DOKUZ EYLÜL UNIVERSITY
GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES

EVALUATION OF RDF PRODUCTION FROM MUNICIPAL SOLID WASTE: A CASE STUDY FOR IZMIR CITY-TURKEY

by
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June, 2015
İZMİR

EVALUATION OF RDF PRODUCTION FROM MUNICIPAL SOLID WASTE: A CASE STUDY FOR IZMIR CITY-TURKEY

A Thesis Submitted to the
Graduate School of Natural and Applied Sciences of Dokuz Eylül University
In Partial Fulfillment of the Requirements for the Master of Science of
Environmental Engineering

by
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June, 2015
İZMİR

M.Sc THESIS EXAMINATION RESULT FORM

We have read the thesis entitled **"EVALUATION OF RDF PRODUCTION FROM MUNICIPAL SOLID WASTE: A CASE STUDY FOR IZMIR CITY-TURKEY"** completed by **AYŞENUR BÖLÜKBAŞ** under supervision of **ASSOC. PROF. DR. GÖRKEM AKINCI** and we certify that in our opinion it is fully adequate, in scope and in quality, as a thesis for the degree of Master of Science.

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ACKNOWLEDGEMENTS

I am grateful to my supervisor, Assoc. Prof. Dr. Görkem AKINCI, for her advices to the subject. I am extremely thankful and indebted to her for sharing expertise, and sincere and valuable guidance and encouragement extended to me.

I express my warm thanks to Dr. Elif Duyuşen GÜVEN for her support and guidance on my research.

I would like to thank the Scientific Research Projects Support Program of Dokuz Eylul University for funding this project (2014.KB.FEN.036).

Moreover, I would like to thank Assist. Prof. Dr. Serkan EKER and Assist. Prof. Dr. Gülden GÖK for their valuable helps during my laboratory studies. I am also thankful to Assist. Prof. Dr. Serpil ÖZMIHÇI for her help and moral support during my study.

I am thankful to my best friends, Meltem Nihan AKSOY, Melody SHOARGHAFFARİ, Betül DİLER and Gülten GÖGAYAZ, for their friendship and support.

I would also like to thank my family. They were always supporting me and encouraging me with their best wishes. Especially I would like to thank my nephew, Arda BÖLÜKBAŞ, for that make me smile and his endless love.

Ayşenur BÖLÜKBAŞ

EVALUATION OF RDF PRODUCTION FROM MUNICIPAL SOLID WASTE: A CASE STUDY FOR IZMIR CITY-TURKEY

ABSTRACT

Waste is an important and inevitable consequences of human activities; therefore, solid waste management becomes the most important and difficult problem for cities. As the amount of the solid wastes increases, the need to find new recovery methods increases. Therefore, these wastes can be used in the waste to energy plants or cement factories as waste fuel or refuse derived fuel (RDF).

This study explains characterization, classification, production, properties and application area of Refuse Derived Fuels (RDFs) produced from solid waste of Izmir.

Firstly, solid wastes are taken from three districts of each country; Karsiyaka, Bornova and Konak. After separation of recyclables, the remaining part (mostly biodegradables) of solid wastes is sieved from six different mesh sizes. The parameters performed within the project are moisture, net calorific value, organic matter, ash content, carbon content, heavy metals contents and water soluble chlorine content.

The water content found 62.6 percent should be less than 35 percent with regard to the Statement about RDF of Turkey in order to provide efficient combustion process. Moreover, the chlorine content should be less than 1 percent as defined in the Statement and the average chlorine content of the samples were found as 0.86 percent. The calorific value of solid wastes in Izmir found as 2941 kcal/kg is sufficient and other parameters are appropriate with respect to the literature and Statement about RDF of Turkey

If the water content is handled properly and the necessary adjustment for chlorine contents is done, efficient performance from the RDF can be obtained.

Keywords: Refuse derived fuel (rdf), solid waste, municipal solid waste management, waste to energy, cement factory

KENTSEL KATI ATIKTAN AKY (RDF) ÜRETİMİNİN DEĞERLENDİRİLMESİ: İZMİR KENTİ-TÜRKİYE İÇİN BİR ÇALIŞMA

ÖZ

Katı atık insan aktiviteleri sonucu ortaya çıkan kaçınılmaz bir sonuçtur. Bu yüzden katı atık yönetimim önemli bir konu haline gelmiştir ve artan katı atık miktarıyla birlikte yeni katı atık teknolojilerine olan ihtiyaç da artmaktadır. Bu kapsamda "Atıktan Türetilmiş Yakıt (ATY)" atıktan enerji üretim tesislerinde ve çimento fabrikalarında ek yakıt olarak kullanılmak üzere geliştirilmiştir.

Bu çalışma İzmir şehri katı atığından üretilen ATY'nin karakterizasyonunu, sınıflandırmasını, üretim yöntemlerini, özelliklerini ve uygulama alanlarını içermektedir.

Çalışma kapsamında Karşıyaka, Bornova ve Konak'tan üç farklı gelir seviyesinden mahallelerden örnekler gelmiş ve ayıklama işlemi gerçekleştirilmiştir. Sonrasında 9 bölgenin ayıklanmış katı atıkları çeşitli boyutlarda eleklerden geçirilip 7 farklı fraksiyon elde edilmiştir. 63 örneğe su muhtevası, ısıl değer, organik madde, kül içeriği, toplam organik karbon, inorganik karbon, ağır metal ve klor analizleri uygulanmıştır.

Su muhtevası Atıktan Türetilmiş Yakıt Tebliğine göre yüzde 35'in altında, klor içeriği yüzde 1'den az ve ısıl değeri 2500 kcal/kg'dan fazla olmalıdır. Bu çalışmada ortalama su içeriği yüzde 62,6, klor değeri yüzde 0,86 ve ısıl değeri 2941 kcal/kg bulunmuştur.

İzmir ili katı atığı ısıl değer ve diğer parametreler açısından ATY üretimine uygundur; ancak sahip olduğu yüksek su muhtevası yanma verimini etkilemektedir. Eğer biyo-kurutma ile su muhtevası yeterli düzeye indirilebilirse ve gerekli klor ayarlamaları yapılırsa İzmir şehrinin katı atığının biyobozunabilir kısmından ATY üretimi yapılabilir.

Anahtar kelimeler: Atıktan türetilmiş yakıt, katı atık, kentsel katı atık yönetimi, atıktan enerji eldesi, çimento fabrikaları

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CHAPTER ONE
INTRODUCTION

1.1 Municipal Solid Waste Management

In the world, there are a lot of source of solid waste. However, the municipal solid waste management is the principal difficulty for human all around the world. About 34 million tons municipal solid waste is generated from houses in a year (Reza, Soltani, Ruparathna, Sadiq, & Hewage, 2013). Because of the population growth, the economic growth and the increase in the living standards the municipal solid waste production increases. Moreover, the consumption frenzy affects the amount of solid wastes generated in the municipalities (Minghua, Xiumin, Rovetta, Qichang, Vicentini, Binkai, et. al. 2008).

Municipal solid waste management is a technical problem affected by political, legal, socio-cultural, environmental and economic substances. Furthermore, available resources are very important. The increase in the solid waste amount results in more land demand for the ultimate landfilling process of solid waste (Sharholy, Ahmad, Vaishya, & Gupta, 2006). Therefore, in order to decrease the amount of solid waste to be disposed, some new methods should be applied. In briefly, the handling, storage, collection and disposal of solid waste are very important problems both in Turkey and all around world.

1.2 İzmir

1.2.1 General Information

Izmir which is the third crowded city of Turkey is located in Aegean region, it is surrounded by Aydın and Manisa Provinces. The coordinates of İzmir are 37^o 45' and 39^o 15' north latitude and 26^o 15' and 28^o 20’ east longitude. The area of İzmir is 12012 km^2. The boundaries of İzmir Metropolitan Municipality can be seen in next figure.

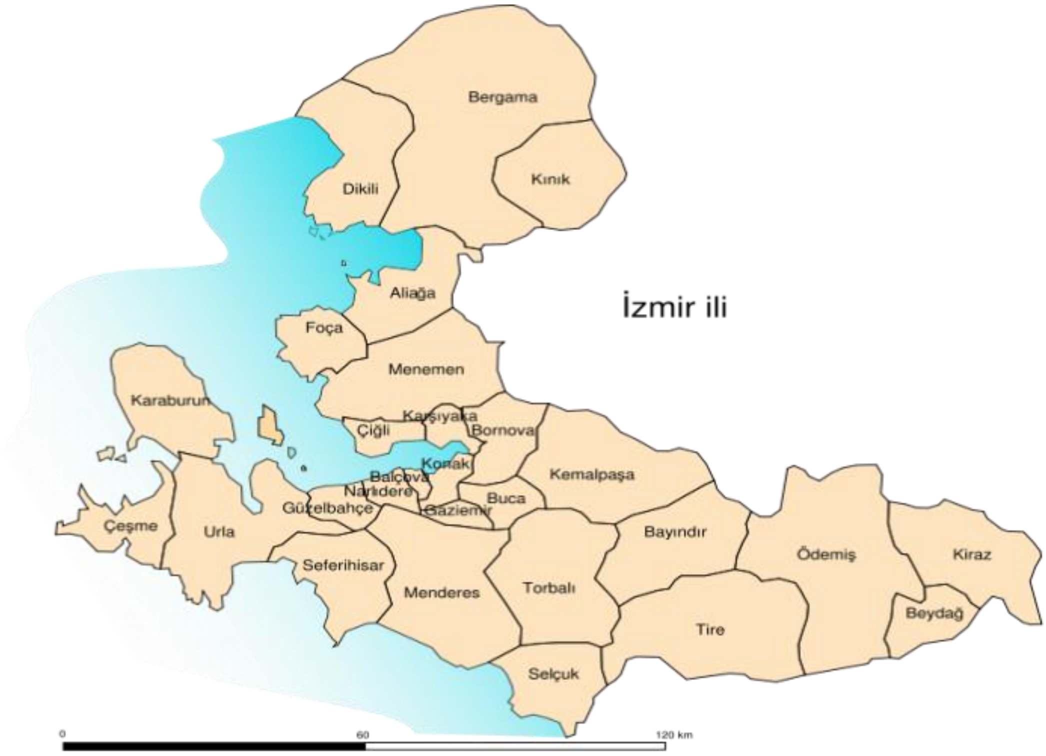

Figure 1.1 Boundaries of İzmir metropolitan municipality

The general climate type of İzmir is Mediterranean climate and the flora type is maquis. In the summer time, the weather is hot and arid; on the other hand, in the winter it is warm and rainy. The temperature is averagely 16 ^{o}C (The Governorate of İzmir, n.d).

1.2.2 Population of İzmir

The population of İzmir increases over the years as seen in the next figure. The population given in the next figure consists of the population which solid waste services are given. The population of Izmir Metropolitan was 4,113,072 with respect to address-based census in 2014.

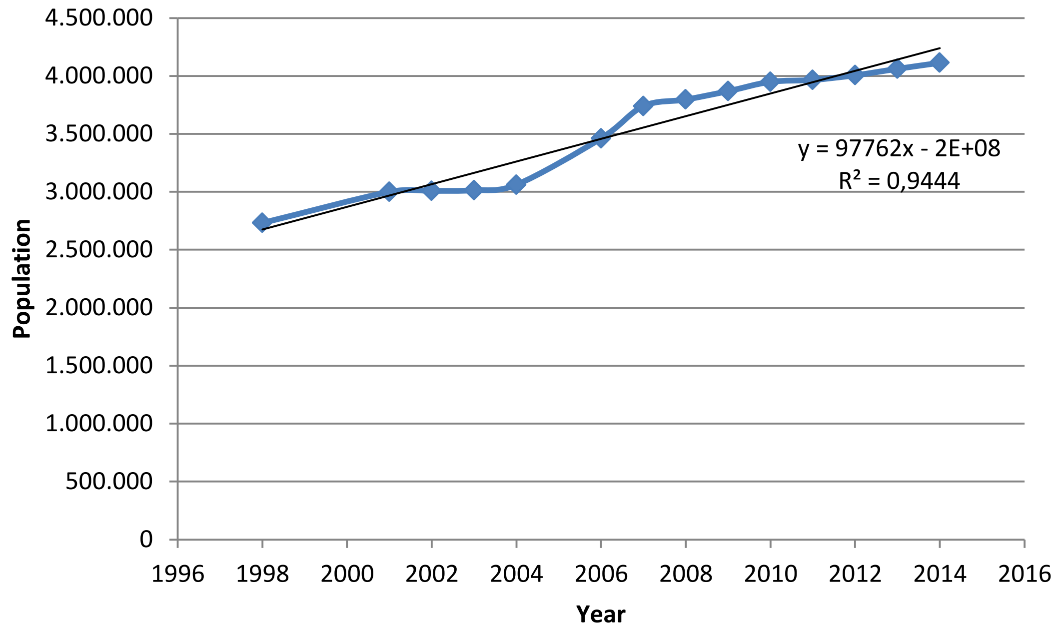

Figure 1.2 The population changes of İzmir during the years

1.3 Current Solid Waste Management of İzmir

The disposal of solid waste generated by İzmir is in the charge of İzmir Metropolitan Municipality. The daily generated solid waste amount is about 4000 ton/day. There are 8 existing transfer station in order to transfer solid waste came from districts by small trucks to final disposal area by big trucks. These transfer stations are Halkapınar, Gediz, Kısık, Gümüldür, Karşıyaka, Selçuk, Torbalı, Foça. The final disposal area is Harmandalı Landfilling Site being in service since 1992 (İzmir Meropolitan Municipality, 2013).

The medical waste amount collected is averagely 16.7 ton/day. There is no sterilization unit in İzmir; hence, the medical wastes are sent to Miroglu Company in Manisa.

Moreover, within the boundaries of İzmir Metropolitan Municipality there are 63 licensed Companies collecting and separating the packaging wastes in order to collect, transfer, separate and recycle packaging wastes of 21 county municipalities and 32 town municipalities by being in cooperation with ÇEVKO and TÜRKÇEV.

The solid waste amount received by Harmandalı Landfilling Area can be seen in the next figure. During the years the solid waste amount increases. There is a little fluctuation in the waste amount.

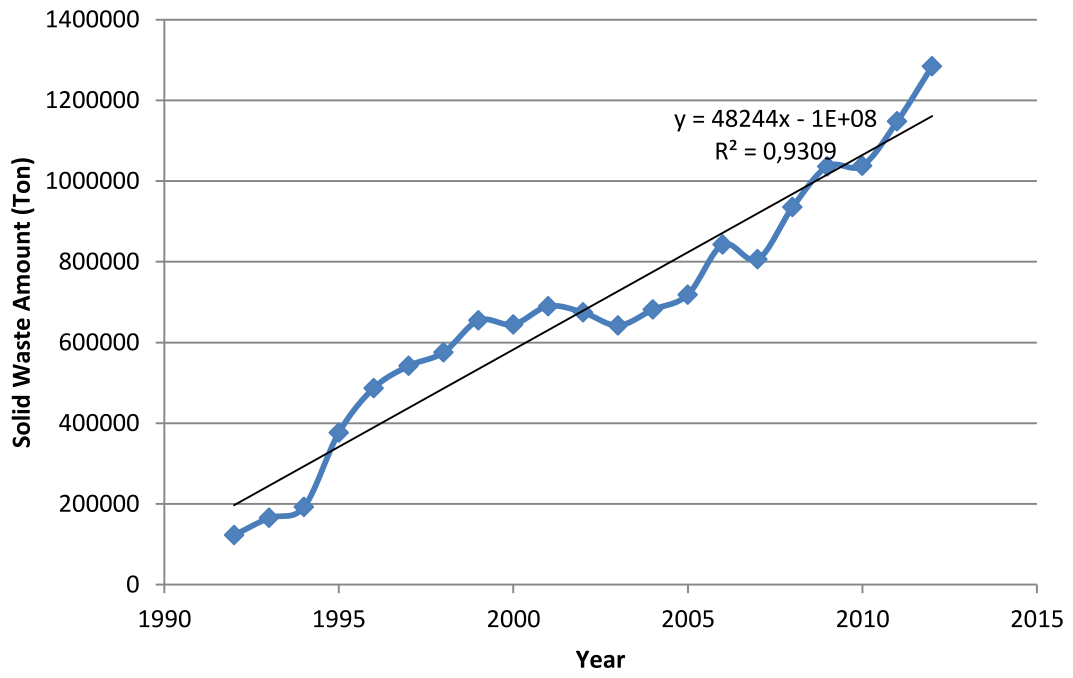

Figure 1.3 Solid waste amount received by Harmandalı landfilling area (İzmir Meropolitan Municipality, 2013)

The composition of the solid waste came to Harmandalı Landfilling Site is given in the Figure 1.4. As it can be seen in the figure, about half of the solid waste is first degree biodegradable. Moreover, the organic content of the solid waste containing of kitchen waste, paper, cardboard and backyard waste is about 60 % (İzmir Meropolitan Municipality, 2013).

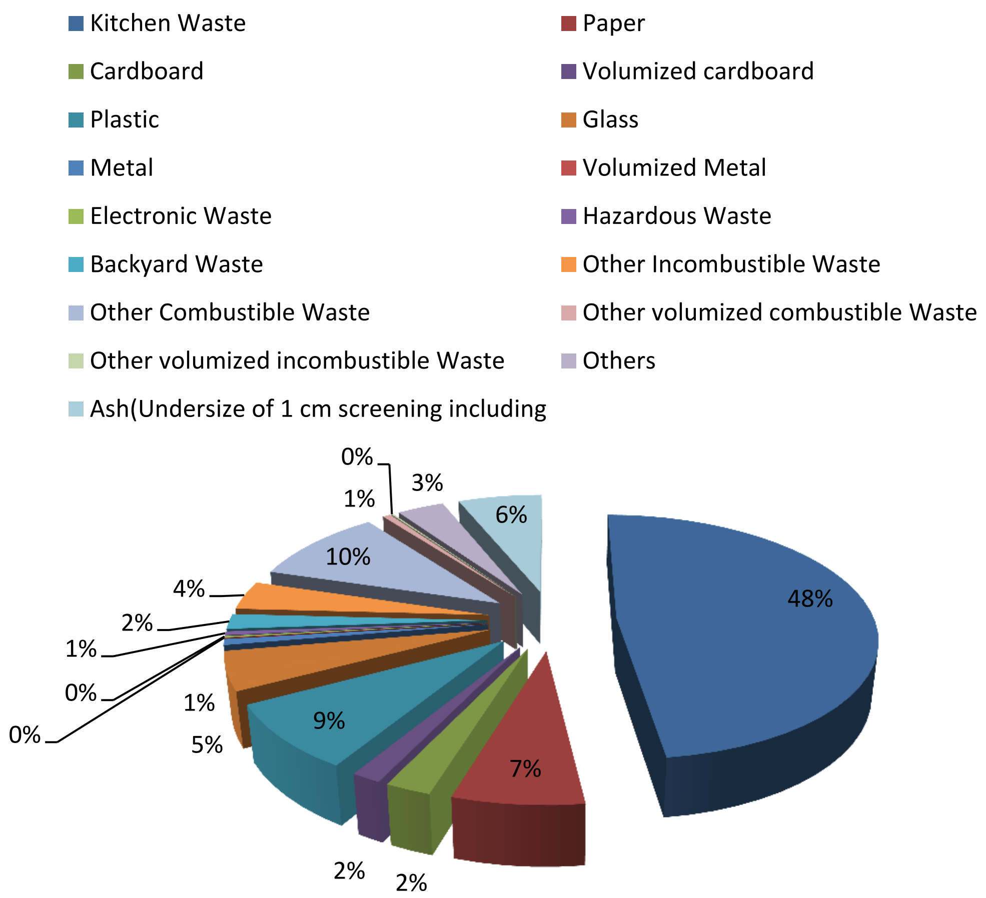

Figure 1.4 The characterization of solid waste received by Harmandalı landfilling site (İzmir Meropolitan Municipality, 2013)

CHAPTER TWO
REFUSE DERIVED FUEL (RDF)

Waste is an important and inevitable consequences of human activities; therefore, solid waste management becomes the most important and difficult problem for cities (Reza, Soltani, Ruparathna, Sadiq, & Hewage, 2013). As the amount of the solid wastes increases, the need to find new recovery methods increases. For European countries, the European Union sets some demands to reduce the amount of landfilled biodegradable waste. According to EU, in 2016 the landfilled biodegradable waste shouldn't be more than 35 % of the waste generated in 1994. Some EU countries have already banned landfilling of biodegradable or organic waste. Moreover, the recovery of solid waste is important due to greenhouse gas (GHG) emission limits. The EU set the target to reduce the GHG emissions by 20 % from the level of 1990 and increase the usage of renewable energy about 20 % of total energy use by 2020. Furthermore, in order to save natural resources like coal and lignite, waste recovery is another solution in European countries. Incineration of wastes with energy recovery has also been accepted in EU (Horttanaien, Teirasvuo, Kapustina, Hupponen, & Luoranen, 2013).

