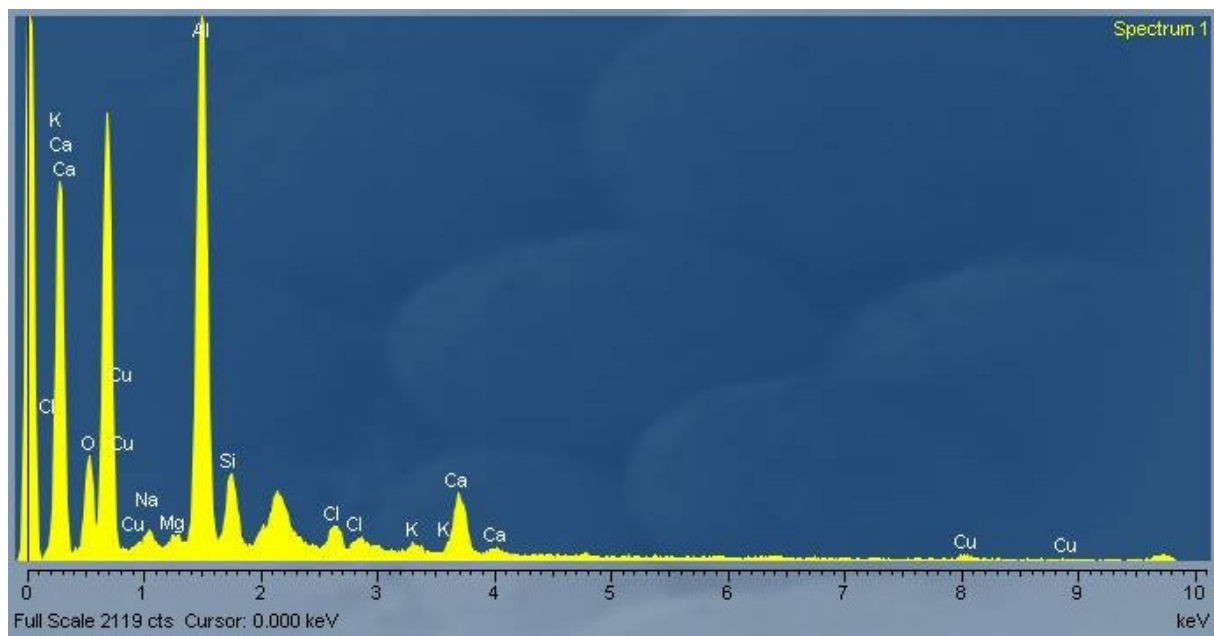
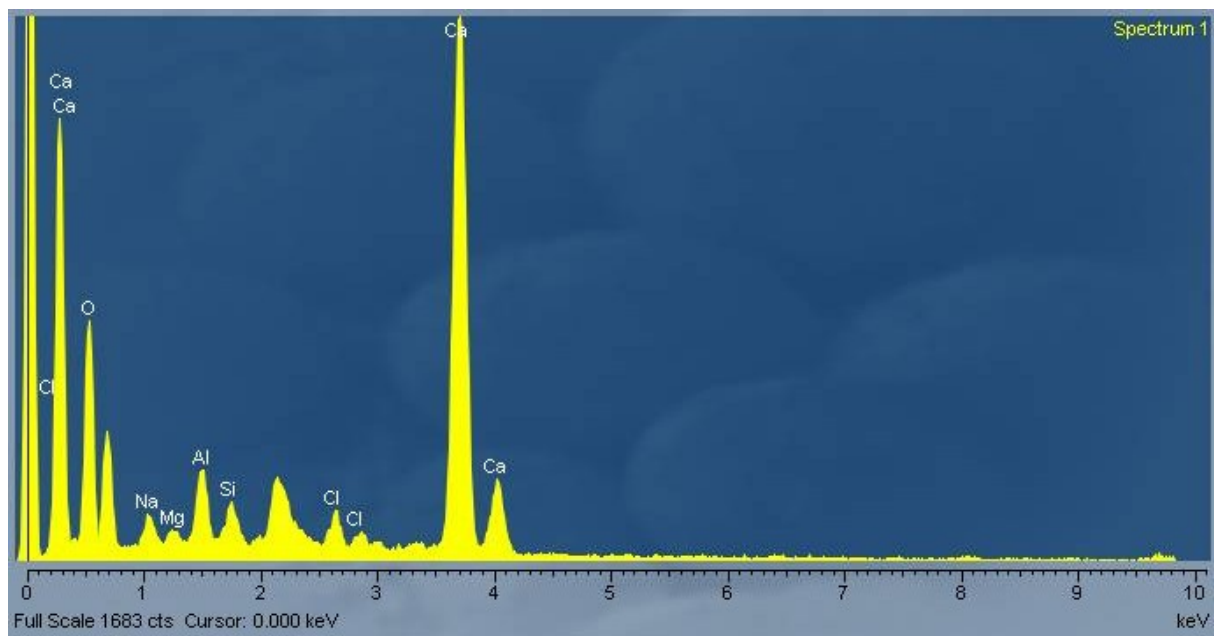


Figure B.14: A view of total suspended particle filter from Fenerbahçe high school.



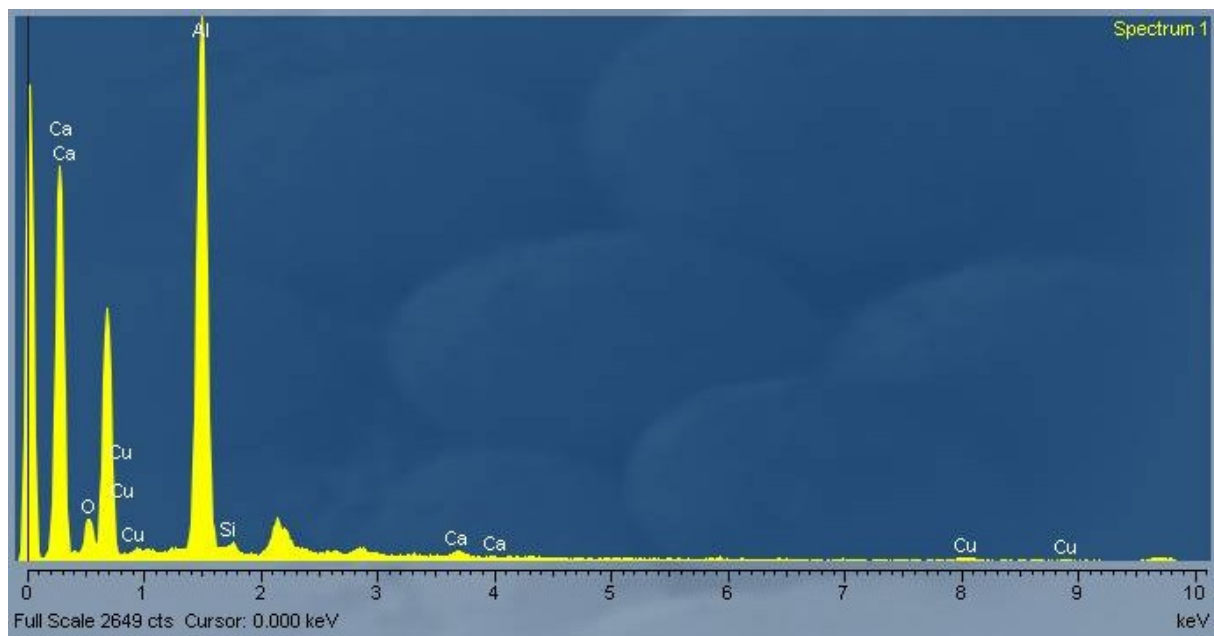
Spectrum	O	Na	Mg	Al	Si	Cl	K	Ca	Cu	Total
Spectrum 1	35.51	2.04	0.87	38.58	8.33	3.44	1.13	7.62	2.49	100.00
Max.	35.51	2.04	0.87	38.58	8.33	3.44	1.13	7.62	2.49	
Min.	35.51	2.04	0.87	38.58	8.33	3.44	1.13	7.62	2.49	

Figure B.15: The spectrum of scene #1 in Figure B.2 and the related table.



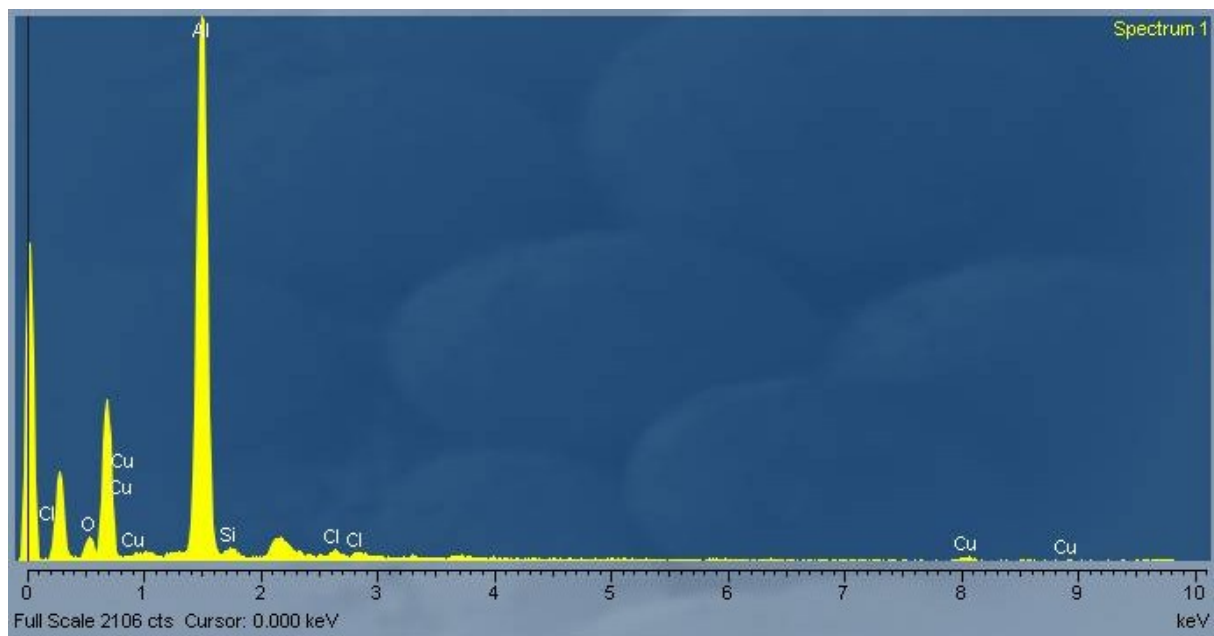
Spectrum	O	Na	Mg	Al	Si	Cl	Ca	Total
Spectrum 1	59.88	2.11	0.68	3.05	1.39	1.70	31.19	100.00
Max.	59.88	2.11	0.68	3.05	1.39	1.70	31.19	
Min.	59.88	2.11	0.68	3.05	1.39	1.70	31.19	

Figure B.16: The spectrum of scene #2 in Figure B.2 and the related table.