The household, industrial, commerce, forestry and agricultural solid wastes have a certain calorific value. Therefore, these wastes can be used in the Waste to Energy plants as waste fuel or refuse derived fuel (RDF). In basic, RDF can be explained as solid fuel prepared from sorted or mixed solid wastes such as municipality waste, commercial waste and production wastes (Sarc & Lorber, 2013). RDF is described as a fuel can be produced from packaging wastes being not economical for recycling, municipal wastes and industrial wastes, which are appropriate to appendix-3 in "The Statement of RDF, Additional Fuel and Alternative Raw Materials". In other words, RDF is an alternative fuel produced from municipal solid waste and RDF can be used as energy source in different industries with respect to Reza and his colleagues. Furthermore, higher fossil fuels prices forces the cement plants, hence alternative fuels are considered in order to save money. RDF is the most suitable process for this aim according to experiences conducted in European Countries. For instance, in Germany in 2007, more than 54% of the heat demand of the industries was met by RDF usage. In next figure, the usage areas of RDF in Germany can be seen. The most of produced RDF has been used for energy production in 2009 (CERTH/ ISFTA, 2011).

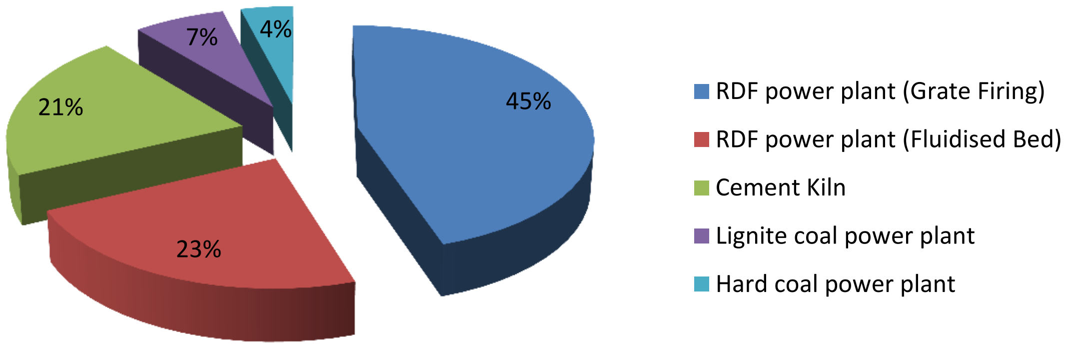

Figure 2.1 Thermal treatment of RDF in 2009 in Germany

Moreover, in 2000 the amount of RDF produced in Europe has been estimated 1,380,000 tons by European Committee for Standardization (CEN). However, about 3 million tons RDF has been produced in 2001 and 13 million tons RDF production have been expected in 2005 (Gendebien, 2003). In 2008, Germany had the biggest RDF production share with 31 % and Italy followed Germany with 15 % (CERTH/ ISFTA, 2011). The treatment capacity of RDF production plants in Italy was 7.5 x 106 ton/ year MSW according to The Italian Environmental Protection Agency (APAT) (Genon & Brizo, 2008).

RDF generally consists of pelletized or fluff municipal solid waste which remains after separation of non-combustible materials such as ferrous materials, glass, grit and other non-combustible materials. Besides separation processes, size reduction is applied. Therefore, more uniform RDF at high heat value is obtained (Worrel & Vesilind, Solid waste engineering, 2012).

2.1 Classification of RDF

Classification of RDF is important for determining where RDF will be used. In order to classify RDF, net calorific value, particle size, impurities, chlorine content, sulfur content, fluorine content, ash content, moisture and heavy metals content such as As, Pb, Sb, Cd, Cr, Co, Cu, Zn, Ni, Hg, Tl, V, Sn and Mn can be used (Sarc & Lorber, 2013). The most crucial criteria for classification of RDF are humidity and calorific value.

Moreover, RDF must have some requirements in order to be used safely, such as:

- Defined calorific value
- Low chlorine content
- Quality issues
- Grain size
- Bulk density
- Availability of required quantities

(Sarc & Lorber, 2013)

The properties of fuel such as heating value and particle size have important role in the selection of application method. The next figure expresses the effect of net calorific value (heating value) [MJ/kg_{os}] and particle size d_{90} [mm].

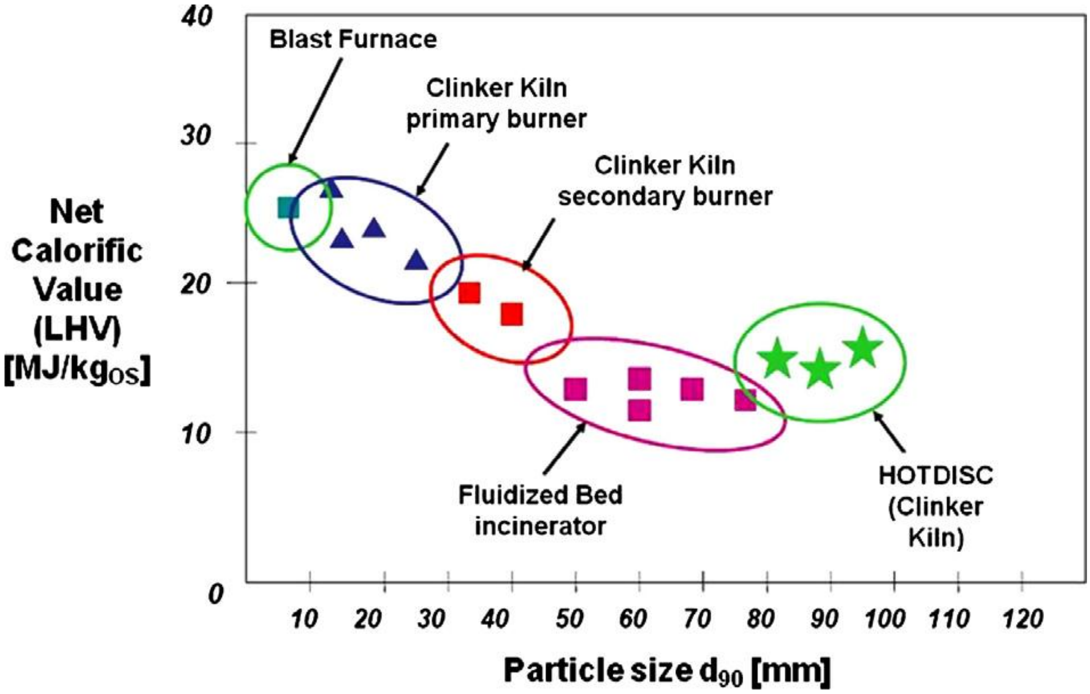

Figure 2.2 The effects of net calorific value and particle size on selection of application method (Sarc & Lorber, 2013)

Some examples of RDF composition can be seen in the Table 2.1. Moreover, the characterization of some RDF examples in the world and Turkey can be viewed in the table 2.2.

Table 2.1 Composition of RDF

Waste Type	**Composition of RDF (%)**			
	ISTAC*-solid waste	**ISTAC-Generated RDF**	**FWMP****	**Lorber-RDF feedstock *** **
Organic fraction	22	0	20.5	6
Fine Fraction			19.6	55
Textile	17.1	66.0	5.8	5
Paper	25.4	17.1	12.4	6
Sanitary articles			8.2	1
Composite materials			9.5	3
Inert materials			3.4	
Metals			2.9	1
Plastic Bag	15.2	13.3		
PET-Plastic	3.2	3.6		
Plastic			9.7	16
Hazardous household waste			1.2	3
Napkin	7.0	0		
Other Combustible	3.7	0		
Wood	1.9	0		
Bone	0.3	0		
Tetra Pak	1.2	0		
Sack	0.5	0		
Tin	0.6	0		
Glass	0.7	0	4.3	4
Aluminum	0.4	0		
Stone	0.8	0		
Other			2.5	
Total	100	100	100	100

* :İstanbul Büyükşehir Belediyesi Çevre Koruma ve Atık Maddeleri Değerlendirme Sanayi ve Ticaret A.Ş-Environmental Protection and Waste Recovery Industry and Trade inc. (Kara, Günay, Tabak, & Yıldız, 2009)
** : Federal Waste Management Plan of Austria (Sarc & Lorber, 2013)
*** : R. Sarc, K.E. Lorber (Sarc & Lorber, 2013)

Table 2.2 Properties of RDF

Parameters	Properties of RDF									
	Lorber-RDF feedstock	**ISTAC-Generated RDF**	**Lechtenberg ***	**Standards of Italy ****	**Kadir Alp-Mixed Solid Waste for Europe ****	**RDF of Indian Plot Plant*****	**RDF of Greve in Chianti (Italy)*****	**RDF of Lomellina II (Italy)*****	**Standards in Statement about RDF of Turkey**	**EURITS **** Standard**
LVH	9 (MJ/kg_{os}) ≈ 2149.2 kcal/kg	3500 kcal/kg		15000 KJ/kg ≈ 3582 kcal/kg	13.3 MJ/kg ≈ 3176.04 kcal/kg	4000 kcal/kg	4108 kcal/kg	2507-3988 kcal/kg	>2500 kcal/kg	15 Gj/t ≈ 3582 kcal/kg
Particle Size (mm)									<50	
Cl	9.3 (g/kg_{DM})	0.9519 %	<1 %	0.9 % $(m/m)^2$	0.6 %		0.4-0.6 %	0.7 %	<1 %	0.5 %
S	3.4 (g/kg_{DM})	0.46 %	<0.5 %	0.6 % $(m/m)^2$	0.2 %	0.2-0.5 %	0.5 %	0.1 %		0.4 %
F	0.18 (g/kg_{DM})				0.01 %					
Ash (%)	41	7.7 %	8-12 %	20 %	16 %	<15 %		3.7-17.3 %		5 %
Humidity		25 %	<20 %	<25 %	24.7 %	10 %	6.5 %	20-30 %	<35%	
DM (%)	73									
Inerts (%)	21							5 %		
Pb	312 (mg/kg_{DM})	26.5 ppm [a]	100 ppm	200 mg/kg	121 mg/kg_{dm}				<600 mg/kg	200 ppm
Cu	892 (mg/kg_{DM})	18.4 ppm	150 ppm	300 mg/kg					<500 mg/kg	200 ppm
Zn	882 (mg/kg_{DM})			500 mg/kg					<4000 mg/kg	200 ppm
K	1986 (mg/kg_{DM})									

Table 2.3 Properties of RDF (continued)

Parameters	Properties of RDF									
	Lorber-RDF feedstock	**ISTAC-Generated RDF**	**Lechtenberg ***	**Standards of Italy ****	**Kadir Alp-Mixed Solid Waste for Europe ****	**RDF of Indian Plot Plant*****	**RDF of Greve in Chianti (Italy)*****	**RDF of Lomellina II (Italy)*****	**Standards in Statement about RDF of Turkey**	**EURITS **** Standard**
Na	3011 (mg/kg_{DM})									
As		0.9 ppm	10 ppm	9 mg/kg	3 mg/kg_{dm}					10 ppm
Cd		1.6 ppm	5 ppm	7 mg/kg	0.6 mg/kg_{dm}				<10 mg/kg	10 ppm
Hg		0.3 ppm	1 ppm		0.4 mg/kg_{dm}				330µg/ MJ	2 ppm
Ni		54.6 ppm	50 ppm	40 mg/kg	21.5 mg/kg_{dm}				<300 mg/kg	200 ppm
Sb		2.9 ppm	20 ppm							10 ppm
Mn				400 mg/kg						200 ppm
Cr				100 mg/kg	70 mg/kg_{dm}				<400 mg/kg	200 ppm
N						1-1.5 %				0.7 %
Ti										2 ppm
Sn										200 ppm
Co					3.7 mg/kg_{dm}					200 ppm
V										200 ppm
Total heavy metals									<2500 mg/MJ	

Table 2.4 Properties of RDF (continued)

Parameters	Properties of RDF									
	Lorber-RDF feedstock	**ISTAC-Generated RDF**	**Lechtenberg ***	**Standards of Italy ****	**Kadir Alp-Mixed Solid Waste for Europe ****	**RDF of Indian Plot Plant*****	**RDF of Greve in Chianti (Italy)*****	**RDF of Lomellina II (Italy)*****	**Standards in Statement about RDF of Turkey**	**EURITS **** Standard**
PCB									<5 ppm	
Oxygen						25-30 %				
Hydrogen						5-8 %				
Total carbon		58 %				35-40 %				
Inorganic Carbon		0.5 %								
Organic carbon		57.5 %								
Fixed carbon							11.4 %			
Volatile matter		92.3 %	50-80 %				71.1 %			
Mineral Matter						15-25 %				
pH		6.7								
Bulk Density		0.154 g/cm^3				0.7 g/cm^3	0.5-0.7 g/cm^3			
Conductivity		3.04 us/cm								
Solvent Content									<15 %	

* :Lechtenberg (Kara, Günay, Tabak, & Yıldız, 2009)
** : (Alp, Refuse derived fuel rdf, 2011)
*** : (Kara, Günay, Tabak, & Yıldız, 2009)
**** :The European Union for Responsible Incineration and Treatment of Special Waste (Alp, Refuse derived fuel rdf, 2011)
[a] : ppm = mg/kg

Furthermore, the classification and required properties of RDF are given in The Statement of RDF, Additional Fuel and Alternative Raw Materials. The RDF produced by RDF facilities is classified as “19 12 10 – Refuse Derived Fuel” without considering hazardous properties if it is produced from municipal wastes as explained it the statement.

According to the statement, the criteria of wastes to be used for RDF production are source of waste and waste code, net calorific value, ash amount, water content, volatile substances amount and pH. In addition to these criteria the parameters below are also important.

Table 2.5 General limits for wastes to be used for RDF production

Parameter	**Limit Value**
Halogenated Organic Compounds	Max 1 % in 1 kg
Halogenated Organic Compounds being insufficient degradable (PCB etc.)	Max 50 mg/kg
Solvent Compound (PAH or VOC)	<15 %
Flash Point	>55 ^{o}C

The heavy metal contents of wastes to be used for RDF production must be as in the below table.

Table 2.6 Heavy metal values of wastes to be used for RDF production

Element	**Symbol**	**Limit Value (mg/kg)**
Lead	Pb	<600
Cadmium	Cd	<10
Chromium	Cr	<400
Copper	Cu	<500
Nickel	Ni	<300
Zinc	Zn	<4000

The statement expresses also the properties of RDF to be produced in RDF facilities as below.

Table 2.7 The properties of RDF

Parameter	Limit Value
Calorific value, kcal/kg	>2500
Particle size, mm	<50
Water content, %	<35
Chlorine content, %	<1
Hg, µg/MJ	<330
Total heavy metals, mg/MJ	<2500
PCB, ppm	<5
Solvent content, %	<15

Moreover, as it has been mentioned in the statement, industrial wastes can be used for producing RDF. These industrial wastes are:

- Paper/cardboard and plastics
- Packaging wastes and rejected products
- Waste tires
- Biomass wastes
- Textile wastes
- Old vehicle wastes
- Hazardous wastes
  - ✓ Waste oils
  - ✓ Industrial sludge
  - ✓ Wood chips saturated with waste
  - ✓ Waste solvents

(Alp, Refuse derived fuel rdf, 2011)

2.2 Production of RDF

After classification and then determining where the produced RDF to be used, the processes to be applied to solid waste can be determined. In order to produce high quality RDF besides classifying and sorting, wastes separation of ferrous and non-ferrous metals, also separation of glasses, stones, ceramics etc. should be applied. Generally, for municipal solid waste these processes are used:

- Source reduction
- Mechanical separation and sorting
- Shredding
- Separation and screening
- Mixing
- Drying and pelletizing
- Packaging
- Storing

Moreover, the statement explains the production methods of RDF with respect to waste types (Table 2.8).

Table 2.8 Production methods of RDF

Equipment	Municipal Waste (non-hazardous Wastes)	Mixed Wastes (Municipal+ Industrial Hazardous and/or Non-hazardous Wastes)	Hazardous Wastes
Hopper (inside or outside mixing)		X	X
Trommel Screen	X	X(1)	
Coarse Shredder (pre-shredding)	X	X	X
Magnetic Separation	X	X	X
Separator (Eddy Current, Ballistic or pneumatic Separator)	X	X	X
Fine Shredder (Post-shredding)	X	X	X
Dryer	X(1)(2)	X(1)(2)	X(1)(2)
Conveyor	X	X	X
Vibration Cute	X(1)	X(1)	

(1)If required it is used.

(2)It is compulsory if the water content of waste is more than 65%.

Sorting and Separation

Separating ferrous and non-ferrous metals, hazardous, combustible and corrosive materials from solid waste is crucial because these materials harm the RDF production equipment; moreover, they influence the quality of RDF; for example they decrease the calorific value of RDF and can increase the chlorine content. For separation hand-sorting, magnetic separator, Eddy-current separator, cyclone separator, air classifiers, sensors and wet separation process can be used.

Screening

As it was mentioned in previous chapters, size of particles is important in order to determine the quality and the usage area of RDF. Therefore, screening is applied to obtain required particle size. According to particle size fraction, the content of solid waste changes, hence the quality changes. For example, organic content is different in each size fraction. Trammel screen would be used to get required particle size.

Bio-drying

In the way of production of RDF from municipal solid waste especially from organic fraction, drying is the most important part in order to provide required calorific value. As an engineering view, besides calorific value cost of RDF production is significant; therefore, drying by means of mechanical dryers working with electricity is not logical. On the other hand, bio-drying is a proper and cheap method for drying solid wastes. Bio-drying has been described as drying with the heat formed during aerobic biodegradation of biodegradable wastes in The Draft Regulation of Biodegradable Waste Management.

The water content of municipal solid waste is more than 60 %, which harms mechanical separation processes and reduce the calorific value. (Shao, He, Yang, Fang, & Lü, 2012) Moreover, this solid waste with high water content is not suitable for direct incineration to provide energy; whose the lower heating value is lower than 1552.85 kcal/kg (Negoi, Ragazzi, Apostol, Rada, & Marculescu, 2009) .Water is removed from the solid waste by thermal energy produced during aerobic degradation conducted by microorganisms of organic fraction with addition of excess air. The water is removed from the solid waste as vapor containing CO2 (g) and H2O (g) and leachate (Shao, He, X., Yang, Fang, Lü & He, P.J., 2012).

The degree of the organic fraction degradation affects the calorific value and the stability of the dried solid materials, whereas the air flow rate influences biomass temperature; as a result, it affects the drying rate (Ledakowicz, Zawadzka, & Krzystek, 2010). Intermittent ventilation is more energy efficient and provides more uniform temperature, pathogen control and organic matter degradation than continuous ventilation. (Shao, He, X., Yang, Fang, Lü & He, P.J., 2012)

As a result of bio-drying, the final product has more heat value which is between 3582 and 4298.4 kcal/kg and can be processed in order to produce RDF. (Negoi, Ragazzi, Apostol, Rada, & Marculescu, 2009) Generally the bio-drying process lasts two to three weeks with respect to type and water content of solid waste (Sadaka, VanDevender, Costello, & Sharara, 2011).

Mixing

Mixing is generally implemented in order to make the solid waste homogenizes. Homogeneity provides equal heat value throughout RDF.

Shredding

Before pelletizing process, for providing required particle size shredding is applied. Hammer mills, flail mills and shear shredder can be utilized for shredding.

Pelletizing

RDF can be used as fluff or pellet. Generally, pelletized RDF is preferred due to easy usage. Pelletizing is a process in which solid waste is compressed or molded into pellet shape.

Finally, RDF is packaged and stored in order to be sold to cement factories and energy plants.

2.3 Usage Areas of RDF

RDF can be used in thermal energy plants constructed in order to produce electricity for the energy market. On the other hand, RDF can be used as substitutive fuel in the cement factories which have high temperature conditions providing proper conditions for thermal destruction. (Genon & Brizo, 2008)

Secondary fuels such as waste oil, tyres, sewage sludge, plastics/paper, wood and solvent are used in Europe with more than 100 kilns across Europe. Besides these fuels, the cement industry seeks a new alternative fuel to decrease its energy bill whose 30-40 % is for energy consumption. Moreover, the cement industry tries to decrease the CO_2 emissions. (Genon & Brizo, 2008)

If RDF is used in klinker kiln as solid fuel, there are four ways to do. These are:

- Via the main burner at the rotary kiln outlet end,
- Via secondary burners to the riser duct at the kiln inlet,
- Via precalciner burners to the precalciner,
- Via a feed chute to the precalciner (for lump fuel). (Lorber, Sarc, Pomberger, & Erdin, 2015)

2.4 Advantages of RDF

- Heat value of RDF is nearly same with lignite.
- RDF can be processed technologically and ecologically.
- It does not cause extra CO_2 and CH_4 emission.
- It provides decrease in effects of greenhouse gases.
- RDF increases the life time of landfilling areas.
- It decreases the usage of raw materials.
- It provides decrease in investment and operation costs (Alp, Refuse derived fuel rdf, 2011).

The most significant advantage of using RDF is that the heat value of RDF is more uniform, hence the usage of excess air for combustion is less. Moreover, due to less excess air requirement smaller air pollution control devices are needed.

The calorific value of RDF varies between 15,000 and 20,000 kj/kg while the calorific value of lignite in Turkey changes from 800 kcal/kg to 5600 kcal/kg (Genon & Brizo, 2008); (Ataman , n.d.). The air requirement the dry waste gas and the waste steam of pet coke are 9.4 Nm3/kg, 9.16 Nm3/kg and 0.41 Nm3/kg, respectively. While the air requirement, the dry waste gas and the waste steam of RDF are 6.16 Nm3/kg, 5.92 Nm3/kg and 0.78 Nm3/kg (Genon & Brizo, 2008).

The usage of RDF as an alternative fuel can cause a smaller formation rate of NOx. The nitrogen causes formation of nitrogen oxides. RDF has 0.3-0.5 % nitrogen compound, as fossil fuels have 1.5-2 % nitrogen compound. Generally, the formation of NOx is affected by the amount of nitrogen in the fuel, the temperatures in the kiln, the residence time and the types of burners. Therefore, it is difficult to estimate the NOx amount by considering these factors. However, the produced off-gases by using RDF will have lower concentration (Genon & Brizo, 2008).

The Sulphur concentration in the conventional fossil fuels is 3-5 % while the concentration in RDF is 0.1-0.2 %. Hence precipitation and clogging problems can be prevented by using RDF as alternative fuel. Furthermore, SOx concentration generated as a result of combustion is less than caused by conventional fuels. Moreover, RDF decreases CO2 about 1.62 kg per kg of used RDF compared to fossil fuels (Genon & Brizo, 2008).

On the contrary, RDF has more chlorine content (0.3-0.5 %) than coke (0.1 %). Chlorine content can cause problems lead from reactions between alkali and chlorine, the volatilization of chlorides and recycling with dust. Also the heavy metal concentrations of RDF are higher than other fossil fuels'. The combustion of 1 ton RDF in a cement kiln leads an increase around 421 mg in the emissions of mercury, 4.1 mg of lead and 1.1 mg of cadmium compared to the use of hard coal. As a result, the usage of RDF can cause problems in terms of heavy metals in the waste gas, hence the quality and the quantity RDF should be analyzed precisely (Genon & Brizo, 2008).

CHAPTER THREE
EXPERIMENTAL

3.1 Materials and Methods

The solid wastes obtained as a result of the characterization have used both for bio-drying reactor experiment and other laboratory experiments.

3.1.1 Sampling and Determination Composition of Solid wastes

Effective sampling is significant to determine actual composition of wastes. Because of that mixing and quartering are important steps in the sampling. After solid wastes are taken to sampling area, wastes are mixed well then they are quartered. Two of quarters are selected as representing whole sampled wastes. After that two quarters are mixed and again quartering is applied and two of quarters are chosen. Two quarters are mixed and can be used as samples.

After quartering, in order to define the composition plastics, glasses, composite materials, textiles, paper and cardboards, porcelains, ceramics, electronics, hazardous wastes, hygiene wastes, wood, and metals are separated and grouped. All groups are weighed and packaged.

For determining RDF quality, particle size has important role. Hence sieving has to be done. After separation, the left part consists of generally biodegradable wastes. In this study, 6 different screens whose mesh sizes are 10, 30, 50, 80, 100 and 120 mm are used and 7 fractions are obtained as a result of screening.

Between 09.04.2014 and 11.04.2014, sampling has been conducted by taking solid wastes from three districts of each county Karşıyaka, Bornova and Konak with respect to incomes of residents. Örnekköy, Alaybey and Mavişehir are districts of Karşıyaka, which are sequenced from low income to high income, Naldöken, Erzene and Kızılay are districts of Bornova, which are sequenced from low income to high income and Basmane, Güzelyalı and Alasancak are districts of Konak, which are sequenced from low income to high income. In the Figure 3.1 the location of counties and in the Figure 3.2 locations of districts can be seen.

Figure 3.1 The locations of sampling counties

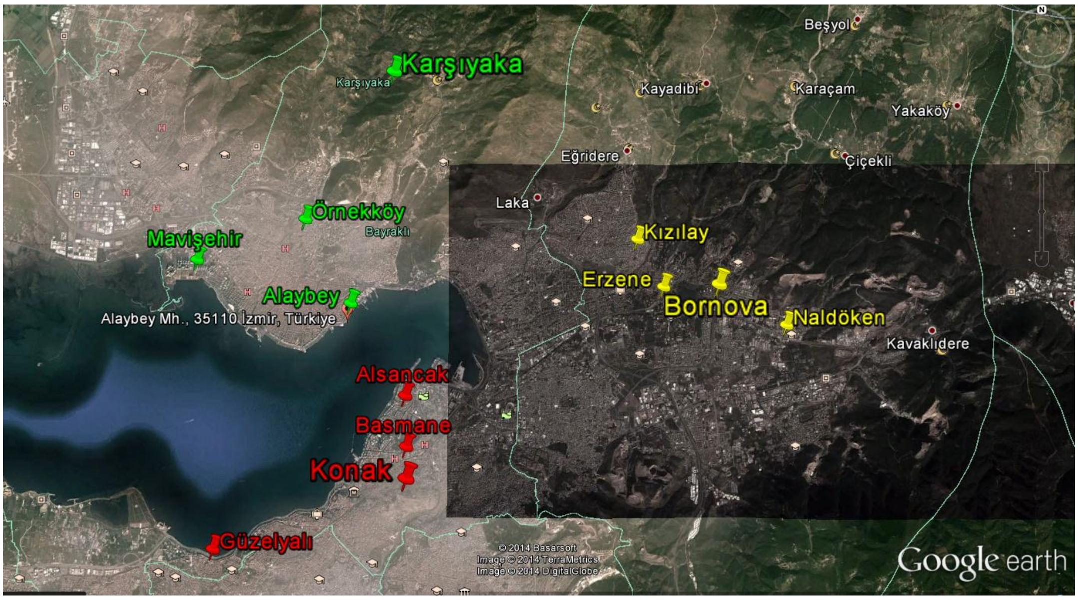

Figure 3.2 The locations of sampling districts

On first day of the sampling (09.04.2014), the solid wastes have been brought from Karsiyaka with three garbage trucks. On second day, the wastes have come from Bornova with three garbage trucks (Figure 3.3). On final day of sampling (11.04.2014), the wastes have been taken from Konak by three garbage trucks. These counties have been selected with regard to their level of development and location. Normally, solid wastes are collected by county municipalities and taken to Izmir Metropolitan Municipality Harmandalı Landfill Area.

Figure 3.3 One of the garbage trucks used in the study and the solid wastes brought from Erzene

After solid wastes have arrived to the university, firstly quarter method has been applied. The wastes come from each districts have been quartered and two quarters were taken as sample. After quartering plastics, glasses, composite materials, textiles, paper and cardboards, porcelains, ceramics, electronics, hazardous wastes, hygiene wastes, wood and metals have been separated from the total of samples. These wastes from each district have been weighed separately in order to form the distribution of each type of solid wastes. After that, the rest of the solid waste, which was biodegradable fraction, has been screened with screens whose mesh sizes were 10, 30, 50, 80, 100 and 120 mm. Oversize part was bagged and weighed, undersize was screened with other screens. Moreover, undersize of last sieve which was named as fine fraction has been bagged and weighed. The oversize parts of each screen were named as follow:

1. Fraction→ oversize of screen with 120 mm mesh size

2. Fraction→ oversize of screen with 100 mm mesh size

3. Fraction→ oversize of screen with 80 mm mesh size

4. Fraction→ oversize of screen with 50 mm mesh size

5. Fraction→ oversize of screen with 30 mm mesh size

6. Fraction→ oversize of screen with 10 mm mesh size

Fine Fraction→ undersize of screen with 10 mm mesh size

Figure 3.4 The screens and the example of the undersized solid wastes

Finally, all bagged organic solid waste have put into refrigerators in order to be used in bio-reactor and analyses.

3.1.2 Water Content Determination

Firstly, in order to determine the water content of each size of organic fraction drying oven and incubator were used. Each organic fraction sequentially was put into the drying oven for both determining water content and obtaining dried samples to be analyzed. Moreover, for this analysis, capsule, metal vessel and weighing instrument were used.

The capsule was weighed then the sample was put into the capsule and again the capsule and the sample were weighed together. This process has been applied to each sample. After weighing, the samples were put into the drying oven with capsule at 105 ^{o}C for 24 hours. The samples were put into incubator with metal vessel at 70 ^{o}C for 48 to 72 hours. At the end of incubation, the sample with the capsule was weighed again. For the determination of water content the equation below was used.

$$\text{Water content} = (A-B)/A*100$$

where:

A: weigh of sample with capsule at the beginning – weigh of capsule

B: weigh of sample with capsule at the end – weigh of capsule

3.1.3 Determination of Organic Content and Ash Content

After water content determination, in order to find organic content and ash content of each organic fraction, the samples were incinerated in muffle furnace. Besides muffle furnace, porcelain crucible, tong, desiccator and weighing instrument were used for the analysis.

The crucible was weighed before sample was put into it. Then they were weighed together. This process was applied to each sample. After weighing, samples were put into the muffle furnace at 550 ^{o}C for 1 hour. At the end of the incineration, the crucibles were taken into desiccator to cool and have constant weight. After cooling, the samples were weighed again. The equations in order to calculate the organic matter content and ash content are given below.

$$\text{Organic matter content} = (C- D)/C*100 = OM$$

where:

C: weigh of sample with crucible at the beginning- weigh of crucible

D: weigh of sample with crucible at the end- weigh of crucible

$$\text{Ash Content} = 100- OM$$

3.1.4 Determination of Total Carbon, Total Organic Carbon and Total Inorganic Carbon

Total carbon (TC) is measured with Teledyne Tekmar Apollo Combustion TOC Analyzer. 0.1 mg dried sample is weighed as staying in the calibration interval and 3 runs are applied for one sample. The average value of 3 runs is taken as a result.

Total carbon consists of both organic and inorganic carbon contents. In order to determine total organic carbon (TOC), firstly inorganic carbon has to be removed with phosphoric acid (1:1). Hence inorganic carbon is oxidized to CO_2. Phosphoric acid is applied to each sample drop by drop until the bubbling stops. Then the samples are placed in to an oven set at 40 ^{o} C for 24 hours. After 24 hours the samples are cooled and ready for analyzing. TOC is measured as TC in the same instrument (Bernard, Bernard, & Brooks, n.d.).

Total inorganic carbon (TIC) is found as subtraction of TOC from TC.

$$TIC = TC - TOC$$

3.1.5 Determination of Calorific Value

Due to being a solid fuel, calorific value of the RDF is important to be effective in incineration. In order to determine the calorific value of solid waste samples, adiabatic calorimeter is used. All samples are grinded and weighed about 0.5 mg. Then they are put into the oxygen bomb and the bomb is set up by adding oxygen after closing the cover of the bomb. Finally the calorimeter is run and the result is obtained after 20 minutes. The results are low heat value because adjustments are done by the calorimeter automatically.

Besides oxygen bomb calorimeter, calorific value can be found from elemental composition of dry biomass. Several studies have been done to obtain the relation between calorific value and elemental composition. One of these studies belongs to Tillman.

Tillman found that the carbon content has a significant effect on calorific value. Thus, he formed the correlation for calorific value of biomass and its elementary components, the formula which he derived is: (Buckley & Domalski, n.d.)

$$Q\ (Mj/kg) = 0.437C - 1.67$$

However, higher heating values (HHV) can be found by this formula, hence the moisture effect should be eliminated. In order to obtain low heat values (LHV) following formula can be used. (U.S Department of Energy, 2011)

$$LHV\ (Mj/kg) = HHV(1- M)- 2.447M$$

where:

2.447 is the latent heat of vaporization of water in Mj/kg at 25 ^{o}C.

M: moisture (mass fraction decimal)

In this study, the samples are dried then TOC contents are found. Thus, the calorific value found by the formula can be taken as LHV by ignoring the hydrogen content.

3.1.6 Determination of Heavy Metals Content

Municipal solid waste (MSW) can be used as soil conditioner after composting or to obtain energy by incineration. In this study the solid waste is used to produce RDF as energy source. But, the heavy metals in MSW and their transformation products decrease the efficient of recovery methods and also affect the disposal. Hence the importance of the heavy metals in MSW increases (Zhang, He, & Shao, 2008).

Defining the heavy metals in MSW is important to identify major contaminant sources and find effective collection/handing, treatment and disposal methods. The heavy metals can be transferred easily into treatment and disposal facilities within the MSW management (Zhang, He, & Shao, 2008). During incineration acid gases, heavy metals etc. can be emitted to the atmosphere and also the heavy metals can remain in the incineration tank and ash (Shi, Wu, Lu, Chen, & Huang, 2007). In the study the MWS is used to produce RDF, then incinerated, therefore; determining heavy metals contents is important to find proper treatment method.

To find heavy metals concentrations in the solid waste, firstly extraction process has to be done. Thus, the heavy metals in the solid wastes can transfer into solutions. As extraction methods there are several ways. In this study, hot plate aqua regia digestion method will be used. Aqua regia is prepared as $HCl:HNO_3$=3:1,v/v. 0.5 g homogenized solid waste sample is taken to 250 ml glass beaker then 12 ml aqua regia is added. After that digestion occurs on a hotplate for 3 hours at 110 ^{o} C. After evaporation, the sample is diluted with 20 ml of 2 % (v/v with H2O) nitric acid and taken to 100 ml volumetric flask. Then it is diluted to 100 ml with distilled water and filtered through 0.45 µm paper (Chen & Ma, 2001).

After extraction the sample solutions are ready. The solutions are read with ICP-OE to determine concentrations of Pb, Cu, Zn, K, Na, As, Cd, Hg, Ni, Mn, Cr, Al, Ca and Ti.

3.1.7 Determination of Water Soluble Chlorine

Chlorine content is important to determine the possibility of corrosion caused by chlorine. During combustion of RDF in the clinkers, chlorine can accumulate and damages the wall of the clinker. Furthermore, the chlorine affects the quality of RDF (Beckmann & Ncube, 2007).

Organic bound chlorine generally is found in fuels made mainly with plastics especially PVC. In biodegradable wastes, about 95 % of total chlorine is formed by inorganic bounds (Beckmann & Ncube, 2007).

Chlorine contents in solid wastes are generally less than 1 %, as ones in garden wastes are less than 0.5 %. Moreover, chlorine content of RDF is about 0.6 % (Beckmann & Ncube, 2007).

Titration with $AgNO_3$ method has been chosen to find the chlorine contents of the solid wastes in the study.

Firstly, eluate is prepared to transfer the chlorine through water. In the standard 10 g dry sample is mixed with 100 ml diluted water and the mixture is shaken for 24 hours. In the study, due to lack of sample 1 g dry sample was mixed with 30 ml diluted water and the mixtures were shaken for 24 hours at 170 rpm. After that 20 ml samples were taken to be titrated.

$AgNO_3$ and K_2CrO_4 reagents are used in the process. In order to prepare 0.0141 N $AgNO_3$, 2.395 g $AgNO_3$ is dissolved in 1 L diluted water. 50 g K_2CrO_4 is dissolved in some water to prepare K_2CrO_4 with 5 %. Until obtain red sediments, $AgNO_3$ solution is added, after that K_2CrO_4 is waited for 12 hours and then filtered. Finally, the solution is completed up to 1 L with diluted water.

In the procedure, 1 ml K_2CrO_4 solution is added 20 ml sample and then titrated with $AgNO_3$ solution until obtaining brick red. The consumption is recorded and the same procedure is applied to the diluted water. The calculation of the water soluble chlorine is done as follow:

$$mg/L\ Cl^- = ((A-B) * N * 35450)/X$$

where:

A: Consumption for sample

B: Consumption for diluted water

X: Volume of sample

N: Normality of $AgNO_3$ = 0.0141

Finally, the results in mg/L were converted to % to compare the results with the statement and the literature.

CHAPTER FOUR
RESULTS AND DISCUSSION

4.1 Results from Physical Analysis of Izmir Solid Waste

4.1.1 Composition of Solid Waste

As a result of characterization, the percentage of organic fraction was found more than other fractions for all districts. Following figures express the distributions of solid waste contents of all districts. After organic fraction, generally plastics, glasses and paper and cardboard were the most generated types of solid wastes.