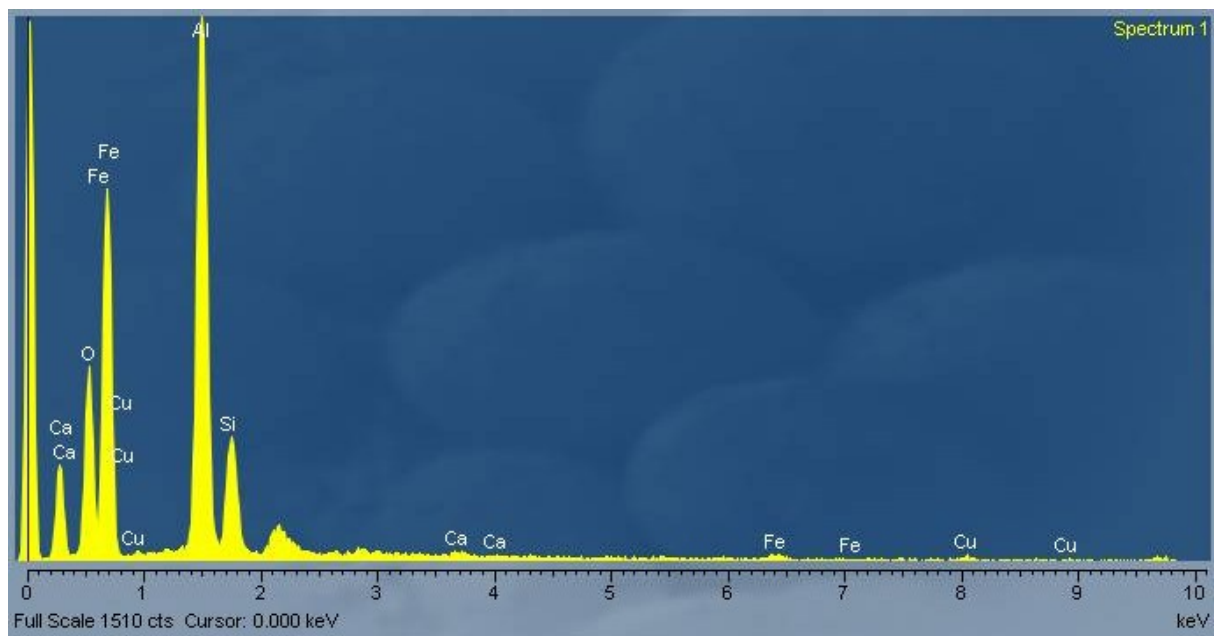
Spectrum	O	Al	Si	Ca	Cu	Total
Spectrum 1	24.61	67.67	1.97	1.51	4.24	100.00
Max.	24.61	67.67	1.97	1.51	4.24	
Min.	24.61	67.67	1.97	1.51	4.24	

Figure B.17: The spectrum of scene #3 in Figure B.2 and the related table.



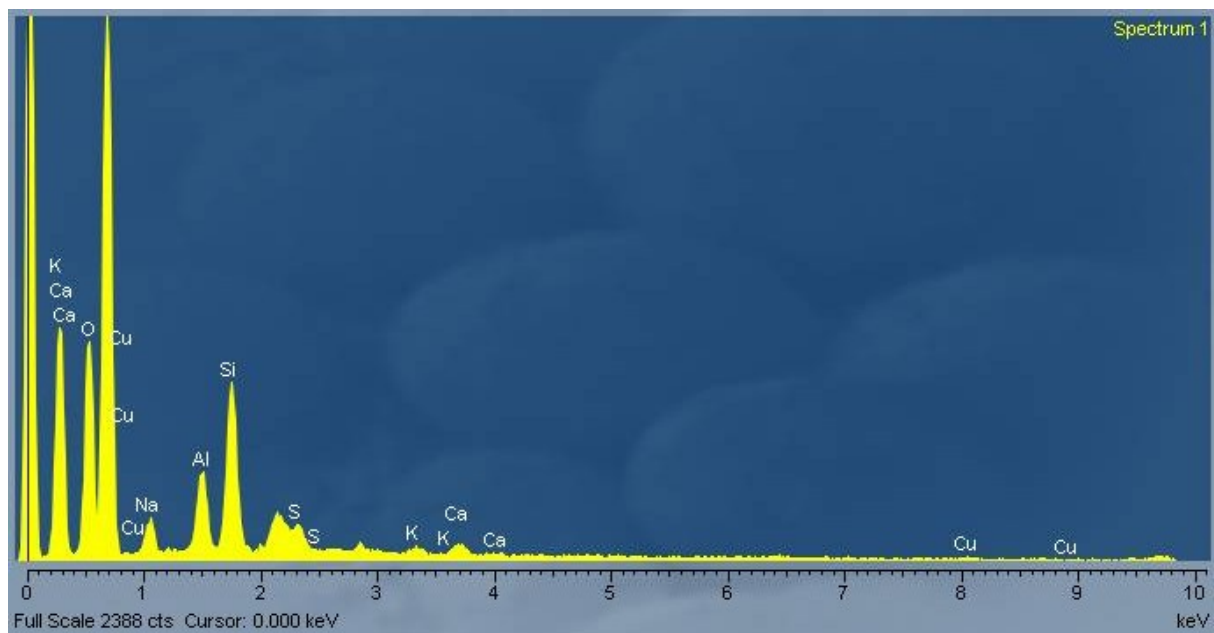
Spectrum	O	Al	Si	Cl	Cu	Total
Spectrum 1	18.90	71.43	2.32	1.97	5.38	100.00
Max.	18.90	71.43	2.32	1.97	5.38	
Min.	18.90	71.43	2.32	1.97	5.38	

Figure B.18:The spectrum of scene #4 in Figure B.2 and the related table.



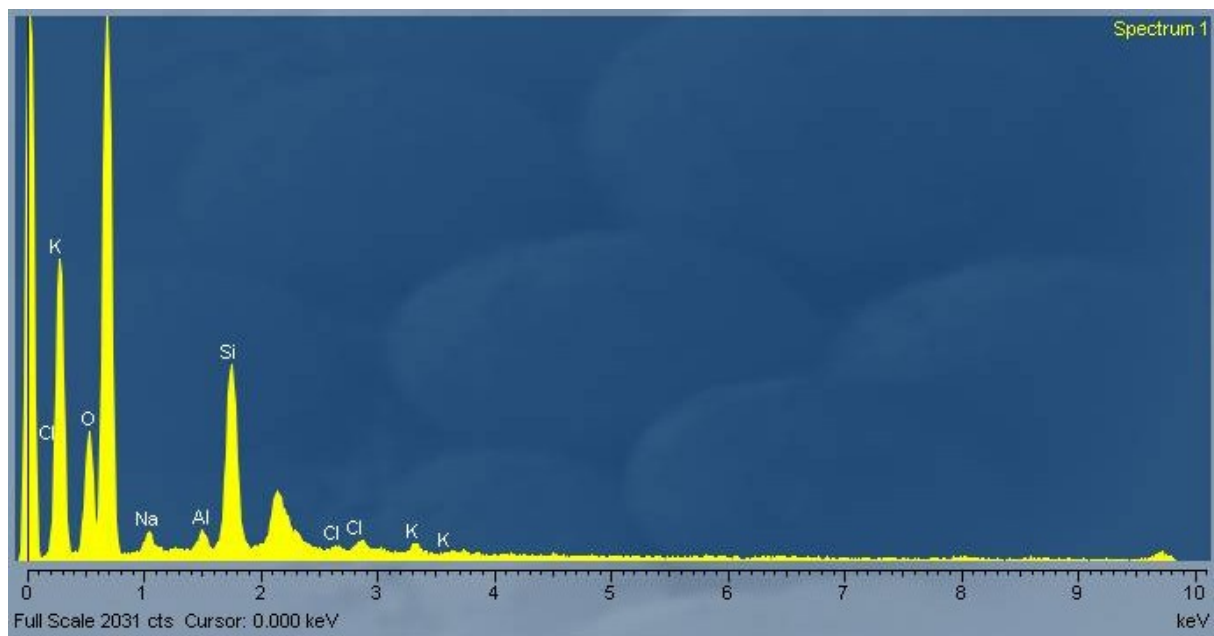
Spectrum	O	Al	Si	Ca	Fe	Cu	Total
Spectrum 1	49.19	35.10	11.92	0.53	1.44	1.82	100.00
Max.	49.19	35.10	11.92	0.53	1.44	1.82	
Min.	49.19	35.10	11.92	0.53	1.44	1.82	

Figure B.19:The spectrum of scene #5 in Figure B.4 and the related table.