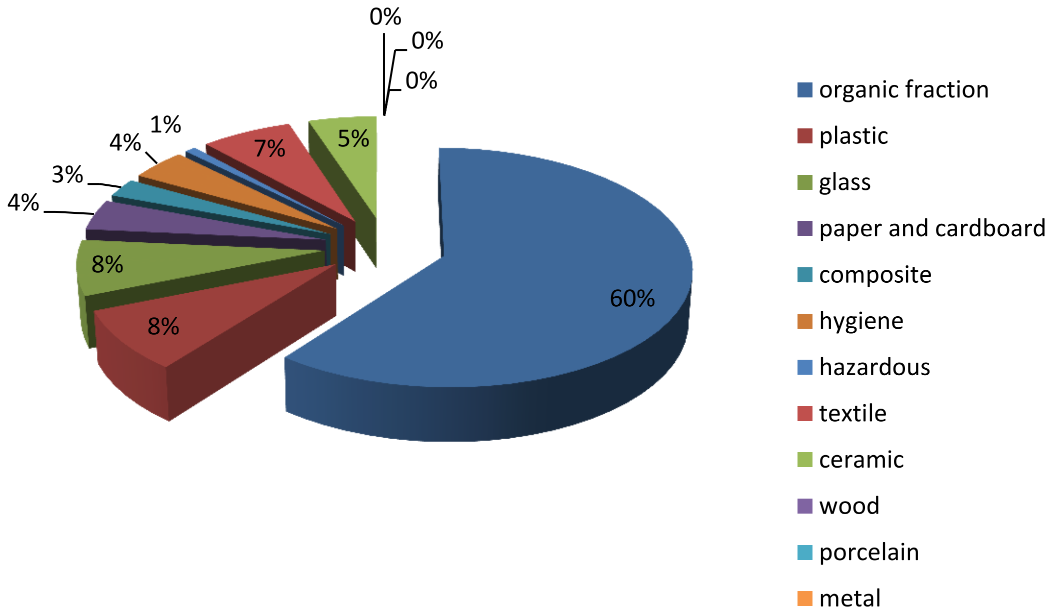

Figure 4.1 Composition of solid waste obtained from Ornekkoy

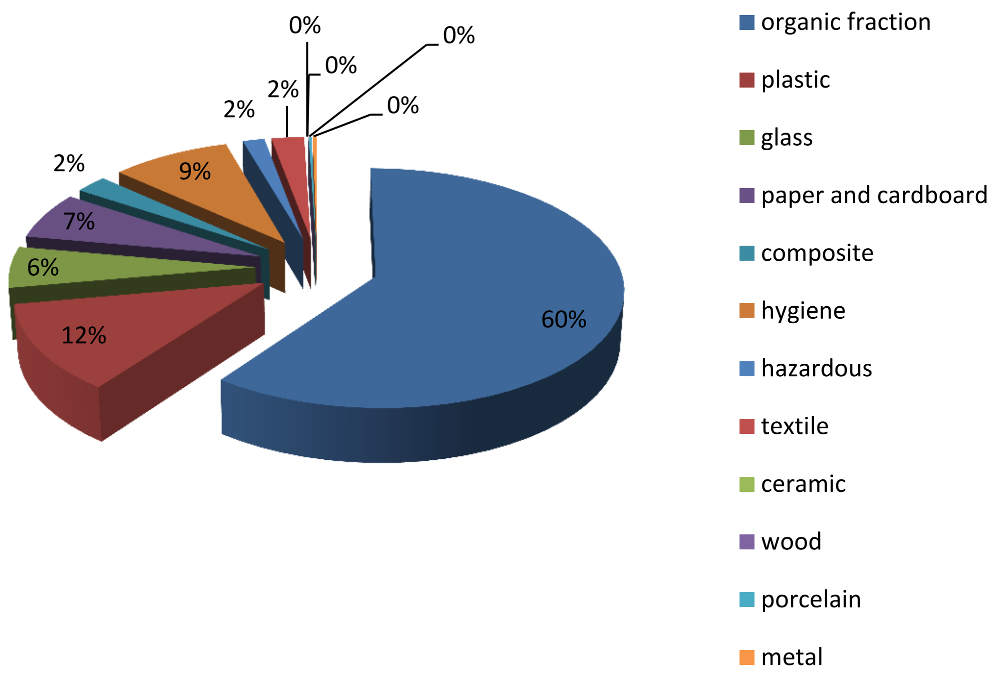

Figure 4.2 Composition of solid waste obtained from Alaybey

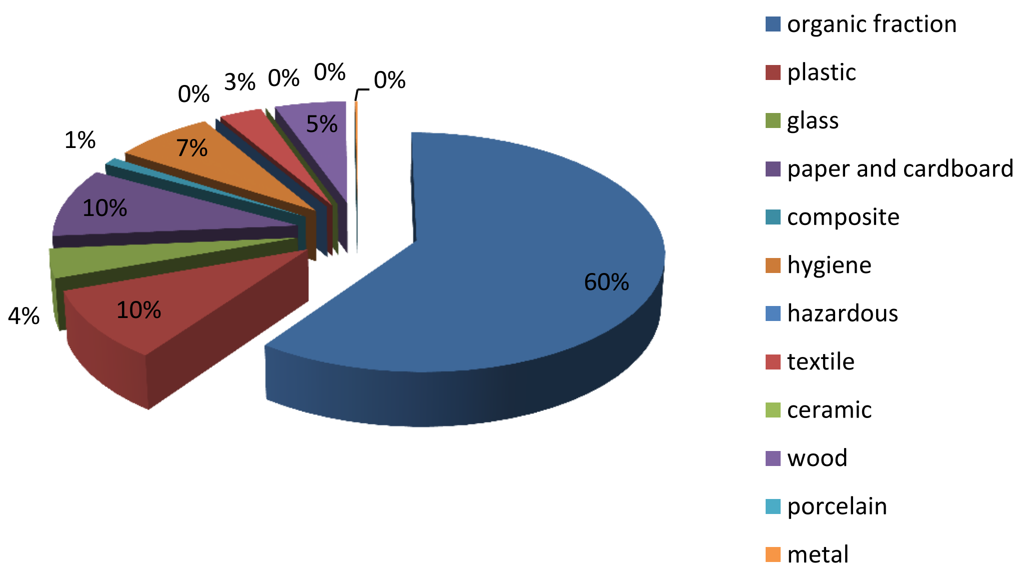

Figure 4.3 Composition of solid waste obtained from Mavisehir

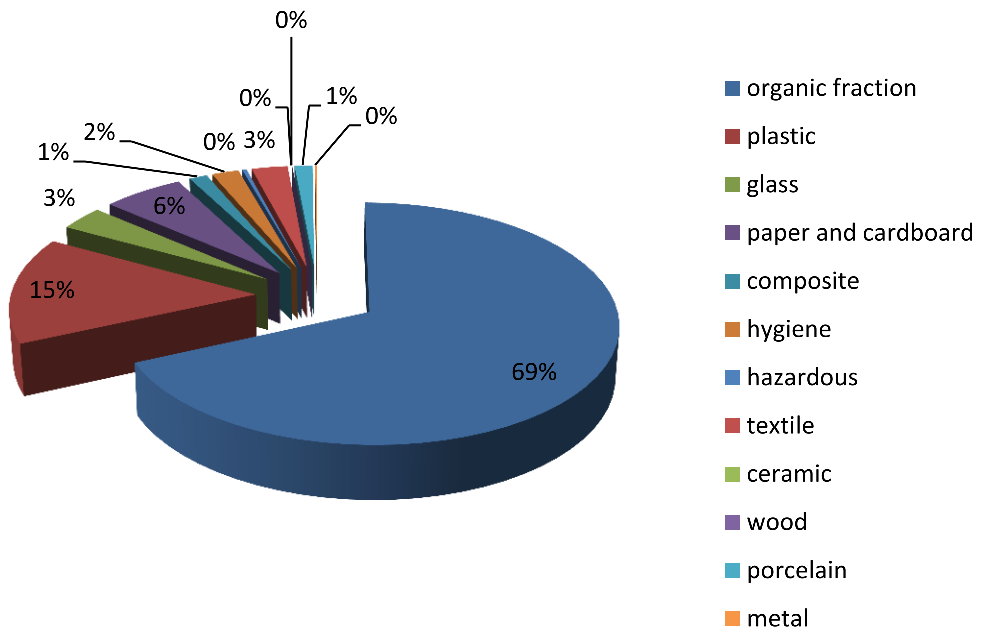

Figure 4.4 Composition of solid waste obtained from Naldoken

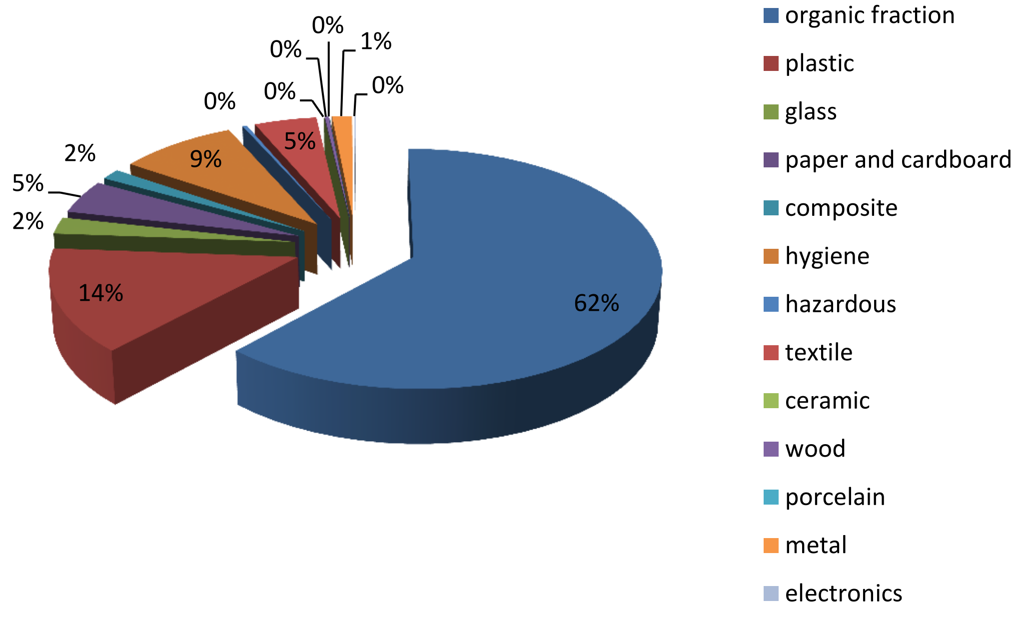

Figure 4.5 Composition of solid waste obtained from Erzene

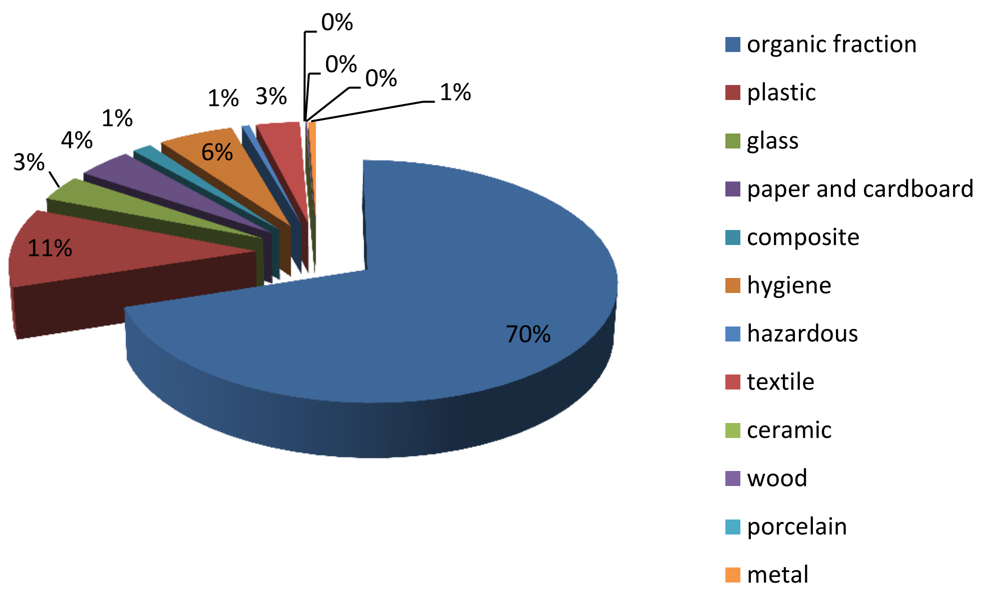

Figure 4.6 Composition of solid waste obtained from Kizilay

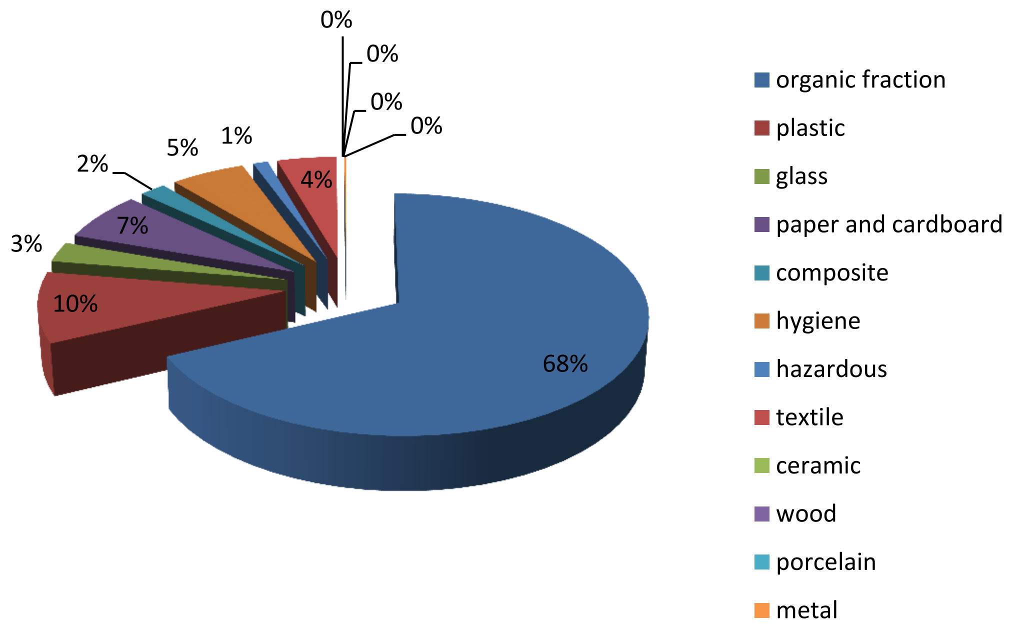

Figure 4.7 Composition of solid waste obtained from Basmane

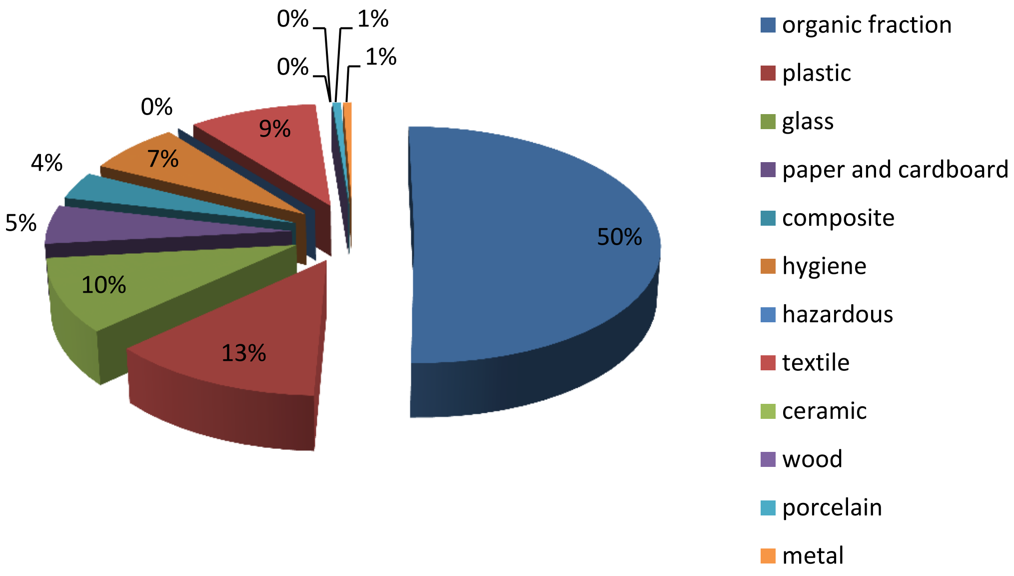

Figure 4.8 Composition of solid waste obtained from Guzelyali

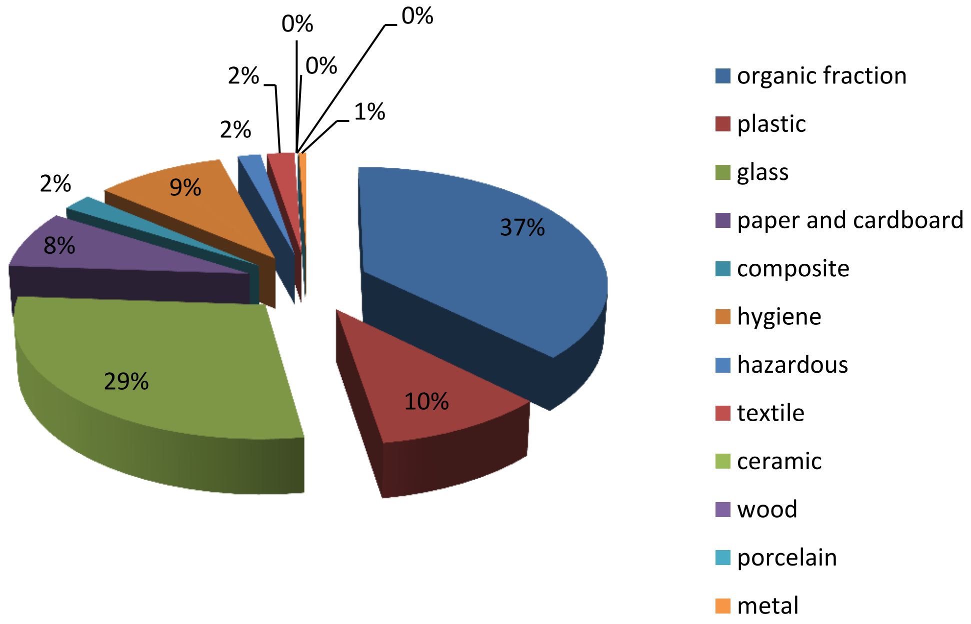

Figure 4.9 Composition of solid waste obtained from Alsancak

In all districts biodegradable fraction has the biggest percentage, and then generally plastics come. In Alsancak, glass has the second biggest share because there are entertainment places.

4.2 Water Content

In order to find water content of each district, method of water content determination has been applied for each district and fraction. The tables of Konak, Bornova and Karsiyaka are given as follow.

Table 4.1 Water content of solid wastes from Konak, % ww

Size Fraction	District Name		
	Basmane	Guzelyali	Alsancak
1st Fraction	77.86	89.82	82.76
2nd Fraction	70.00	76.32	76.47
3rd Fraction	58.35	48.53	55.34
4th Fraction	52.83	47.65	52.65
5th Fraction	78.69	77.14	78.48
6th Fraction	69.74	72.73	72.53
Fine Fraction	61.01	63.62	67.55

The limit defined in the statement of RDF for water content is 35 %; therefore, all samples' water contents in Konak are above the limit.

Table 4.2 Water content of solid wastes from Bornova, % ww

Size Fraction	District Name		
	Naldoken	Erzene	Kizilay
1st Fraction	80.41	48.98	47.13
2nd Fraction	68.18	57.14	70.00
3rd Fraction	80.38	60.61	63.34
4th Fraction	50.74	34.63	52.76
5th Fraction	66.67	73.68	60.66
6th Fraction	75.71	62.90	72.22
Fine Fraction	57.68	53.57	33.83

Only water content of fine fraction of Kizilay is less than the limit. The other water content values of Bornova are more than the limit.