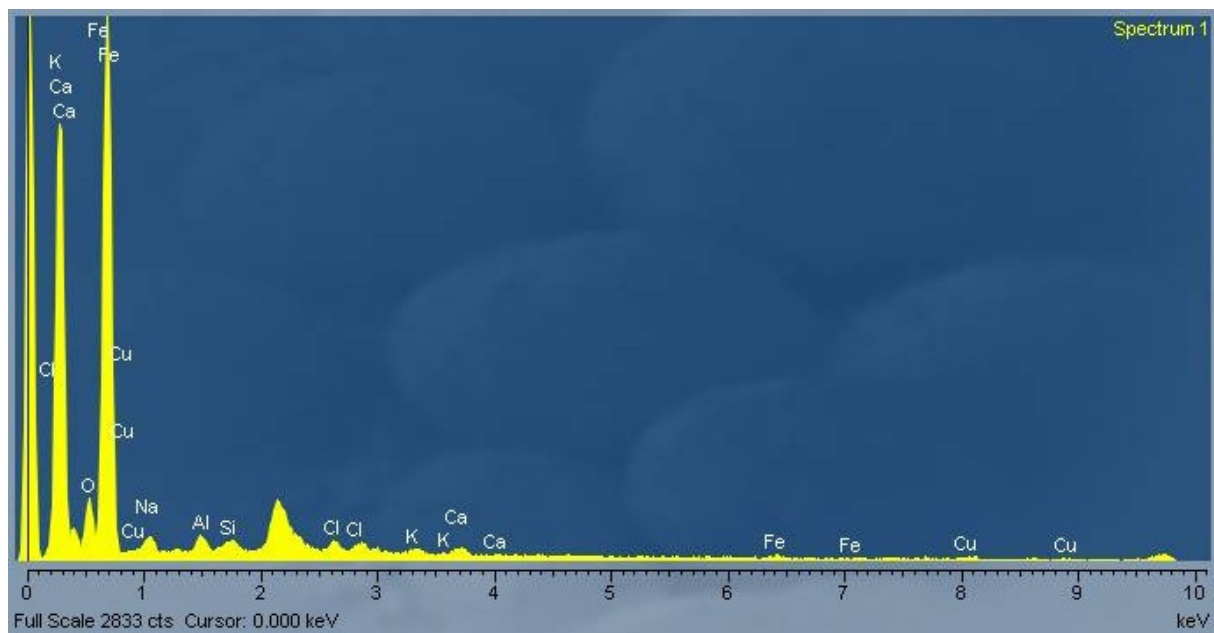
Spectrum	O	Na	Al	Si	S	K	Ca	Cu	Total
Spectrum 1	62.46	6.34	7.71	17.30	1.70	1.00	1.89	1.60	100.00
Max.	62.46	6.34	7.71	17.30	1.70	1.00	1.89	1.60	
Min.	62.46	6.34	7.71	17.30	1.70	1.00	1.89	1.60	

Figure B.20:The spectrum of scene #6 in Figure B.6 and the related table.



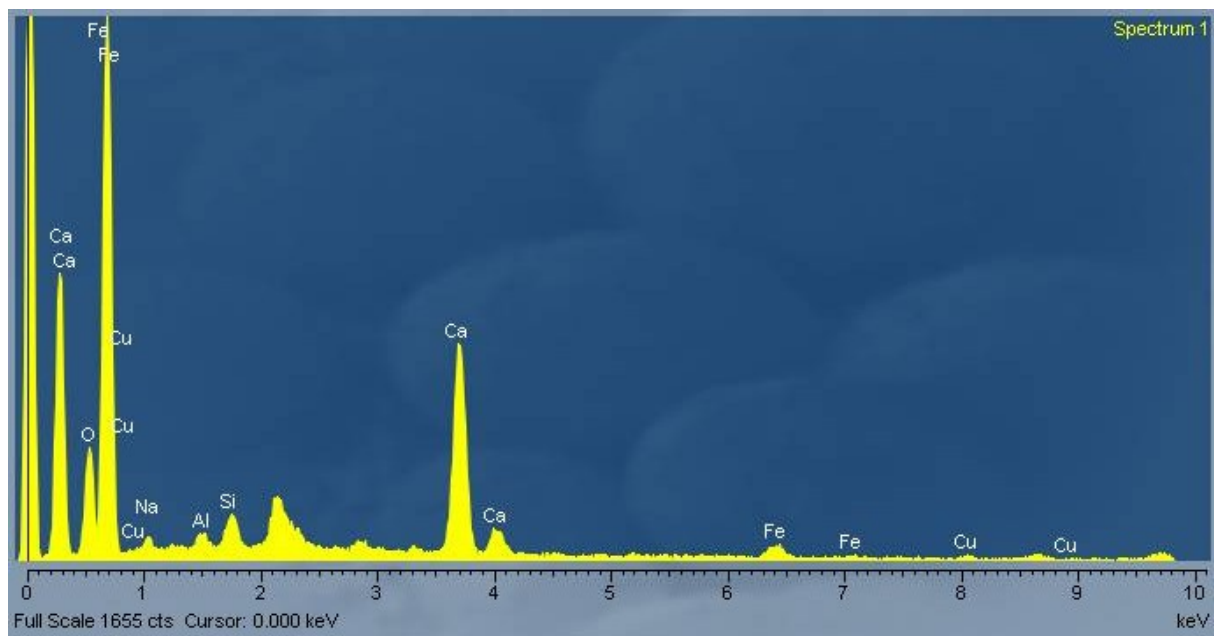
Spectrum	O	Na	Al	Si	Cl	K	Total
Spectrum 1	62.54	4.22	2.57	27.13	1.54	2.00	100.00
Max.	62.54	4.22	2.57	27.13	1.54	2.00	
Min.	62.54	4.22	2.57	27.13	1.54	2.00	

Figure B.21:The spectrum of scene #7 in Figure B.6 and the related table.



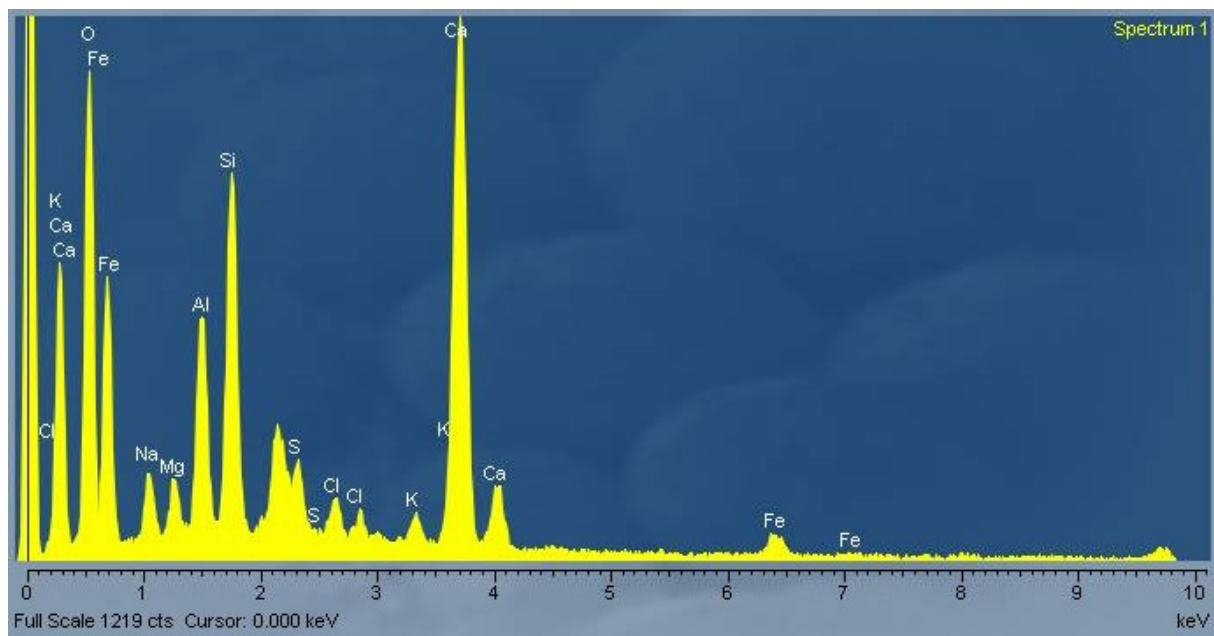
Spectrum	O	Na	Al	Si	Cl	K	Ca	Fe	Cu	Total
Spectrum 1	64.92	6.76	5.51	2.85	4.59	2.28	3.57	2.78	6.74	100.00
Max.	64.92	6.76	5.51	2.85	4.59	2.28	3.57	2.78	6.74	
Min.	64.92	6.76	5.51	2.85	4.59	2.28	3.57	2.78	6.74	

Figure B.22:The spectrum of scene #8 in Figure B.6 and the related table.



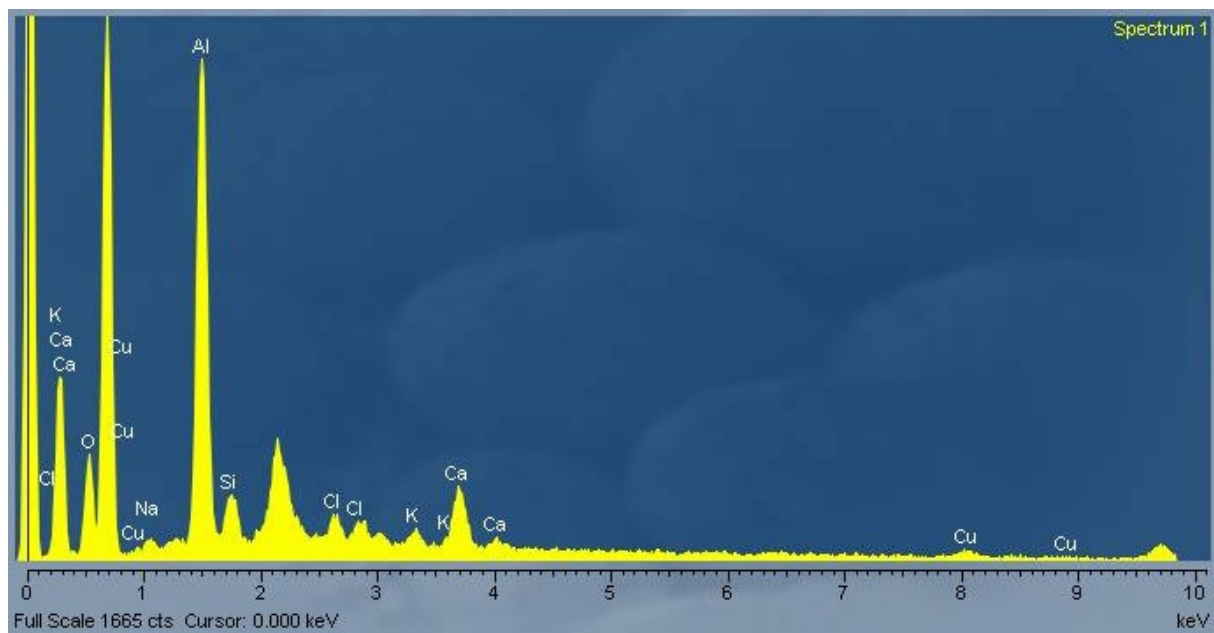
Spectrum	O	Na	Al	Si	Ca	Fe	Cu	Total
Spectrum 1	62.93	1.33	1.43	2.75	25.51	4.23	1.81	100.00
Max.	62.93	1.33	1.43	2.75	25.51	4.23	1.81	
Min.	62.93	1.33	1.43	2.75	25.51	4.23	1.81	

Figure B.23:The spectrum of scene #9 in Figure B.6 and the related table.



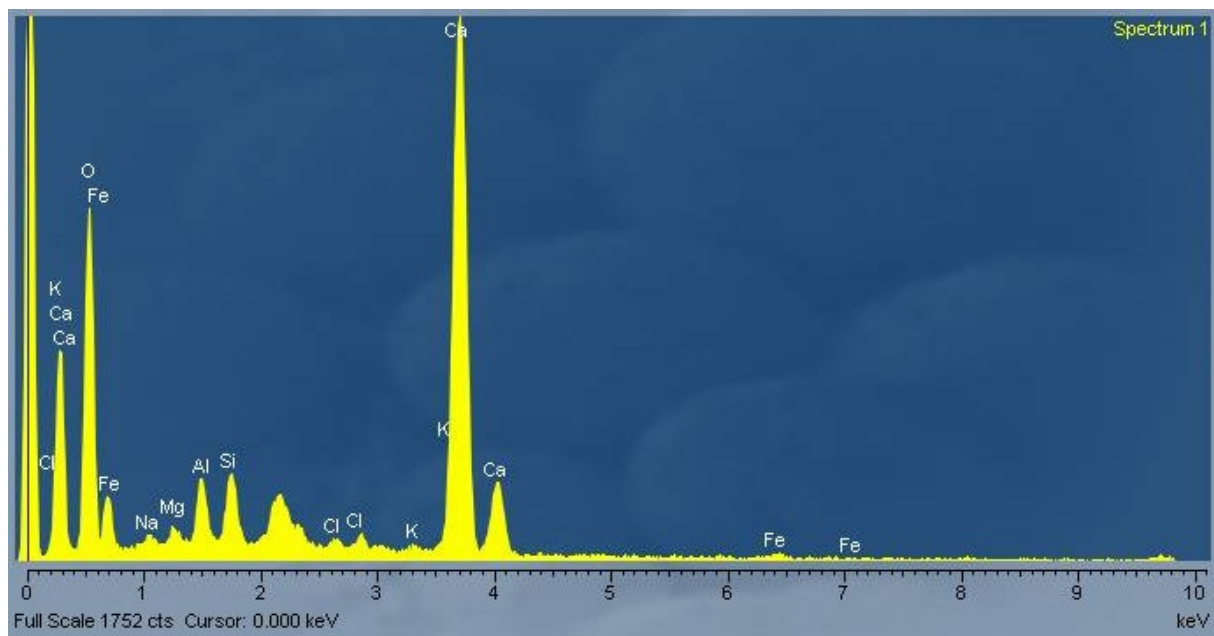
Spectrum	O	Na	Mg	Al	Si	S	Cl	K	Ca	Fe	Total
Spectrum 1	57.32	2.75	1.67	5.23	8.86	1.04	1.35	0.90	18.89	1.98	100.00
Max.	57.32	2.75	1.67	5.23	8.86	1.04	1.35	0.90	18.89	1.98	
Min.	57.32	2.75	1.67	5.23	8.86	1.04	1.35	0.90	18.89	1.98	

Figure B.24:The spectrum of scene #10 in Figure B.9 and the related table.



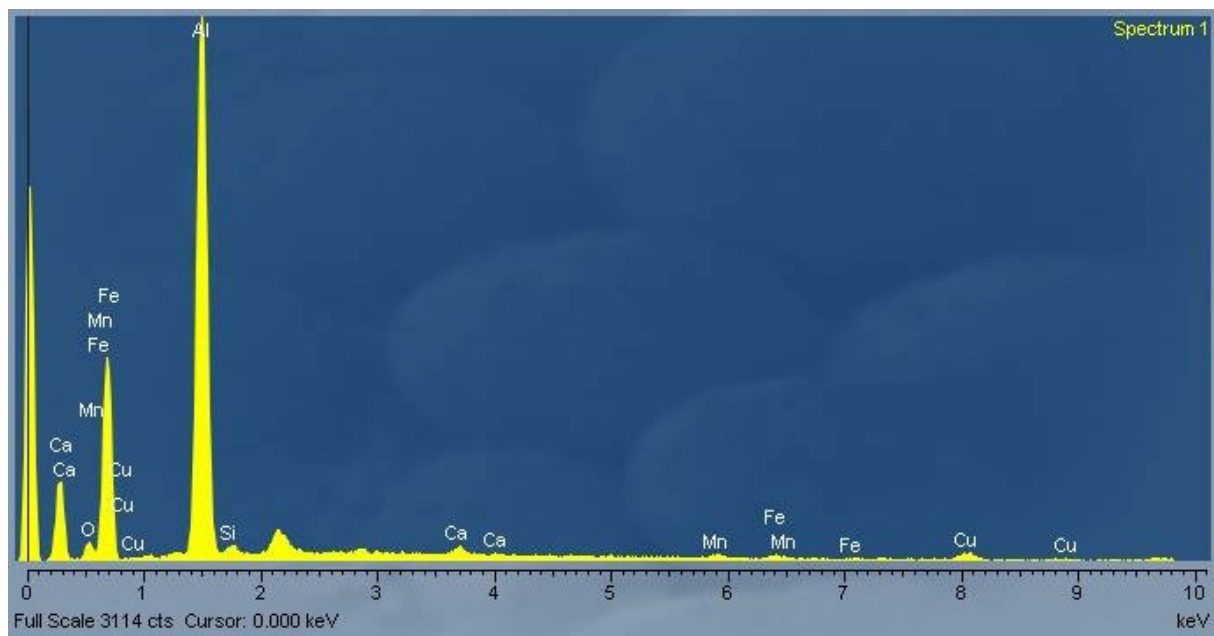
Spectrum	O	Na	Al	Si	Cl	K	Ca	Cu	Total
Spectrum 1	38.74	2.18	36.69	5.61	3.56	1.92	7.92	3.37	100.00
Max.	38.74	2.18	36.69	5.61	3.56	1.92	7.92	3.37	
Min.	38.74	2.18	36.69	5.61	3.56	1.92	7.92	3.37	

Figure B.25:The spectrum of scene #11 in Figure B.9 and the related table.



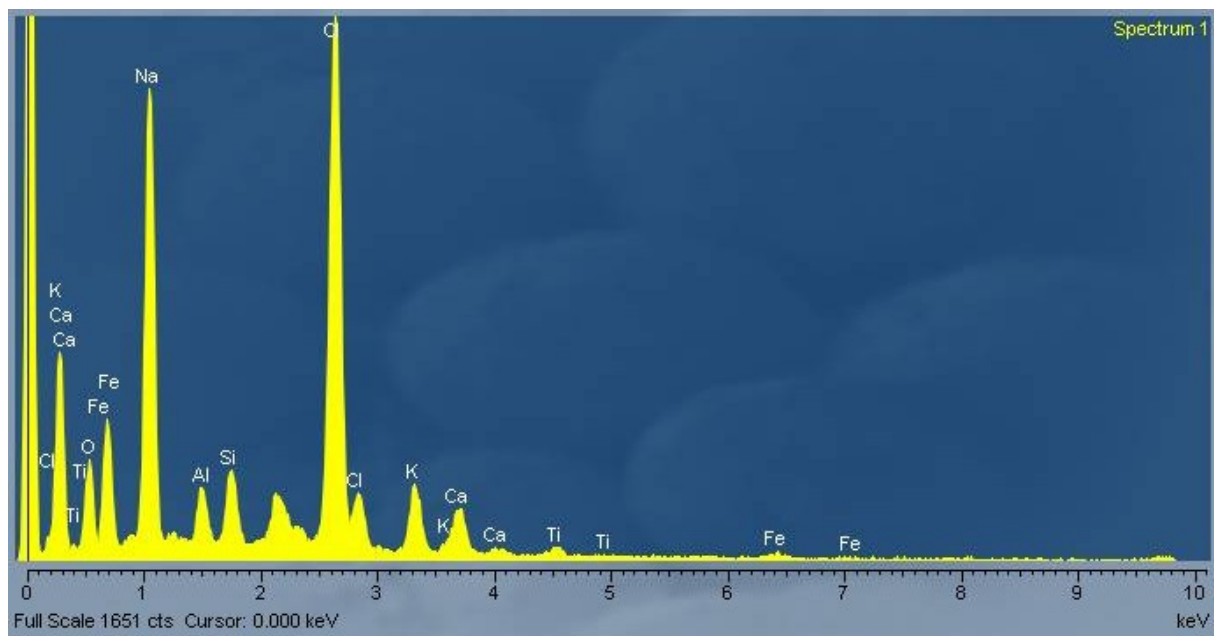
Spectrum	O	Na	Mg	Al	Si	Cl	K	Ca	Fe	Total
Spectrum 1	64.93	0.65	0.62	2.22	2.41	0.52	0.26	27.90	0.50	100.00
Max.	64.93	0.65	0.62	2.22	2.41	0.52	0.26	27.90	0.50	
Min.	64.93	0.65	0.62	2.22	2.41	0.52	0.26	27.90	0.50	

Figure B.26: The spectrum of scene #12 in Figure B.9 and the related table.