Table 4.3 Water content of solid wastes from Karsiyaka, % ww

Size Fraction	**District Name**		
	Ornekkoy	**Alaybey**	**Mavisehir**
1st Fraction	52.27	76.79	69.23
2nd Fraction	77.78	78.79	76.92
3rd Fraction	55.33	72.85	63.85
4th Fraction	57.74	66.08	40.79
5th Fraction	68.00	82.61	75.47
6th Fraction	68.63	80.00	58.82
Fine Fraction	54.45	57.45	49.25

The water contents of Karsiyaka samples exceed the limit.

4.3 Organic and Ash Content

General method for determination of organic and ash content has been used in the study. The following results in the Table 4.4, 4.5 and 4.6 were obtained for each fraction and district.

Table 4.4 Organic and ash content of Konak

District Name	Size Fraction	Organic Content, %	Ash Content, %
Basmane	1st Fraction	62.57	37.43
	2nd Fraction	77.56	22.44
	3rd Fraction	76.19	23.81
	4th Fraction	88.13	11.87
	5th Fraction	71.2	28.8
	6th Fraction	66.48	33.52
	Fine Fraction	43.33	56.67
Guzelyali	1st Fraction	71.67	28.33
	2nd Fraction	76.22	23.78
	3rd Fraction	86.55	13.45
	4th Fraction	82.38	17.62
	5th Fraction	70.63	29.37
	6th Fraction	53.98	46.02
	Fine Fraction	69.83	30.17
Alsancak	1st Fraction	81.54	18.46
	2nd Fraction	80.22	19.78
	3rd Fraction	82.87	17.13
	4th Fraction	87.38	12.62
	5th Fraction	80.69	19.31
	6th Fraction	44.99	55.01
	Fine Fraction	56.90	43.10

Table 4.5 Organic and ash content of Bornova

District Name	Size Fraction	Organic Content, %	Ash Content, %
Naldoken	1st Fraction	71.78	28.22
	2nd Fraction	75.54	24.46
	3rd Fraction	70.66	29.34
	4th Fraction	85.02	14.98
	5th Fraction	60.8	39.2
	6th Fraction	73.23	26.77
	Fine Fraction	60.87	39.13
Erzene	1st Fraction	75.00	25.00
	2nd Fraction	74.76	25.24
	3rd Fraction	92.16	7.84
	4th Fraction	85.71	14.29
	5th Fraction	41.76	58.24
	6th Fraction	48.09	51.91
	Fine Fraction	44.85	55.15
Kizilay	1st Fraction	73.33	26.67
	2nd Fraction	81.25	18.75
	3rd Fraction	53.01	46.99
	4th Fraction	78.06	21.94
	5th Fraction	72.14	27.86
	6th Fraction	49.56	50.44
	Fine Fraction	24.79	75.21

Table 4.6 Organic and ash content of Karsiyaka

District Name	Size Fraction	Organic Content, %	Ash Content, %
Ornekkoy	1st Fraction	73.68	26.32
	2nd Fraction	70.19	29.81
	3rd Fraction	72.44	27.56
	4th Fraction	70.79	29.21
	5th Fraction	62.5	37.5
	6th Fraction	68.4	31.6
	Fine Fraction	40.31	59.69
Alaybey	1st Fraction	62.3	37.7
	2nd Fraction	69.44	30.56
	3rd Fraction	67.67	32.33
	4th Fraction	83.62	16.38
	5th Fraction	74.4	25.6
	6th Fraction	74.58	25.42
	Fine Fraction	52	48
Mavisehir	1st Fraction	62.6	37.4
	2nd Fraction	69.89	30.11
	3rd Fraction	69.47	30.53
	4th Fraction	81.63	18.37
	5th Fraction	69.1	30.9
	6th Fraction	55.87	44.13
	Fine Fraction	54.05	45.95

4.4 Total Carbon, Total Organic Carbon and Total Inorganic Carbon

In TOC analyzer total carbon and total organic carbon have been measured for each sample. The TOC analyzer gave the TC results for Mavisehir-5 as in the Figure 4.10. Moreover, the results for TOC of Alsancak-5 can be seen in the Figure 4.11.

Deatails of Each Repeat				
Repeat #	Sample Weight (mg)	Raw Data (a.u)	Carbon Content (ug)	C. Concetration (%)
1	100	148,936	40489	40,489
2	100	145,722	39563	39,563
3	100	149,432	40632	40,632

Graphical

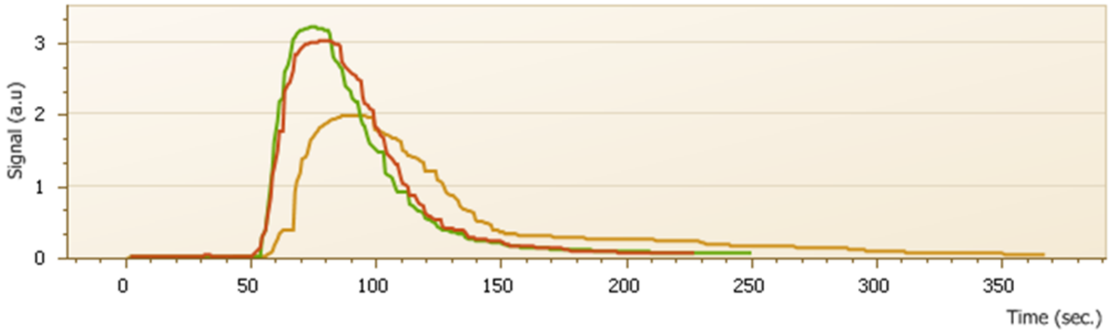

Figure 4.10 Example result of TOC analyzer for TC

Deatails of Each Repeat				
Repeat #	Sample Weight (mg)	Raw Data (a.u)	Carbon Content (ug)	C. Concetration (%)
1	100	159,97	43669	43,669
2	100	159,663	43580	43,58
3	100	157,701	43015	43,015

Graphical

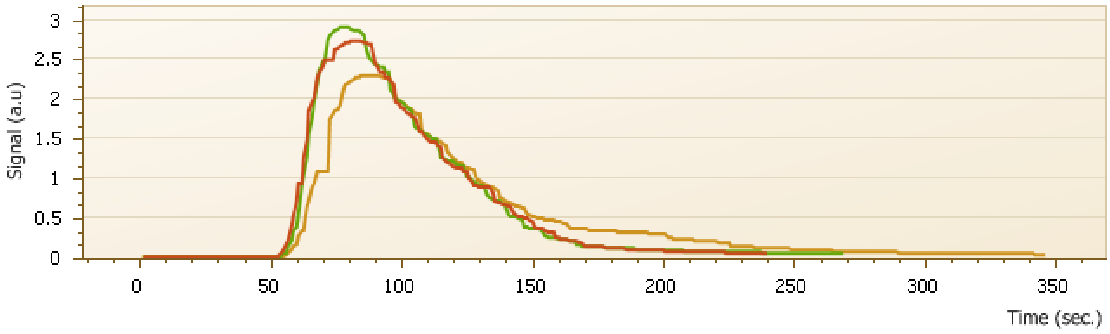

Figure 4.11 Example result of TOC analyzer for TOC

The TC, TOC and TIC results found for each fraction of all districts as follows.

Table 4.7 Carbon contents of Alsancak, %

Alsancak				
	Fraction	**TC**	**TOC**	**TIC**
	1	42.1	38.2	3.9
	2	38.4	33.5	4.9
	3	29.5	24.9	4.6
	4	39.7	33.5	6.2
	5	44.3	42.8	1.5
	6	29.0	23.5	5.5
	fine	39.9	33.4	6.5

Table 4.8 Carbon contents of Guzelyali, %

Guzelyali				
	Fraction	**TC**	**TOC**	**TIC**
	1	39.6	36.5	3.1
	2	47.3	41.5	5.8
	3	40.9	36.8	4.0
	4	36.4	31.8	4.7
	5	44.1	40.4	3.6
	6	40.8	37.9	2.9
	fine	40.8	36.9	3.9

Table 4.9 Carbon contents of Basmane, %

Basmane				
	Fraction	**TC**	**TOC**	**TIC**
	1	34.5	31.6	2.9
	2	44.8	37.4	7.4
	3	44.4	37.7	6.7
	4	40.7	38.0	2.7
	5	42.4	41.4	1.0
	6	36.8	36.2	0.6
	fine	40.6	23.3	17.4

Table 4.10 Carbon contents of Kizilay, %

Kizilay				
	Fraction	**TC**	**TOC**	**TIC**
	1	41.1	36.8	4.4
	2	33.3	31.4	1.9
	3	30.2	29.5	0.7
	4	27.1	23.2	3.8
	5	40.1	39.0	1.1
	6	26.5	22.6	3.8
	fine	12.2	9.3	2.9

Table 4.11 Carbon contents of Erzene, %

Erzene				
	Fraction	**TC**	**TOC**	**TIC**
	1	41.6	32.7	8.9
	2	43.3	41.0	2.3
	3	37.8	36.6	1.3
	4	40.2	32.8	7.4
	5	40.2	35.5	4.7
	6	43.5	42.3	1.2
	fine	44.5	34.1	10.4

Table 4.12 Carbon contents of Naldoken, %

Naldoken				
	Fraction	**TC**	**TOC**	**TIC**
	1	39.9	33.1	6.8
	2	38.8	35.8	3.1
	3	44.7	43.7	1.0
	4	41.2	38.1	3.2
	5	40.8	39.2	1.5
	6	40.1	38.7	1.4
	fine	40.5	34.7	5.8

Table 4.13 Carbon contents of Mavisehir, %

Mavisehir				
	Fraction	TC	TOC	TIC
	1	44.7	35.2	9.4
	2	40.2	35.3	4.9
	3	36.8	29.1	7.8
	4	41.0	38.8	2.2
	5	43.4	34.5	8.9
	6	38.3	31.7	6.6
	fine	30.6	25.1	5.6

Table 4.14 Carbon contents of Alaybey, %

Alaybey				
	Fraction	TC	TOC	TIC
	1	37.4	30.2	7.1
	2	40.6	32.9	7.7
	3	41.9	32.8	9.1
	4	38.8	32.4	6.4
	5	43.4	38.9	4.5
	6	40.9	30.7	10.2
	fine	39.3	26.8	12.6

Table 4.15 Carbon contents of Ornekkoy, %

Ornekkoy				
	Fraction	TC	TOC	TIC
	1	38.0	17.2	20.8
	2	40.2	23.7	16.5
	3	39.4	35.9	3.5
	4	41.2	31.8	9.4
	5	37.8	26.8	10.9
	6	40.9	39.5	1.5
	fine	31.8	26.8	5.0

The maximum total carbon value is observed in Guzelyali-2 as 47.277 %, while the minimum total carbon value is seen in Kizilay-fine as 12.198 %. The biggest total organic carbon value can be observed in Naldoken-3 as 43.744 %. The smallest total organic carbon value is in Kizilay-fine as 9.27 %. The maximum total inorganic carbon value can be observed in Ornekkoy-1 as 20.832, as the minimum total inorganic carbon value is seen in Basmane-6 as 0.621 %.

4.5 Calorific Value

At the beginning of the experiments, obtaining calorific value of each fraction for each district and samples of each bio-drying reactor was determined; however, a few samples' calorific values have been obtained with calorimeter. The left samples have been analyzed for calorific value by TOC equation. The results obtained are as follow.

Table 4.16 Calorimeter results of Guzelyali Samples

District	Fraction	Heat Value, kcal/kg
Guzelyali	1	3668
	2	4232
	3	4169
	4	2892
	5	3712
	6	4443
	fine	4013

Table 4.17 Calorimeter results of some samples

District	Fraction	Heat Value, kcal/kg
Mavisehir	4	3931
	5	3827
Alaybey	5	3736
Alsancak	5	3597
Kizilay	5	2843
Naldoken	5	3865

The calorific value results calculated with respect to TOC contents of the samples are as follows.

Table 4.18 Calorific values of Alsancak

Alsancak				
	Fraction	TOC	LHV (Mj/kg)	LHV(kcal/kg)
	1	38.2	15.0	3591.0
	2	33.5	13.0	3097.6
	3	24.9	9.2	2197.9
	4	33.5	13.0	3099.5
	5	42.8	17.0	4070.5
	6	23.5	8.6	2054.9
	fine	33.4	12.9	3087.5

Table 4.19 Calorific values of Güzelyali

Güzelyalı				
	Fraction	TOC	LHV (Mj/kg)	LHV(kcal/kg)
	1	36.5	14.3	3417.0
	2	41.5	16.5	3938.0
	3	36.8	14.4	3448.6
	4	31.8	12.2	2917.1
	5	40.4	16.0	3824.8
	6	37.9	14.9	3559.6
	fine	36.9	14.5	3457.7

Table 4.20 Calorific values of Basmane

Basmane				
	Fraction	TOC	LHV (Mj/kg)	LHV(kcal/kg)
	1	31.6	12.1	2901.3
	2	37.4	14.7	3503.6
	3	37.7	14.8	3536.4
	4	38.0	15.0	3573.9
	5	41.4	16.4	3929.6
	6	36.2	14.1	3379.8
	fine	23.3	8.5	2030.4

The calorific values of 3rd and 6th of Alsancak and fine fraction of Basmane are under the limit value defined in the Statement of RDF which is 2500 kcal/kg.

Table 4.21 Calorific values of Kizilay

Kizilay				
	Fraction	TOC	LHV (Mj/kg)	LHV(kcal/kg)
	1	36.8	14.4	3440.4
	2	31.4	12.1	2881.4
	3	29.5	11.2	2680.3
	4	23.2	8.5	2027.1
	5	39.0	15.4	3670.0
	6	22.6	8.2	1966.1
	fine	9.3	2.4	569.1

Table 4.22 Calorific values of Erzene

Erzene				
	Fraction	TOC	LHV (Mj/kg)	LHV(kcal/kg)
	1	32.7	12.6	3013.2
	2	41.0	16.2	3881.9
	3	36.6	14.3	3421.1
	4	32.8	12.7	3029.6
	5	35.5	13.8	3309.5
	6	42.3	16.8	4020.4
	fine	34.1	13.2	3164.7

Table 4.23 Calorific values of Naldoken

Naldoken				
	Fraction	TOC	LHV (Mj/kg)	LHV(kcal/kg)
	1	33.1	12.8	3058.8
	2	35.8	14.0	3335.9
	3	43.7	17.4	4169.6
	4	38.1	15.0	3578.1
	5	39.2	15.5	3699.2
	6	38.7	15.3	3647.9
	fine	34.7	13.5	3223.2

The calorific values of 4^{th}, 6^{th} and fine fractions in Kizilay are less than the limit value.

Table 4.24 Calorific values of Mavisehir

Mavisehir				
	Fraction	TOC	LHV (Mj/kg)	LHV(kcal/kg)
	1	35.2	13.7	3281.2
	2	35.3	13.8	3291.5
	3	29.1	11.0	2636.1
	4	38.8	15.3	3654.8
	5	34.5	13.4	3207.9
	6	31.7	12.2	2911.3
	fine	25.1	9.3	2218.3

Table 4.25 Calorific values of Alaybey

Alaybey				
	Fraction	TOC	LHV (Mj/kg)	LHV(kcal/kg)
	1	30.2	11.5	2757.5
	2	32.9	12.7	3032.8
	3	32.8	12.7	3027.3
	4	32.4	12.5	2986.1
	5	38.9	15.3	3662.6
	6	30.7	11.7	2806.6
	fine	26.8	10.0	2396.8

Table 4.26 Calorific values of Ornekkoy

Ornekkoy				
	Fraction	TOC	LHV (Mj/kg)	LHV(kcal/kg)
	1	17.2	5.8	1393.7
	2	23.7	8.7	2076.0
	3	35.9	14.0	3351.6
	4	31.8	12.2	2921.5
	5	26.8	10.1	2404.0
	6	39.5	15.6	3721.7
	fine	26.8	10.0	2401.2

The calorific values of 1^{st}, 2^{nd}, 5^{th} and fine fractions of Ornekkoy, fine fractions of Alaybey and Mavisehir stay under the limit defined as 2500 kcal/kg.

The maximum calorific value can be seen in Naldoken-3 as 4169.625 kcal/kg, while the minimum calorific value is observed in Ornekkoy-1 as 1393.739 kcal/kg.

The calorific values in bulk have been calculated as in the next figure.

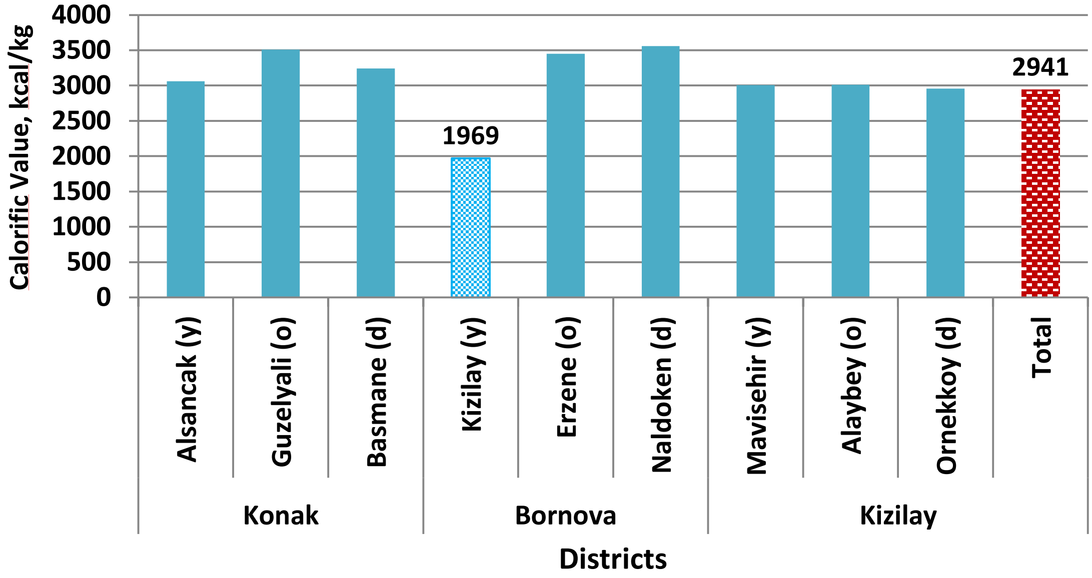

Figure 4.12 Calorific values in bulk

The average calorific value has the maximum value in Naldoken; on the contrary, the smallest one can be observed in Kizilay.

As a result of calorimeter analyzes the heat value of RDF samples except Kizilay are in the range of standard values. Although calorific value of Kizilay is under the limit, the calorific value of the weight based average of all samples is 2941 kcal/kg which is more than 2500 kcal/kg.

4.6 Heavy Metal Content

4.6.1 Heavy Metal Content in Fractions

4.6.1.1 Cadmium Content

The cadmium content graphs are between the Figure 4.13 and 4.18. The limit value defined in the Statement of RDF is 10 ppm.

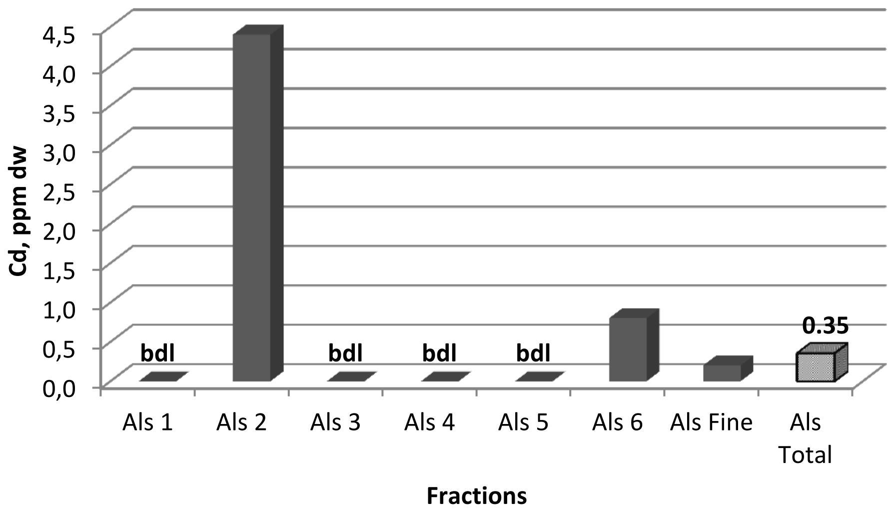

Figure 4.13 Cadmium content of Alsancak

*bdl: below the detection limit

Cadmium hasn’t been detected in any fractions of Guzelyali.