Spectrum	O	Al	Si	Ca	Mn	Fe	Cu	Total
Spectrum 1	18.75	65.99	2.22	1.71	2.05	1.67	7.60	100.00
Max.	18.75	65.99	2.22	1.71	2.05	1.67	7.60	
Min.	18.75	65.99	2.22	1.71	2.05	1.67	7.60	

Figure B.27: The spectrum of scene #13 in Figure B.10 and the related table.



Spectrum	O	Na	Al	Si	Cl	K	Ca	Ti	Fe	Total
Spectrum 1	32.65	25.59	2.54	3.36	27.19	4.18	3.03	0.81	0.65	100.00
Max.	32.65	25.59	2.54	3.36	27.19	4.18	3.03	0.81	0.65	
Min.	32.65	25.59	2.54	3.36	27.19	4.18	3.03	0.81	0.65	

Figure B.28: The spectrum of scene #14 in Figure B.14 and the related table.

APPENDIX C

MAPS

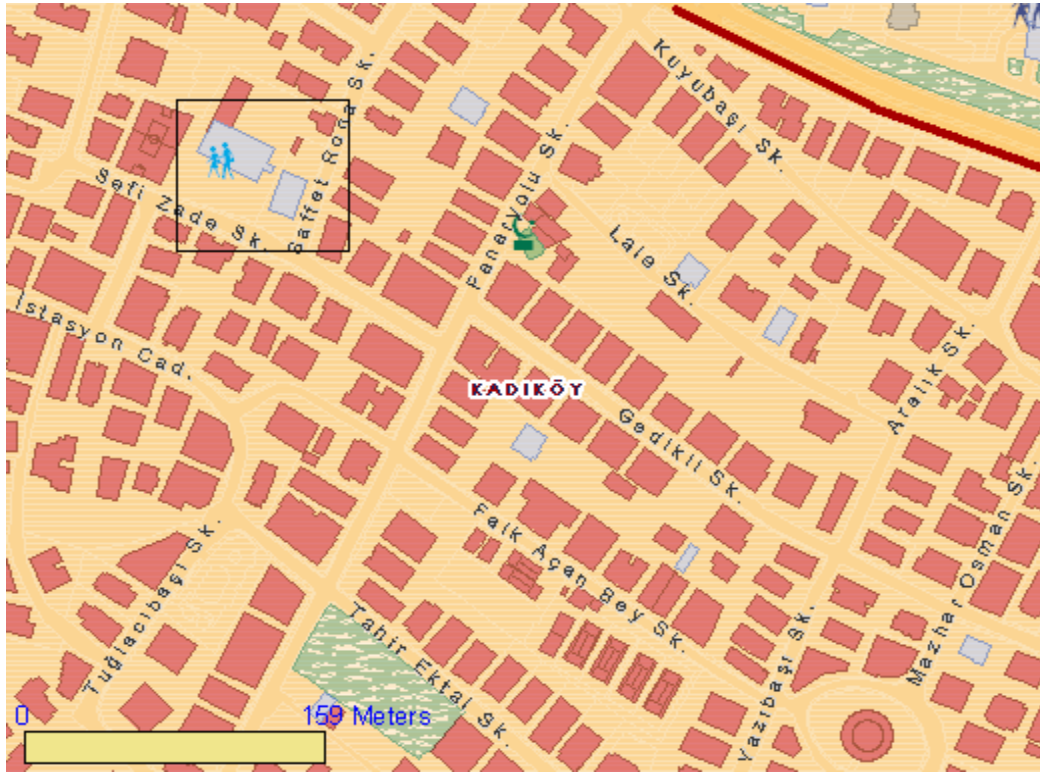


Figure C.1: Melahat Şefizade İ.Ö.O in map.

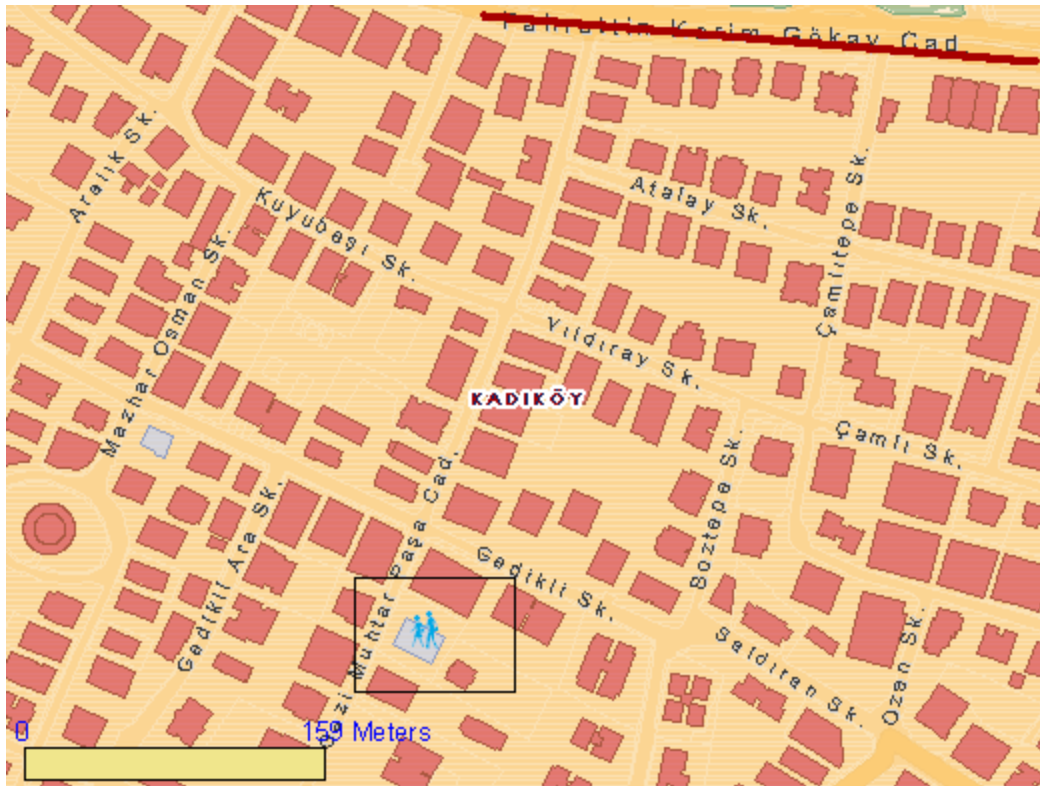


Figure C.2: Mustafa Aykın İ.Ö.O in map.

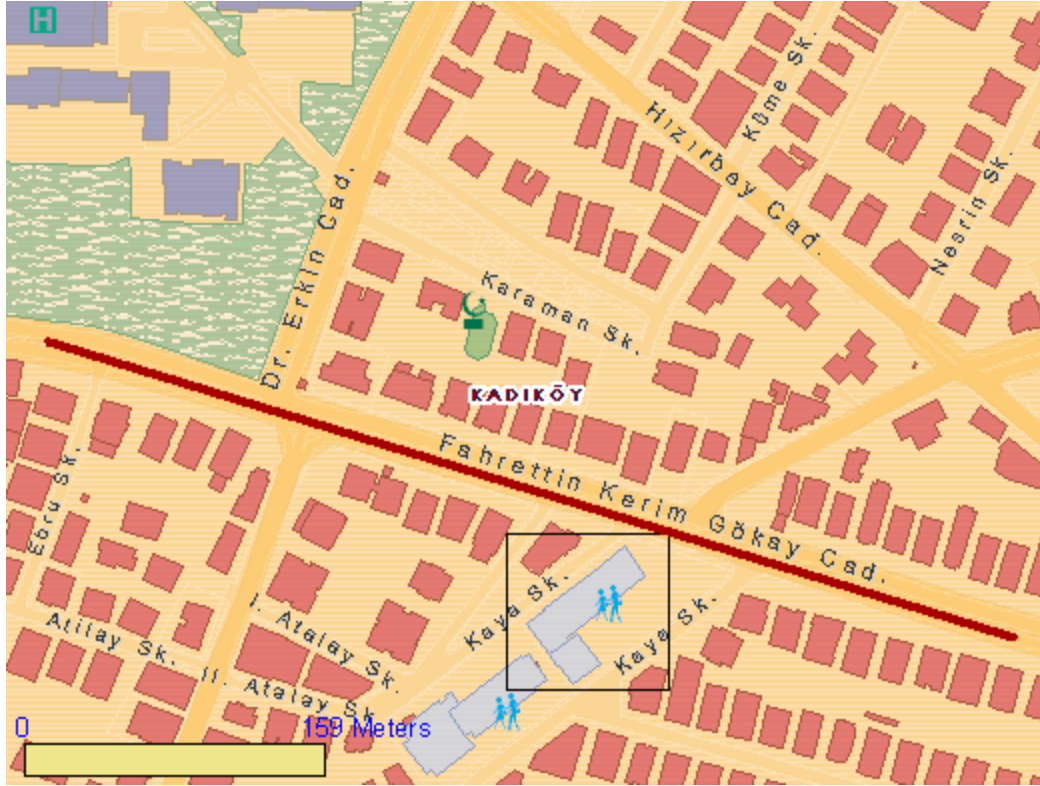


Figure C.3: Faik Reşit Unat İ.Ö.O in map.