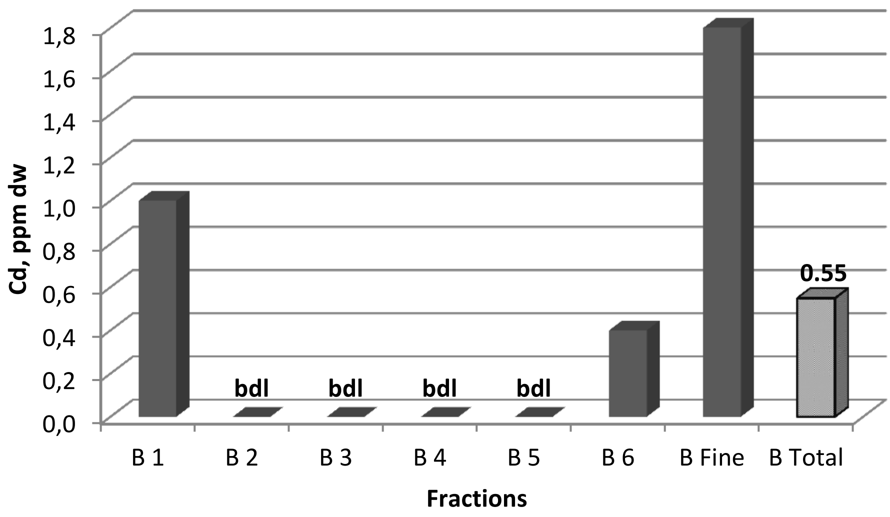

Figure 4.14 Cadmium content of Basmane

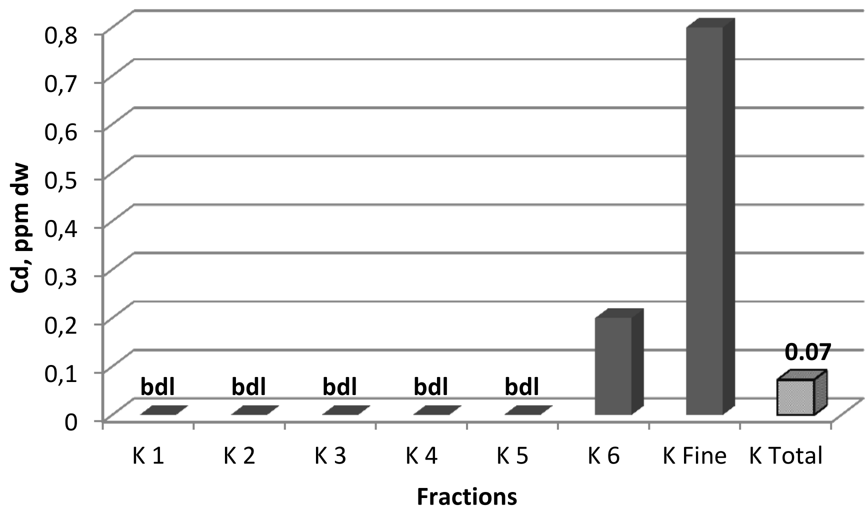

Figure 4.15 Cadmium content of Kizilay

All Cd concentrations were found under detection limit for Erzene.

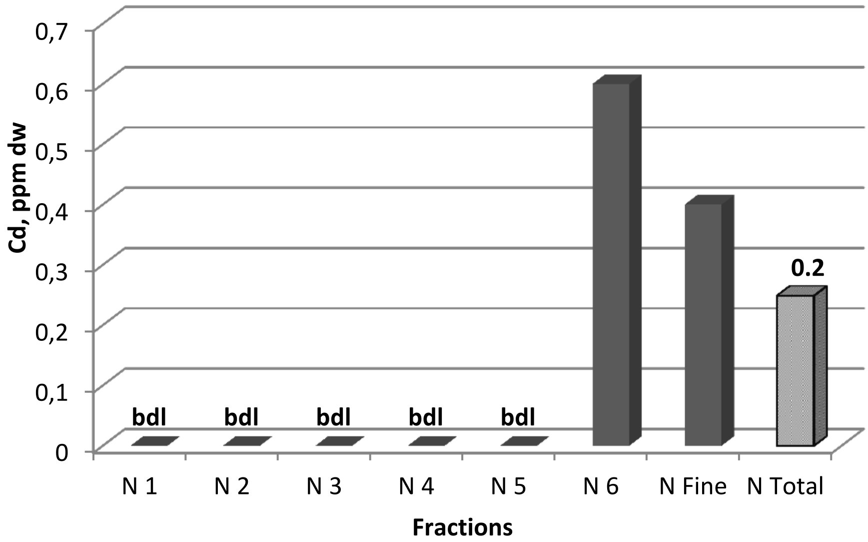

Figure 4.16 Cadmium content of Naldoken

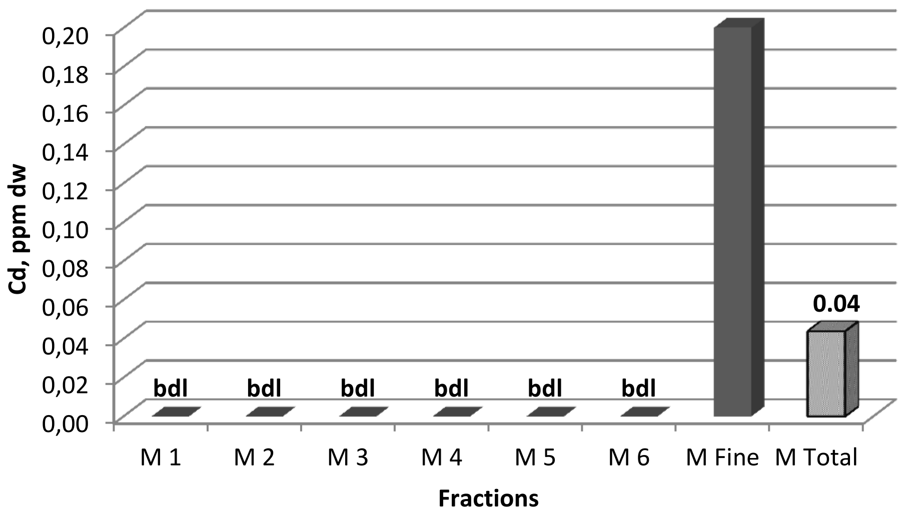

Figure 4.17 Cadmium content of Mavisehir

All Cd concentrations were found under detection limit for Alaybey.

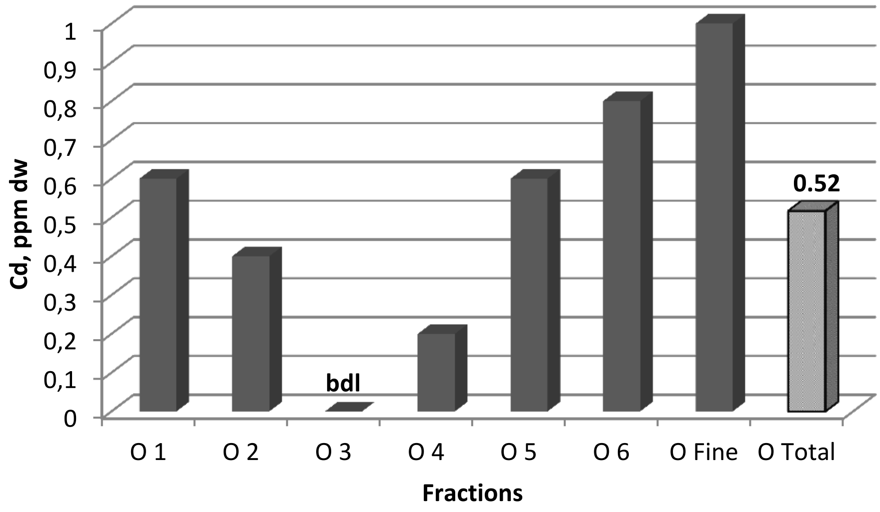

Figure 4.18 Cadmium content of Ornekkoy

All cadmium results are under the limit.

4.6.1.2 Chromium Content

Chromium content graphs of the districts starts from the Figure 4.19 to the Figure 4.27. The limit for chromium is defined as 400 ppm in the Statement of RDF.

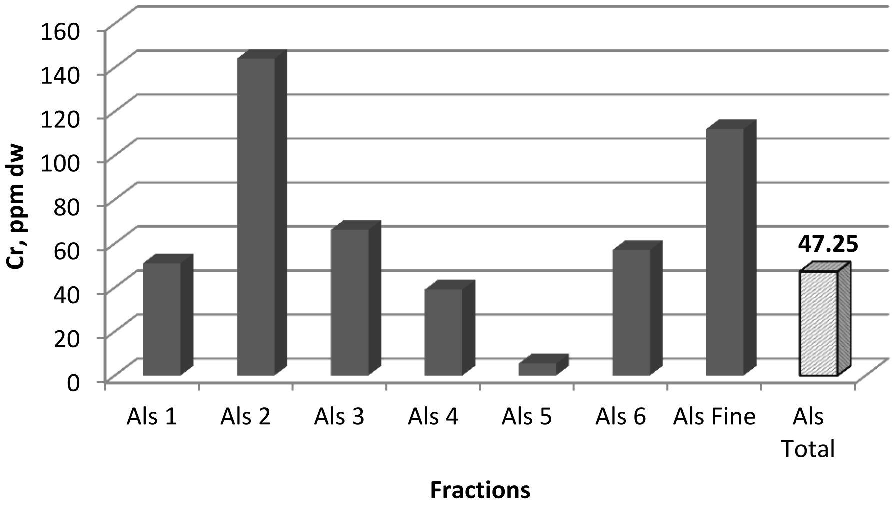

Figure 4.19 Chromium content of Alsancak

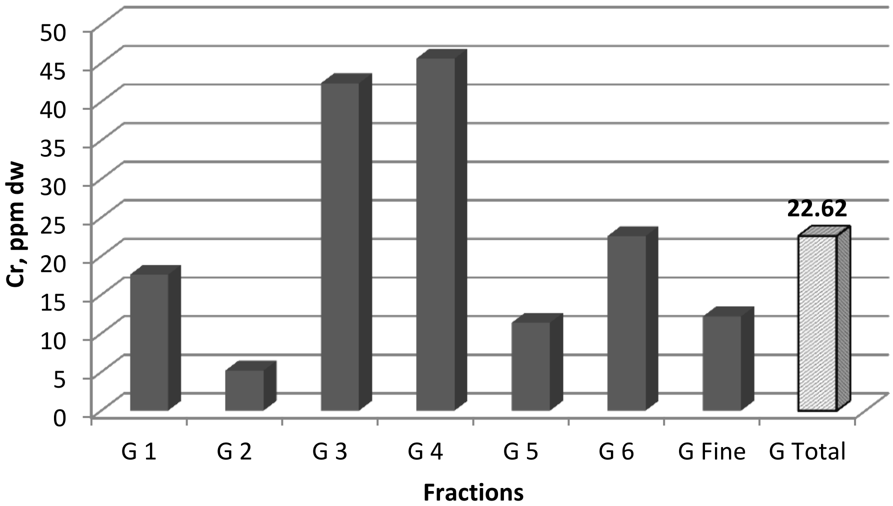

Figure 4.20 Chromium content of Guzelyali

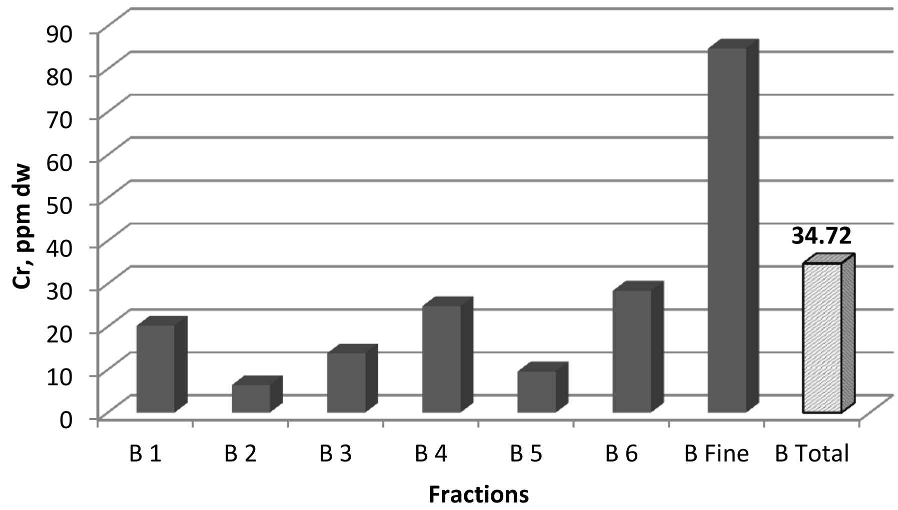

Figure 4.21 Chromium content of Basmane

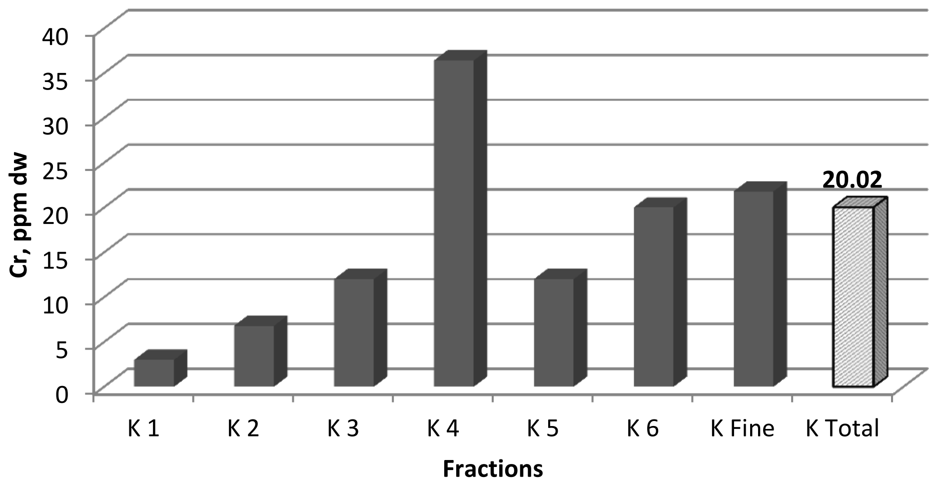

Figure 4.22 Chromium content of Kizilay

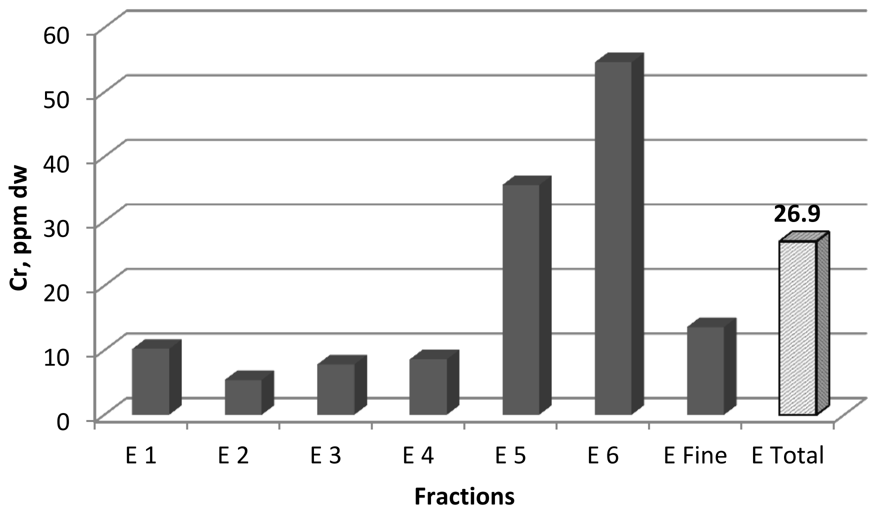

Figure 4.23 Chromium content of Erzene

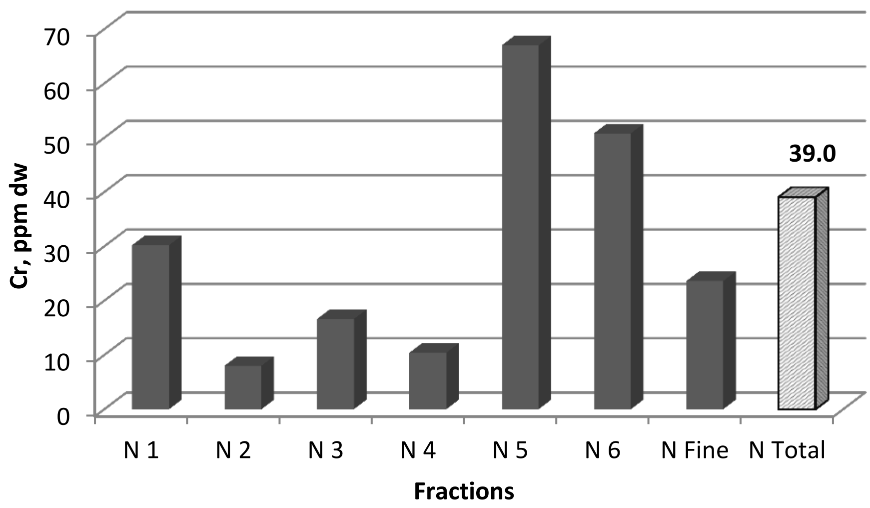

Figure 4.24 Chromium content of Naldoken

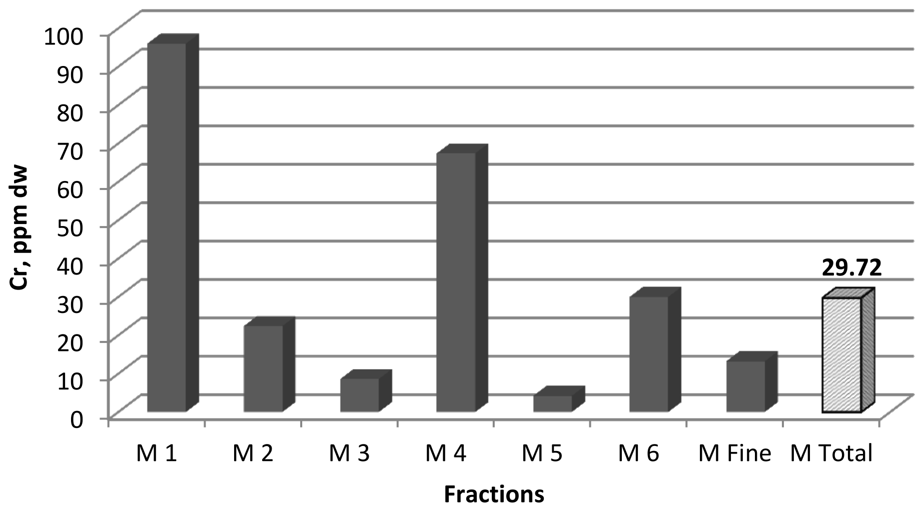

Figure 4.25 Chromium content of Mavisehir

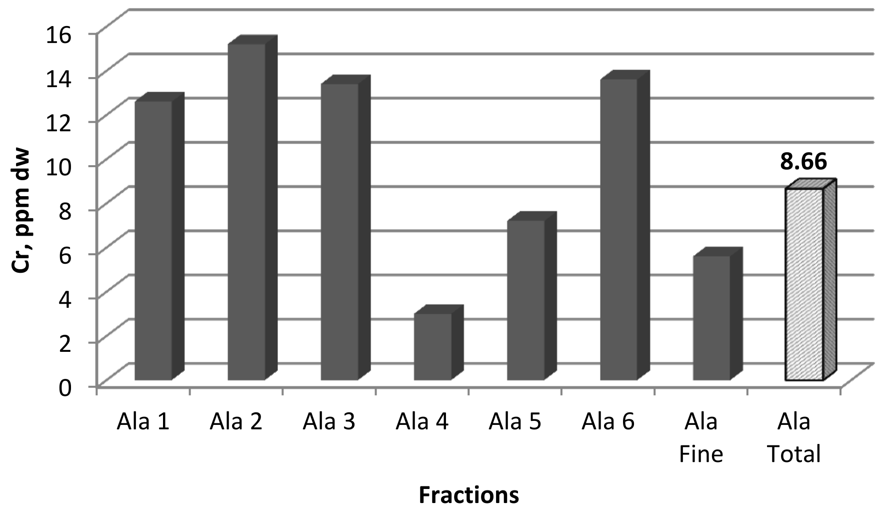

Figure 4.26 Chromium content of Alaybey

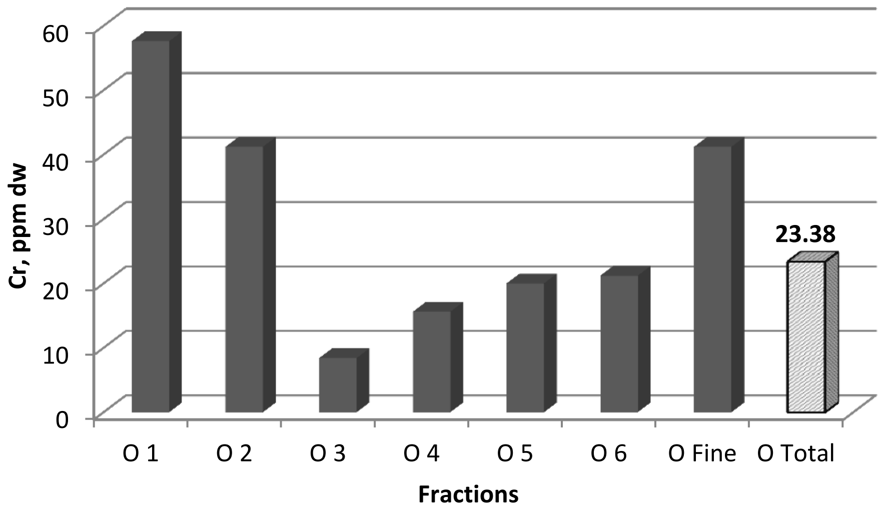

Figure 4.27 Chromium content of Ornekkoy

Chromium values of all districts are less than the limit value defined in the statement.

4.6.1.3 Cupper Content

Cupper content graphs of the districts are between the Figure 4.28 and 4.36. The limit value determined in the Statement for cupper is 500 ppm.

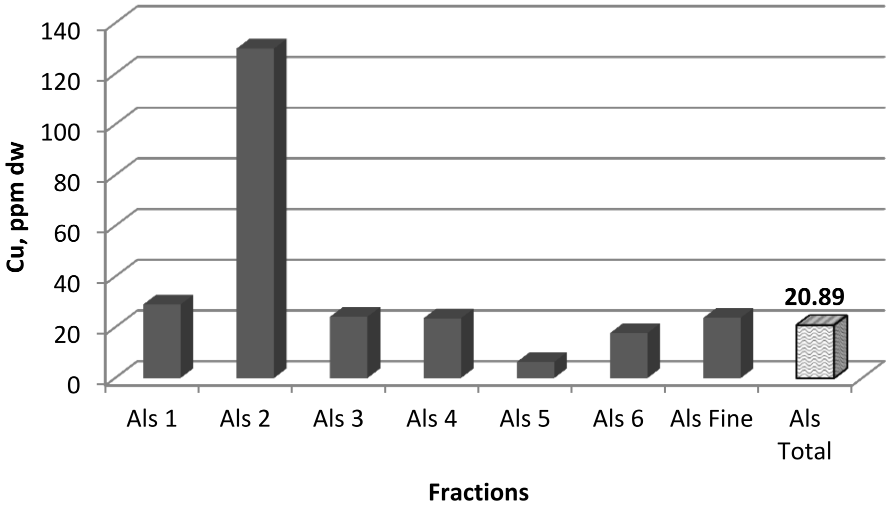

Figure 4.28 Cupper content of Alsancak

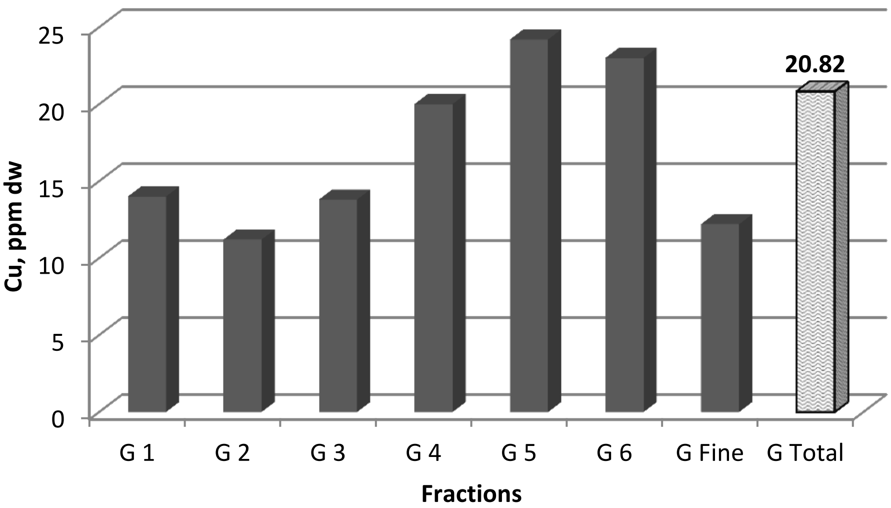

Figure 4.29 Cupper content of Guzelyali

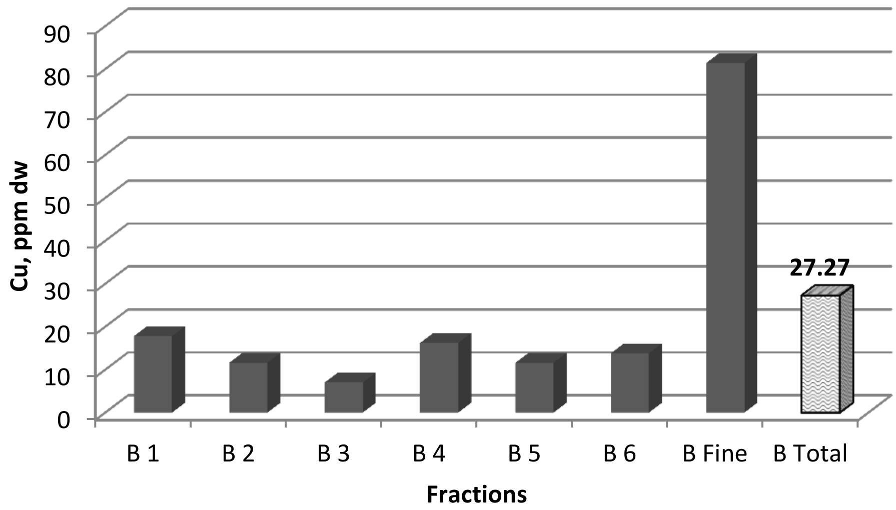

Figure 4.30 Cupper content of Basmane

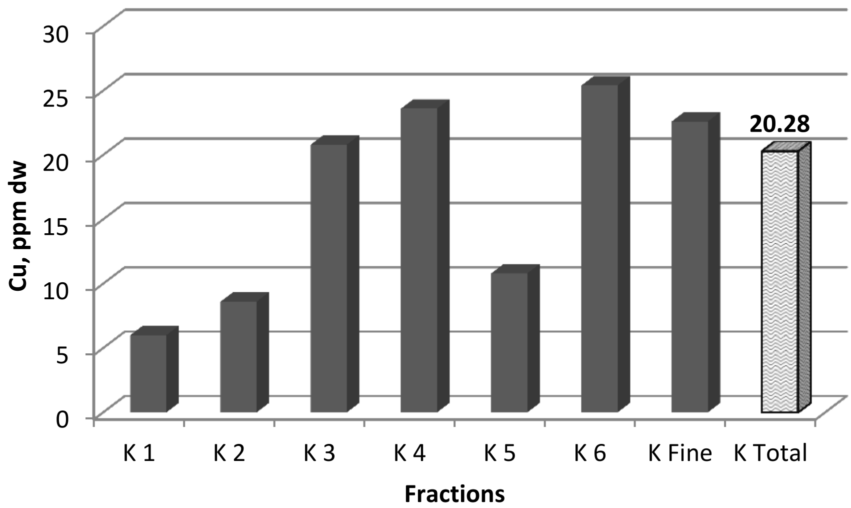

Figure 4.31 Cupper content of Kizilay

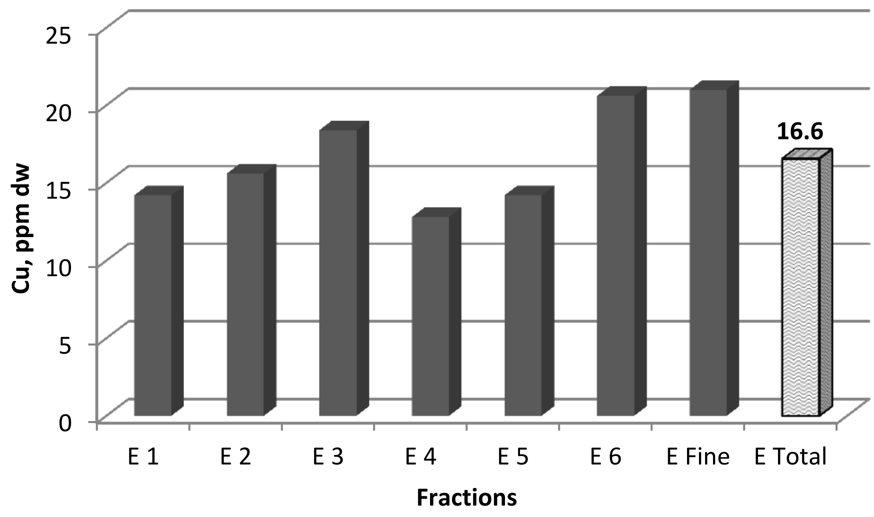

Figure 4.32 Cupper content of Erzene

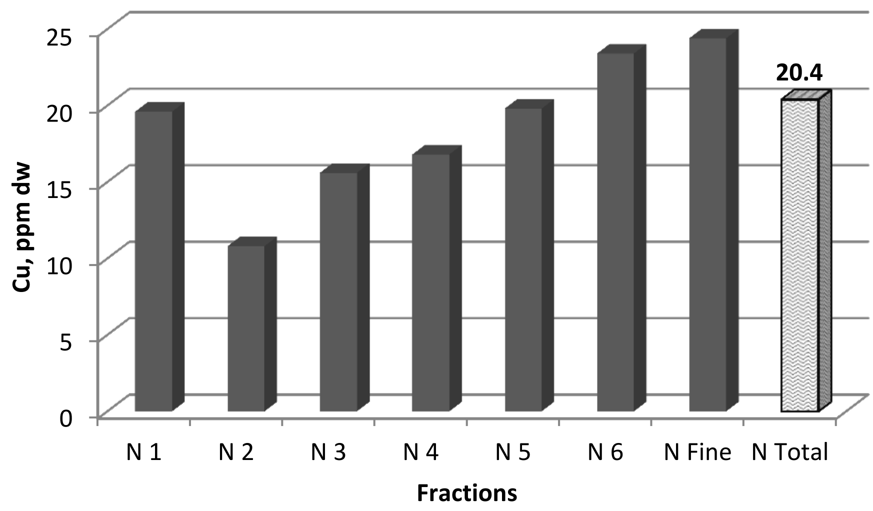

Figure 4.33 Cupper content of Naldoken

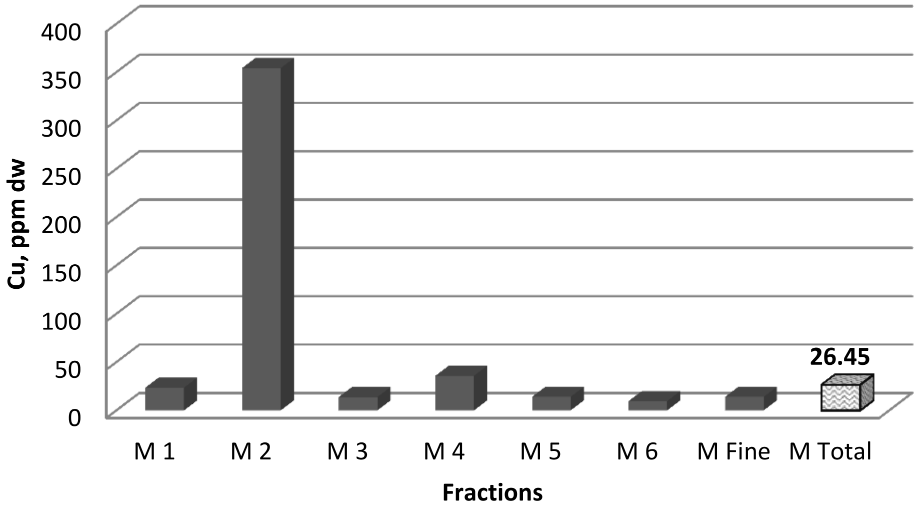

Figure 4.34 Cupper content of Mavisehir

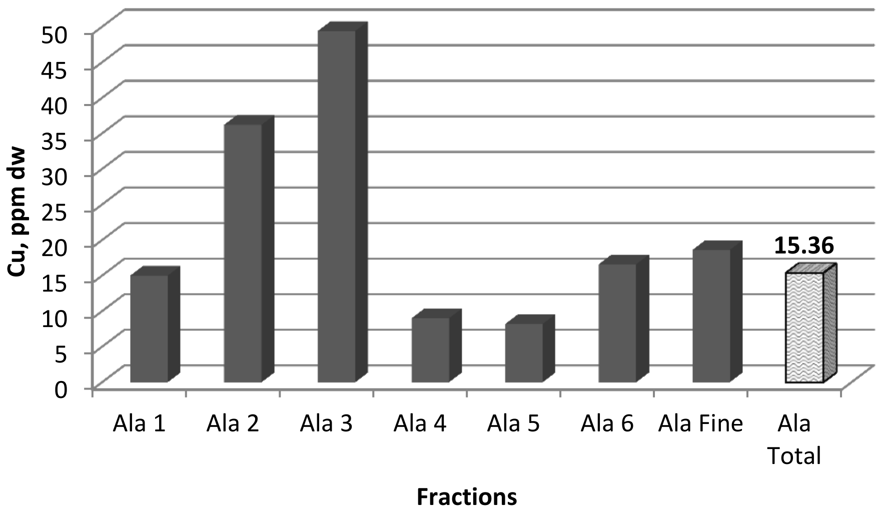

Figure 4.35 Cupper content of Alaybey

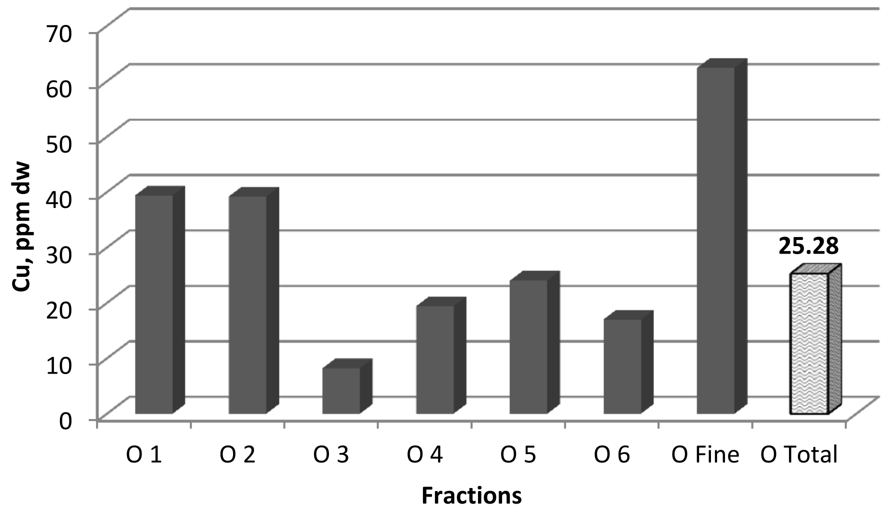

Figure 4.36 Cupper content of Ornekkoy

Cupper contents of all districts have been found less than the limit value.

4.6.1.4 Potassium Content

Potassium content graphs of the districts are between the Figure 4.37 and 4.45. No limit value is indicated in the statement of RDF.