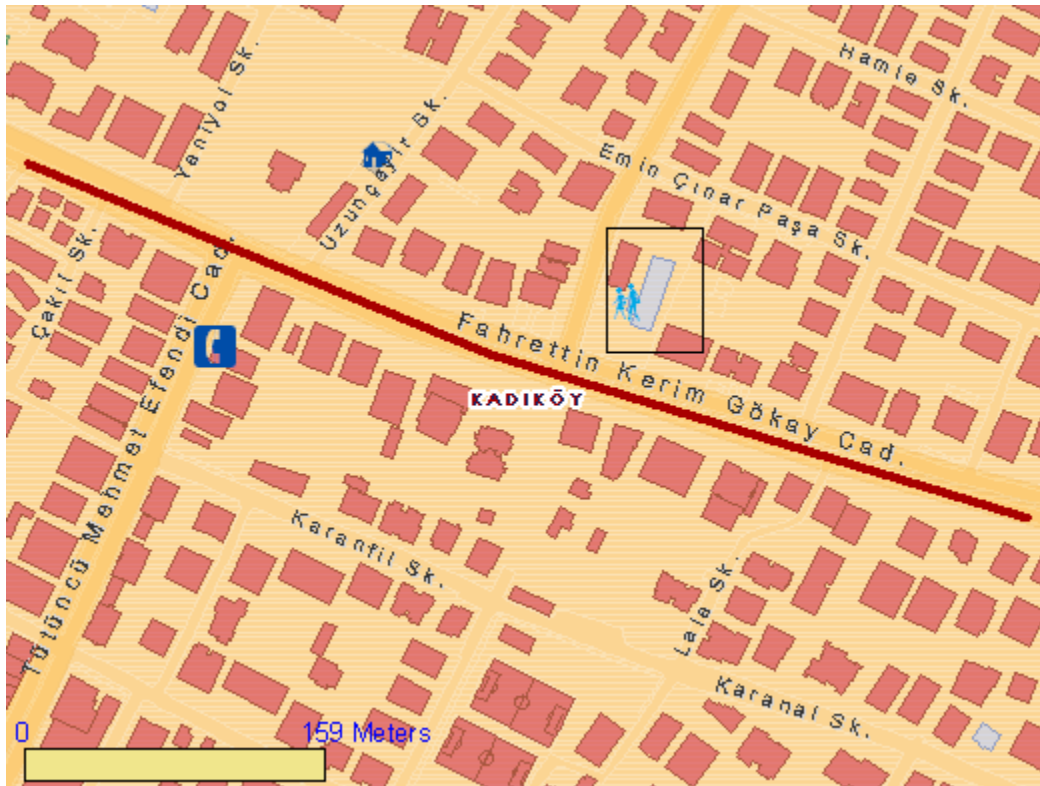


Figure C.4: Öğretmen Harun Reşit İ.Ö.O in map.

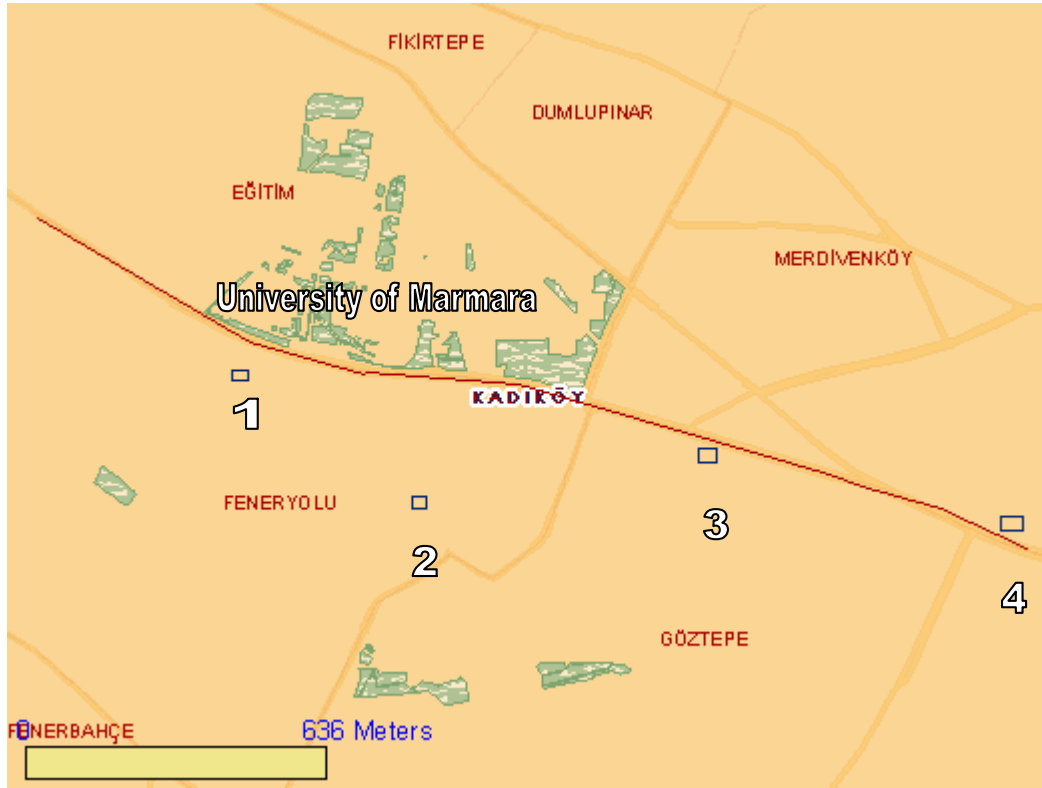


Figure C.5: The overall view of the four schools in map.

1. Melahat Şefizade İ.Ö.O
2. Mustafa Aykın İ.Ö.O
3. Faik Reşit Unat İ.Ö.O
4. Öğretmen Harun Reşit İ.Ö.O

* Red line is the Fahrettin Kerim Gökay Street in each figure.

** The black boxes are the exact places of the schools in Figures C.1,2,3 and 4

*** The blue boxes are the four schools in Figure C.5.

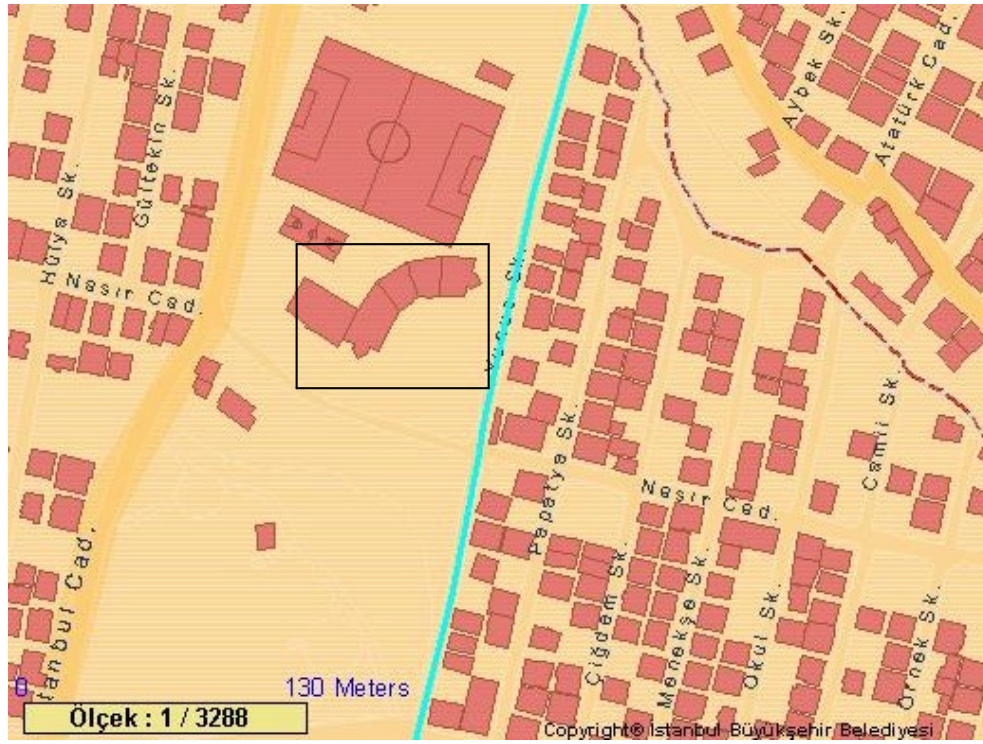


Figure C.6: Fenerbahçe high school in Kayışdağı in map.

APPENDIX D

GRAPHS

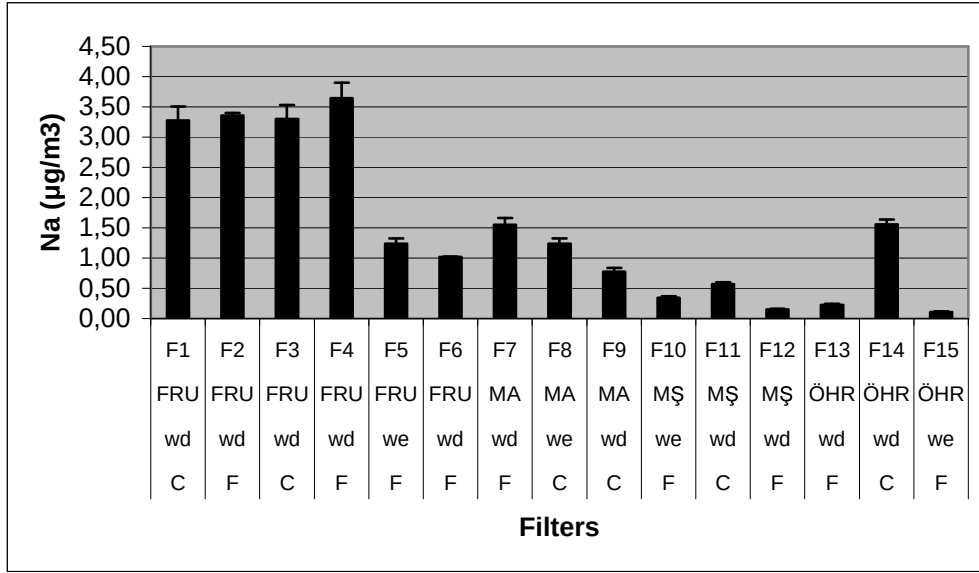


Figure D.1: Elemental Concentration Distribution Chart for Sodium (Na)

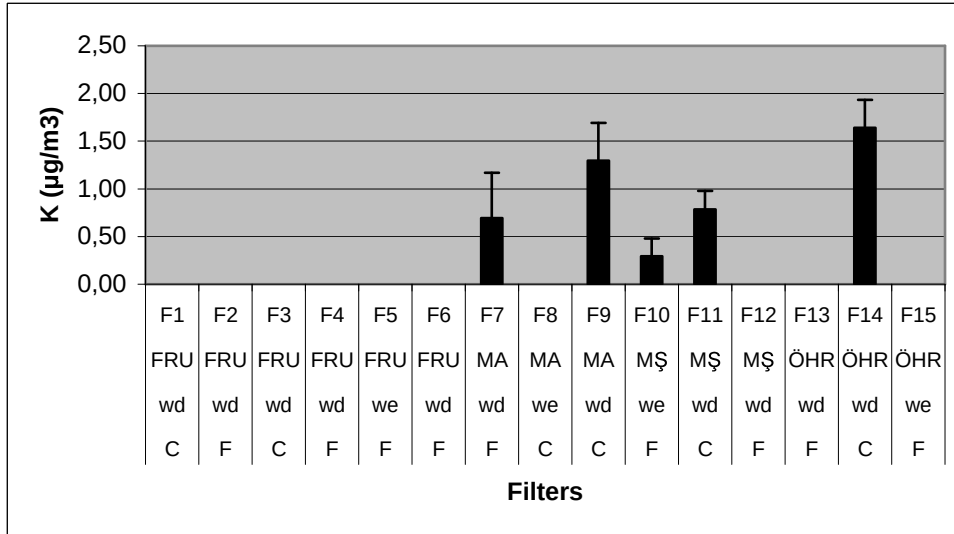


Figure D.2: Elemental Concentration Distribution Chart for Potassium (K)

FRU : Faik Reşit Unat Primary School
MA : Mustafa Aykın Primary School
MŞ : Melahat Şefizade Primary School
ÖHR : Öğretmen Harun Reşit Primary School

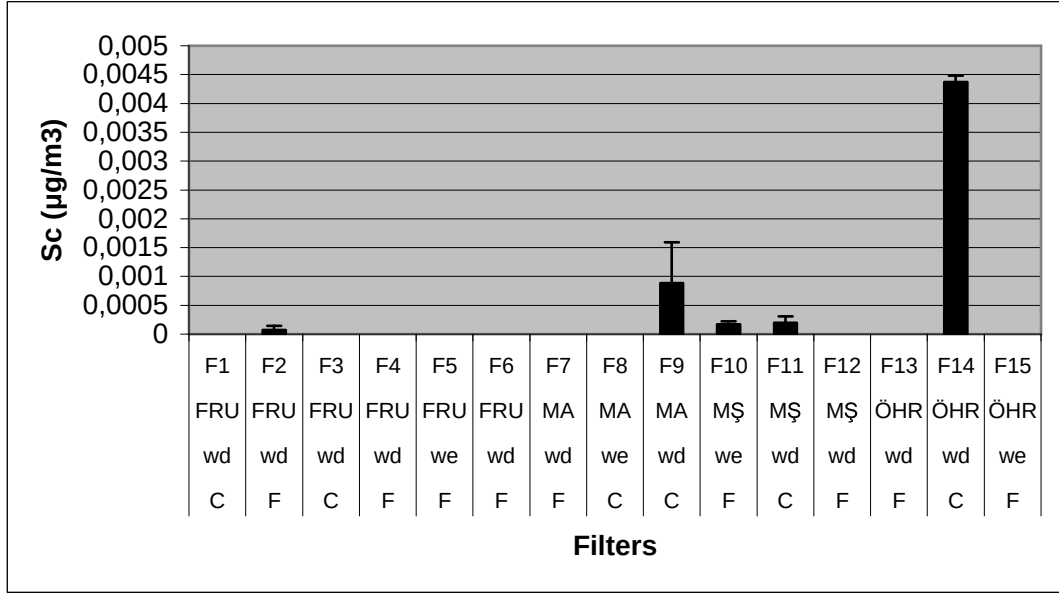


Figure D.3: Elemental Concentration Distribution Chart for Scandium (Sc)

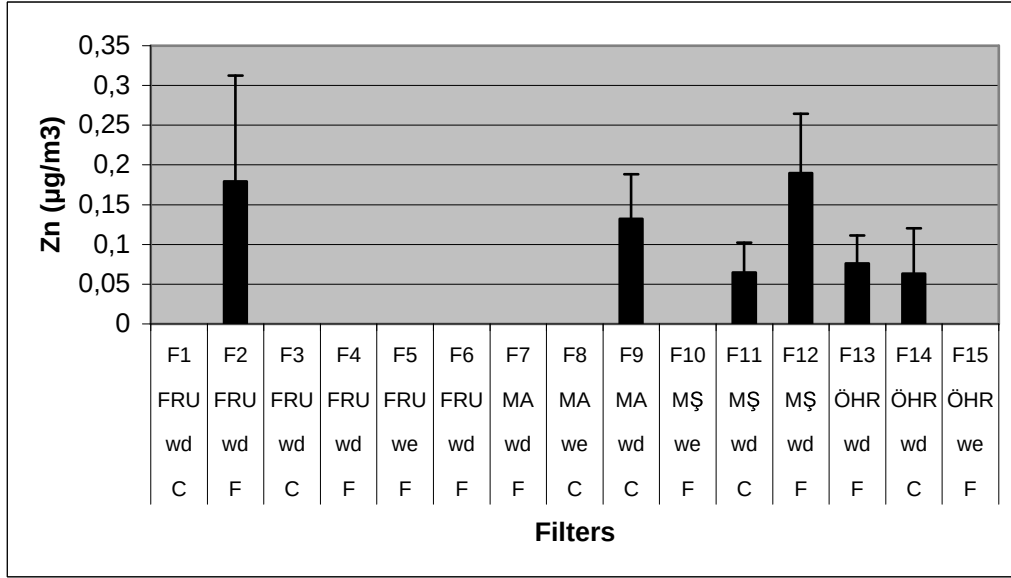


Figure D.4: Elemental Concentration Distribution Chart for Zinc (Zn)

FRU : Faik Reşit Unat Primary School
MA : Mustafa Aykın Primary School
MŞ : Melahat Şefizade Primary School
ÖHR : Öğretmen Harun Reşit Primary School

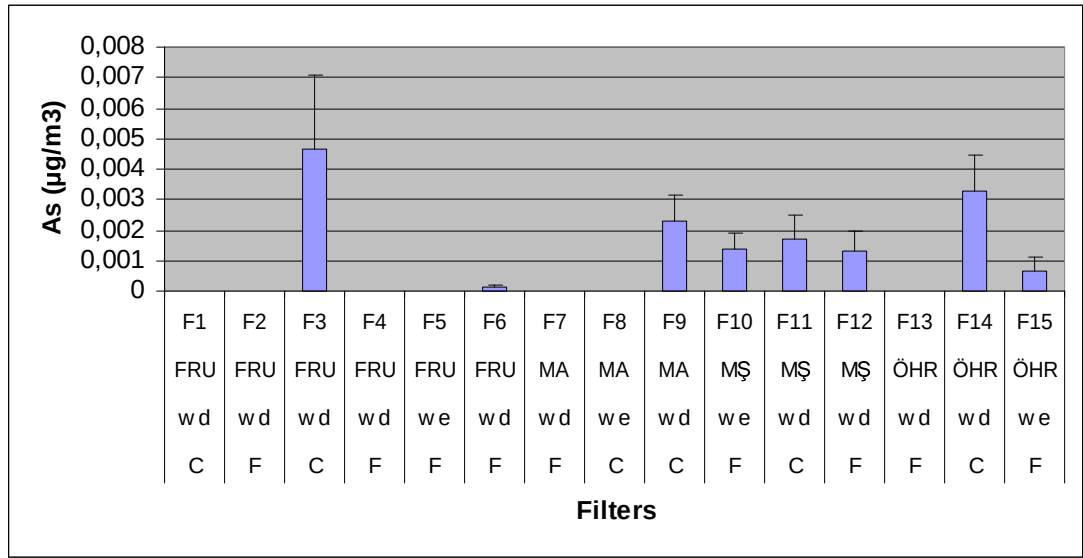


Figure D.5: Elemental Concentration Distribution Chart for Arsenic (As)

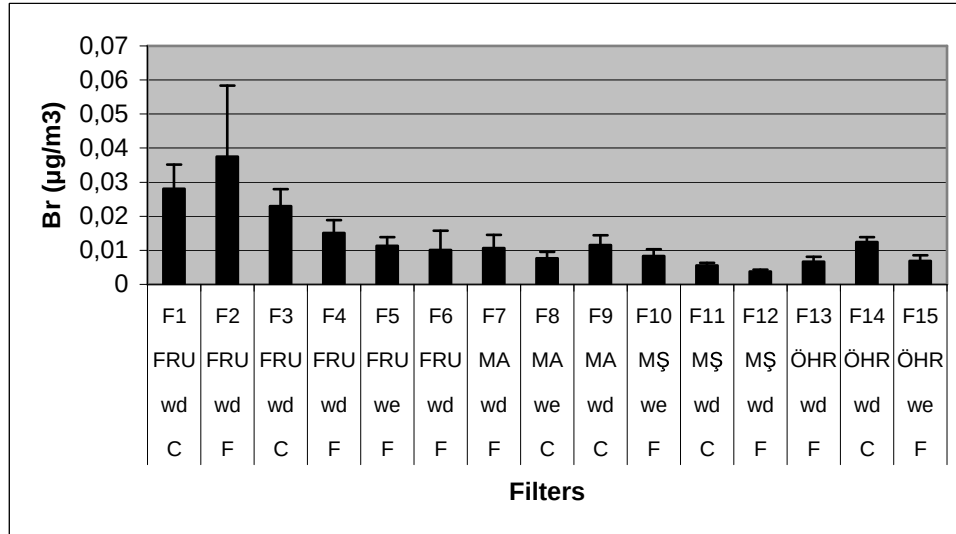


Figure D.6: Elemental Concentration Distribution Chart for Bromine (Br)

FRU : Faik Reşit Unat Primary School
MA : Mustafa Aykın Primary School
MŞ : Melahat Şefizade Primary School
ÖHR : Öğretmen Harun Reşit Primary School

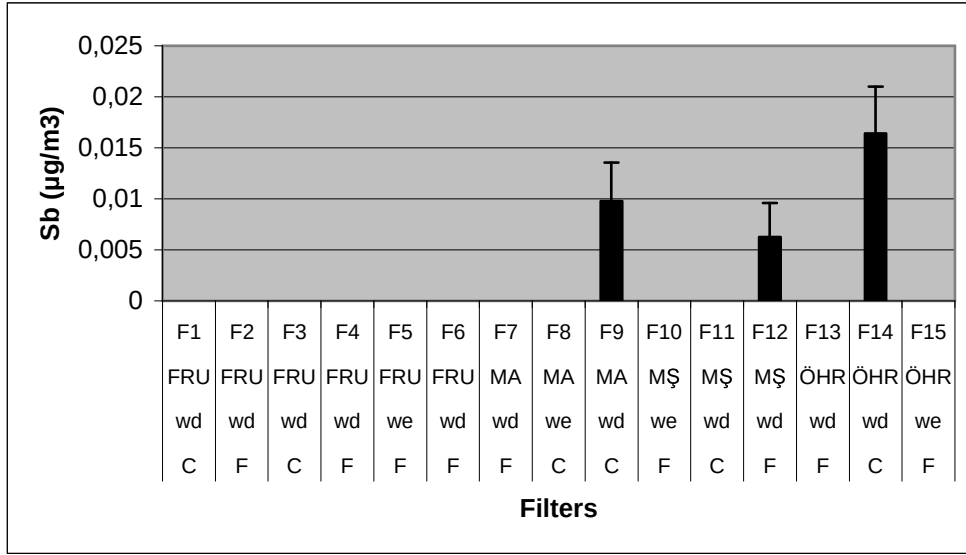


Figure D.7: Elemental Concentration Distribution Chart for Antimony (Sb)

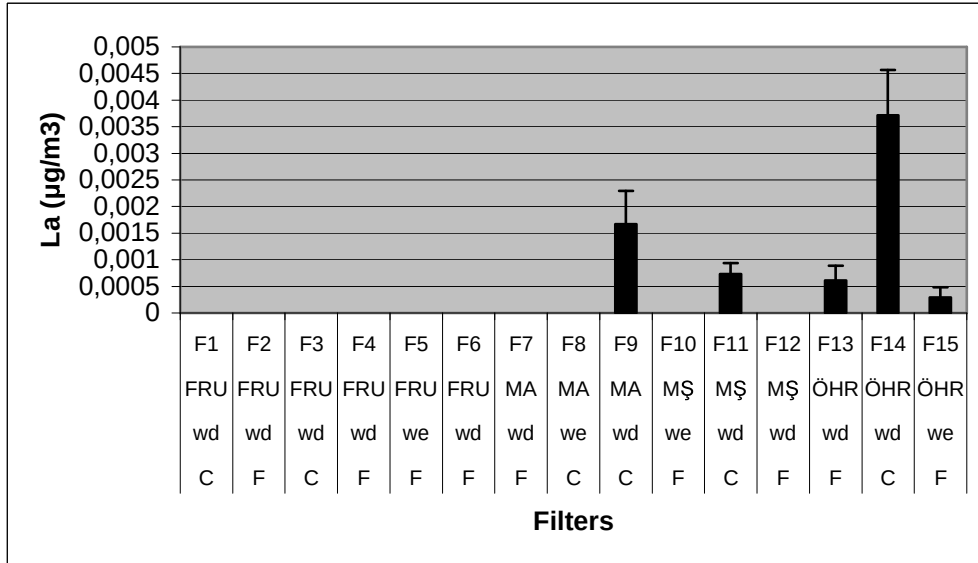


Figure D.8: Elemental Concentration Distribution Chart for Lanthanum (La)

FRU : Faik Reşit Unat Primary School
MA : Mustafa Aykın Primary School
MŞ : Melahat Şefizade Primary School
ÖHR : Öğretmen Harun Reşit Primary School

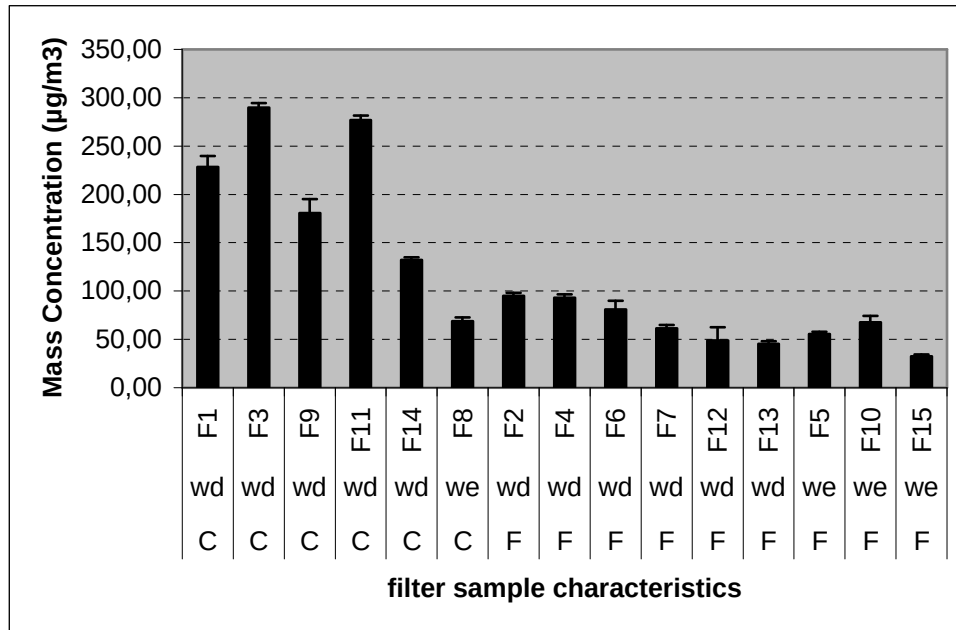


Figure D.9: The graph of mass concentrations and sample characteristics of state school study.
(F: Filter Number, wd: weekday, we: weekend, C: Coarse – PM₁₀, F: Fine – PM_{2.5})

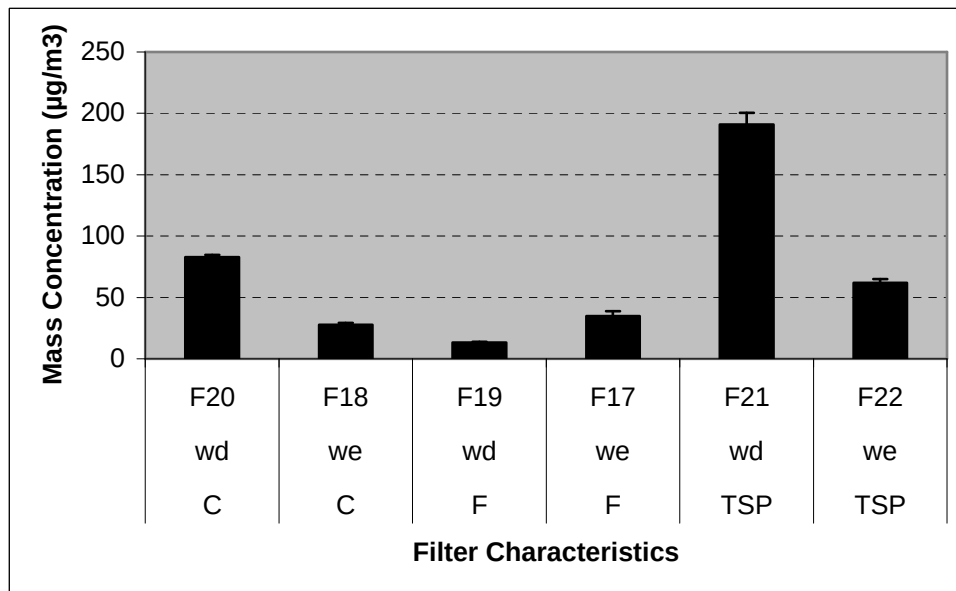


Figure D.10: The graph of mass concentrations and sample characteristics of Private Fenerbahçe school study.
(F: Filter Number, wd: weekday, we: weekend, C: Coarse – PM₁₀, F: Fine – PM_{2.5}, TSP: Total Suspended Particulate)

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