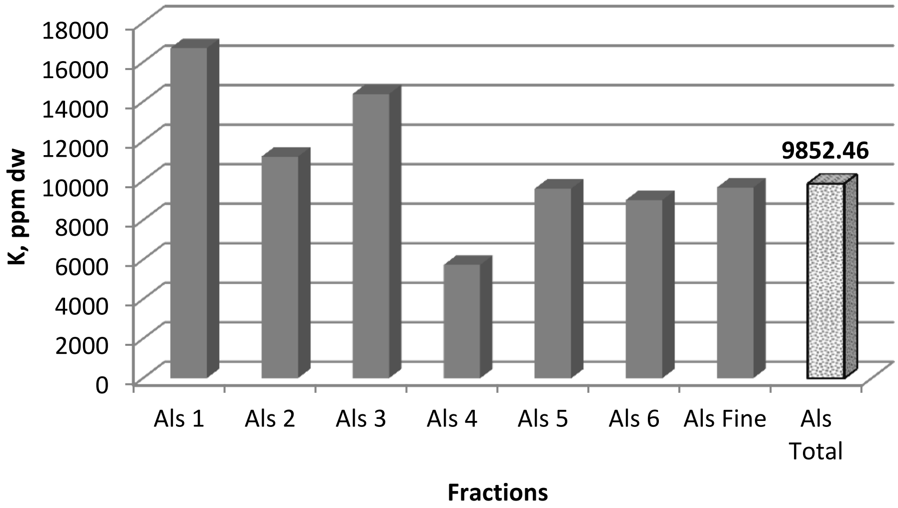

Figure 4.37 Potassium content of Alsancak

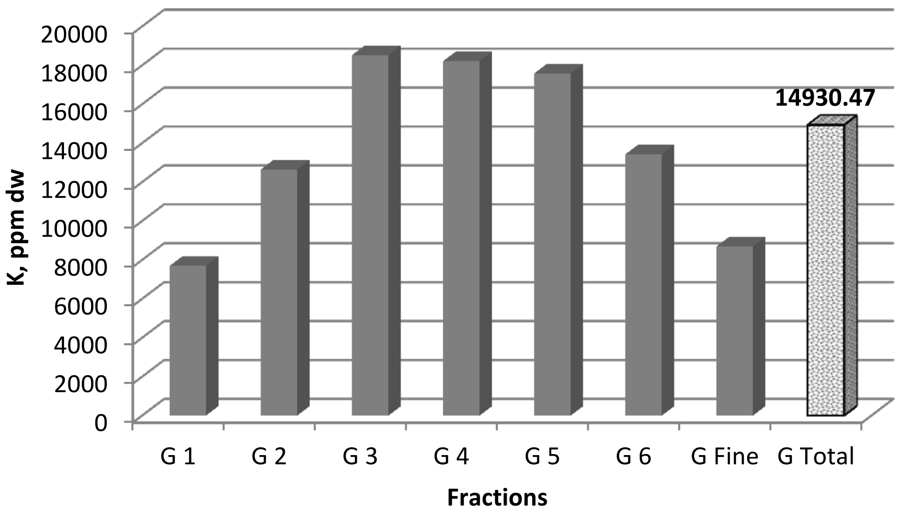

Figure 4.38 Potassium content of Guzelyali

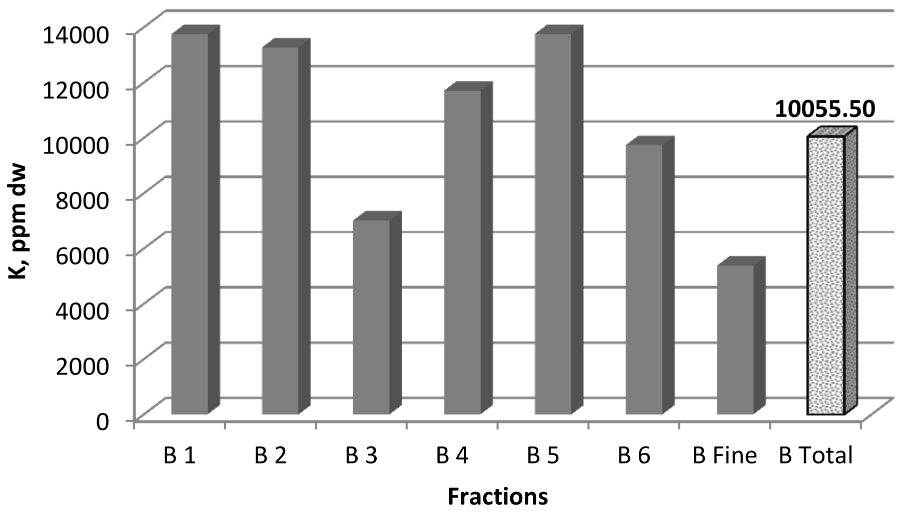

Figure 4.39 Potassium content of Basmane

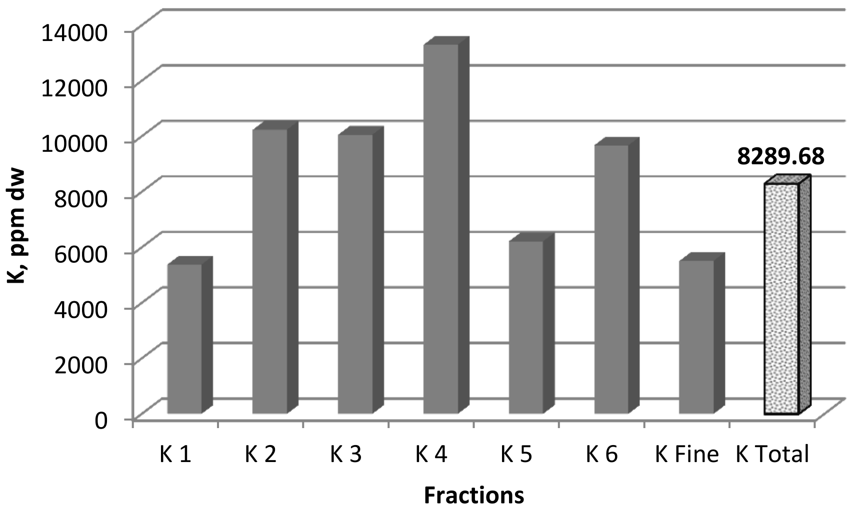

Figure 4.40 Potassium content of Kizilay

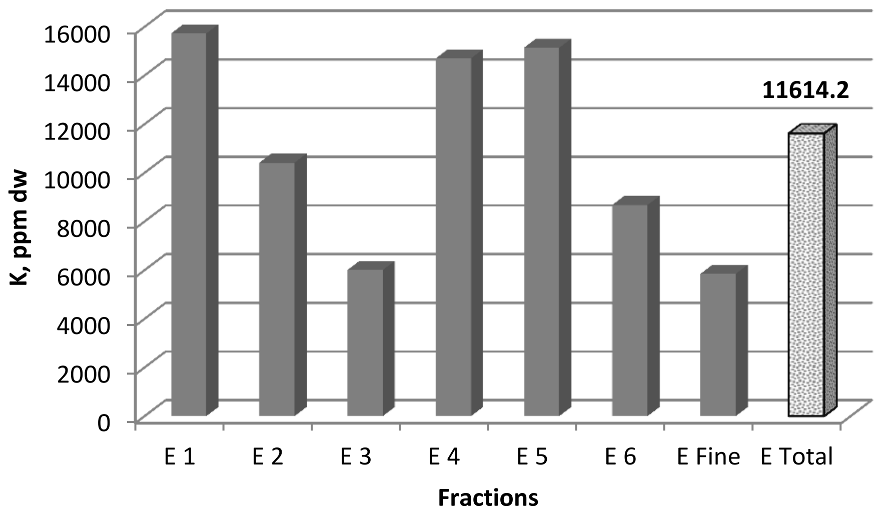

Figure 4.41 Potassium content of Erzene

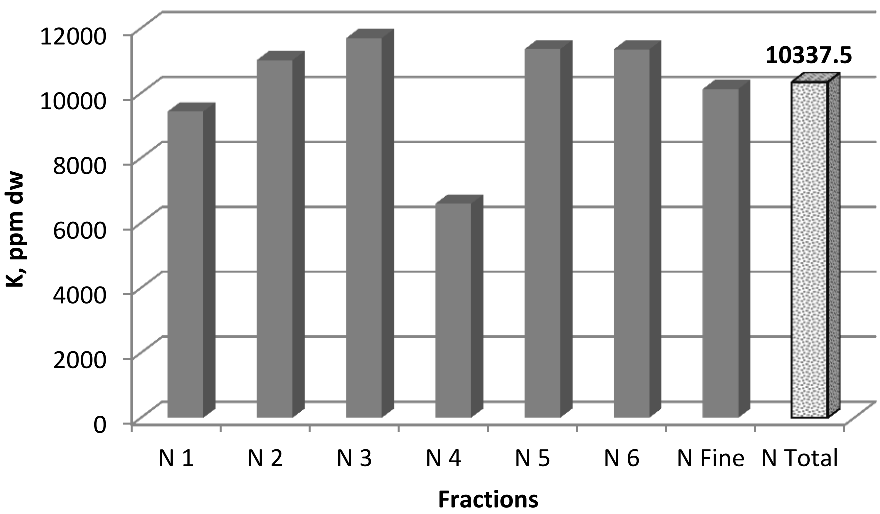

Figure 4.42 Potassium content of Naldoken

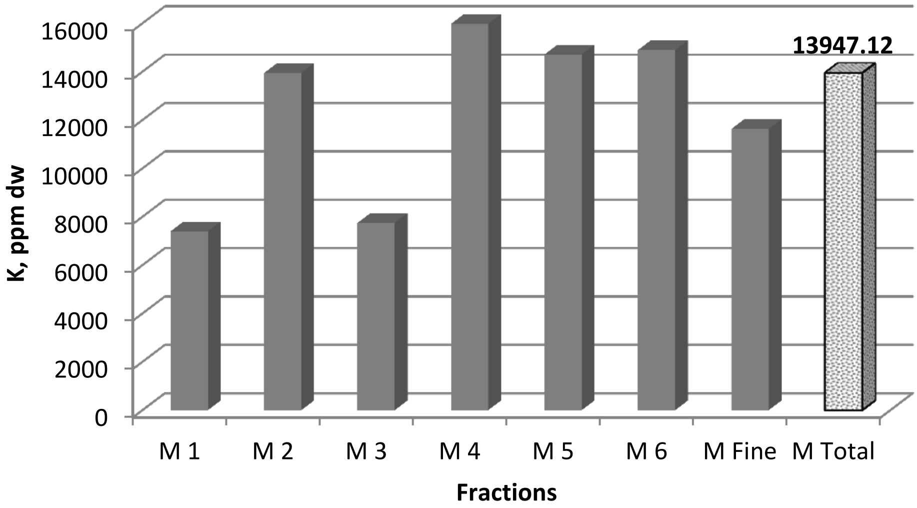

Figure 4.43 Potassium content of Mavisehir

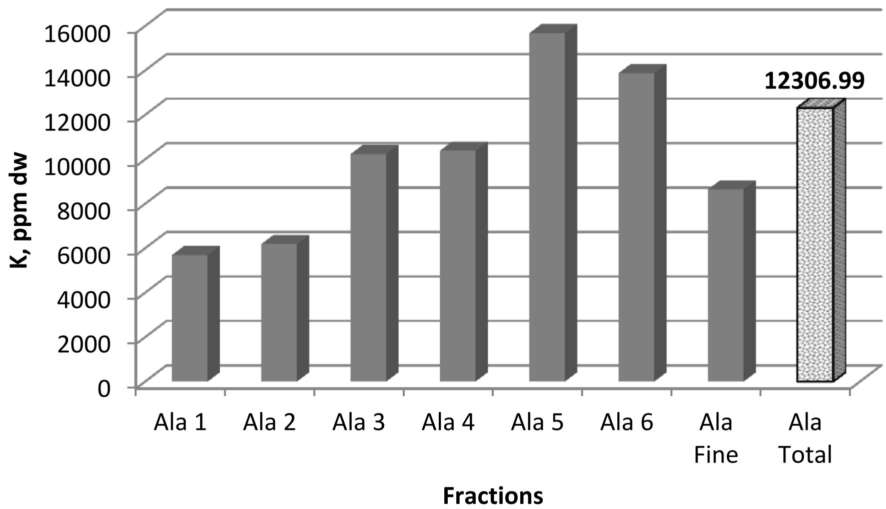

Figure 4.44 Potassium content of Alaybey

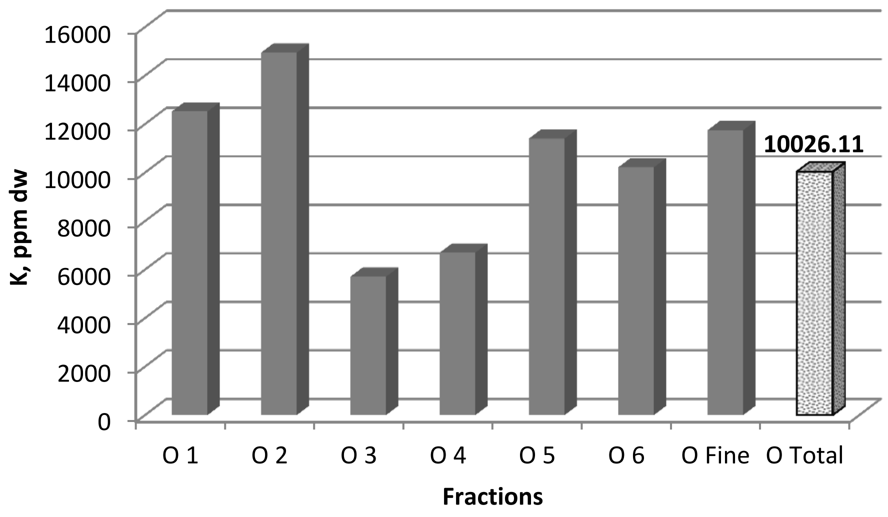

Figure 4.45 Potassium content of Ornekkoy

4.6.1.5 Manganese Content

Manganese content graphs of the districts starts from the Figure 4.46 to 4.54. There is no limit value defined in the statement; however there is a limit value determined by Italy as 400 ppm.

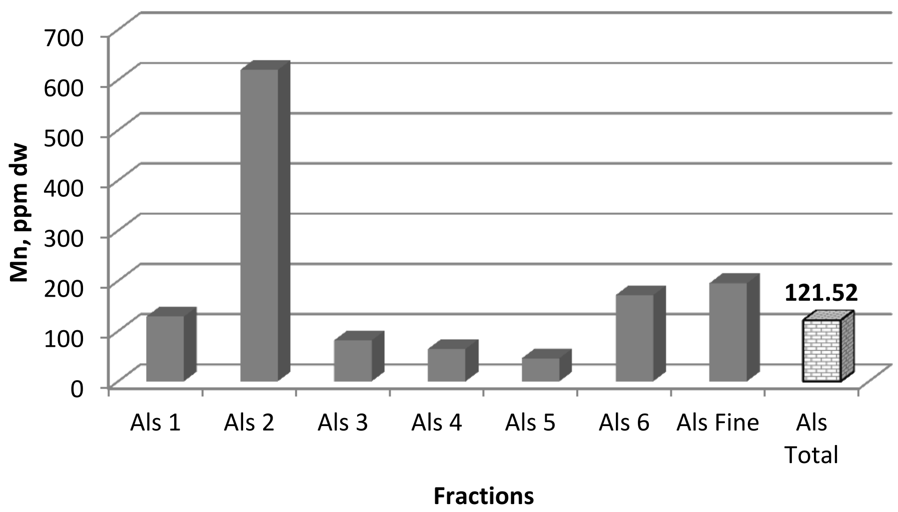

Figure 4.46 Manganese content of Alsancak

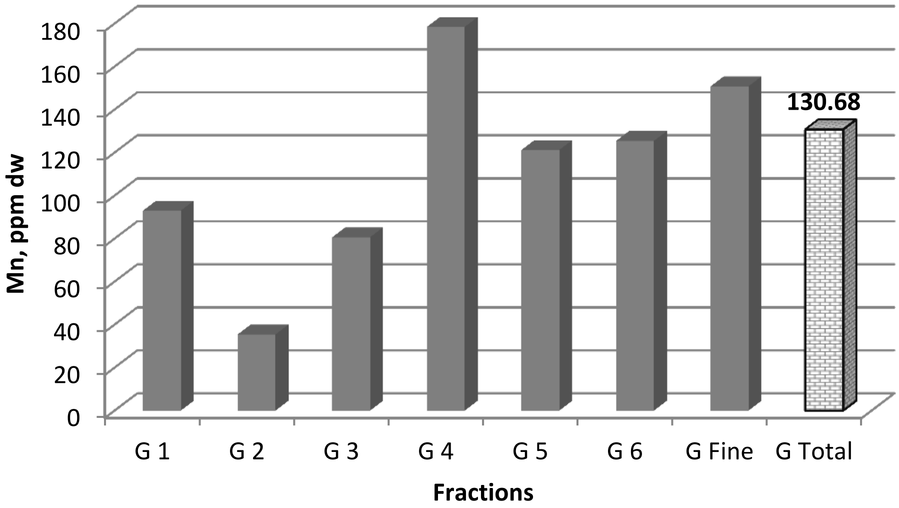

Figure 4.47 Manganese content of Guzelyali

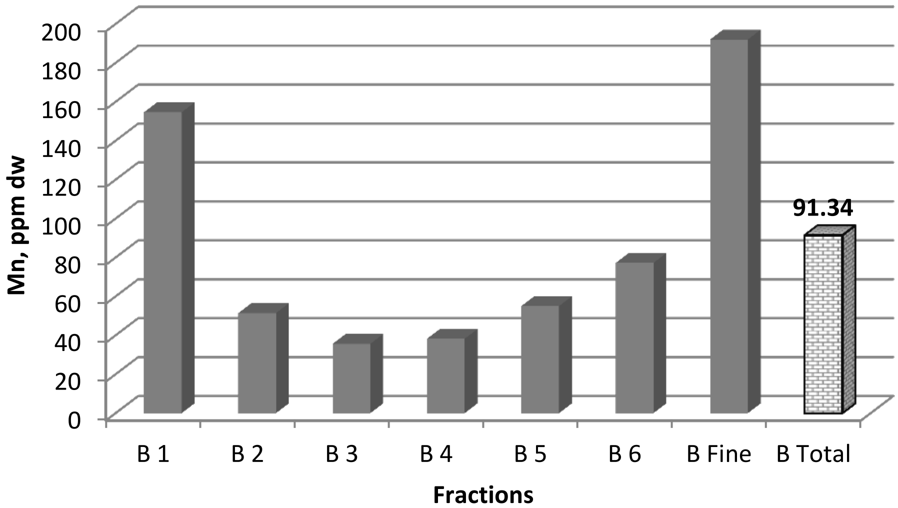

Figure 4.48 Manganese content of Basmane

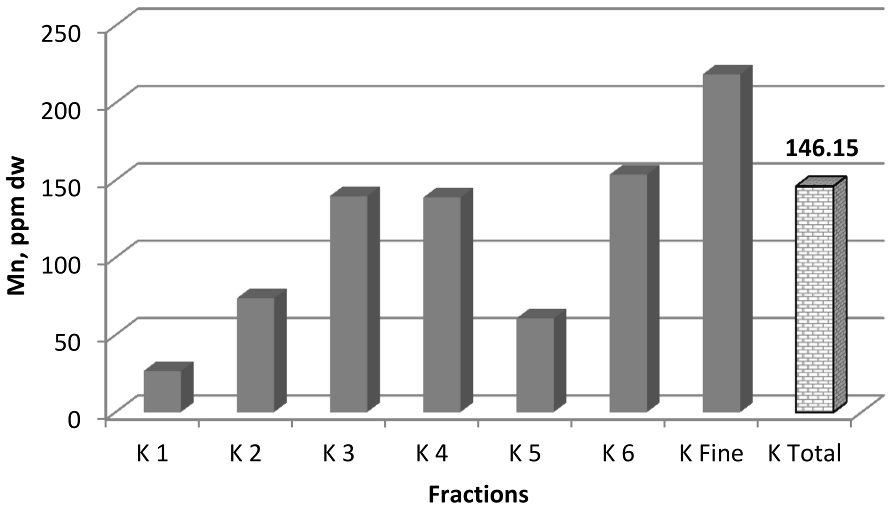

Figure 4.49 Manganese content of Kizilay

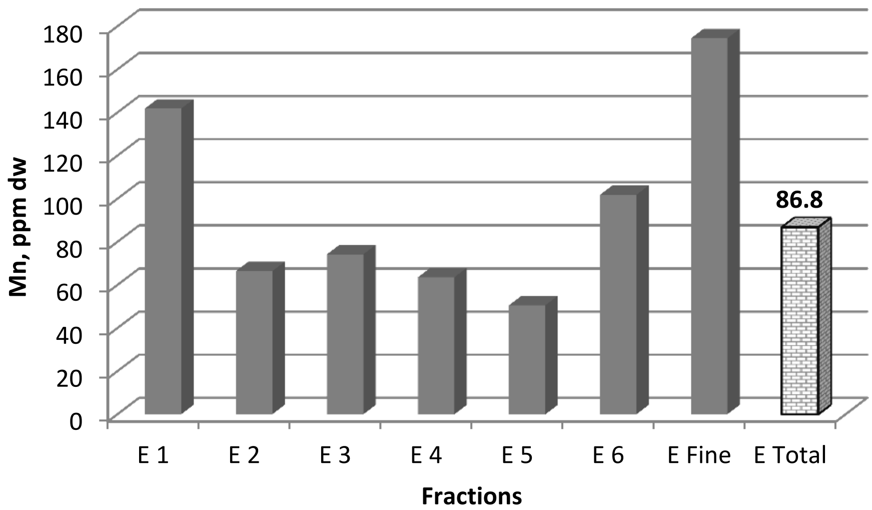

Figure 4.50 Manganese content of Erzene

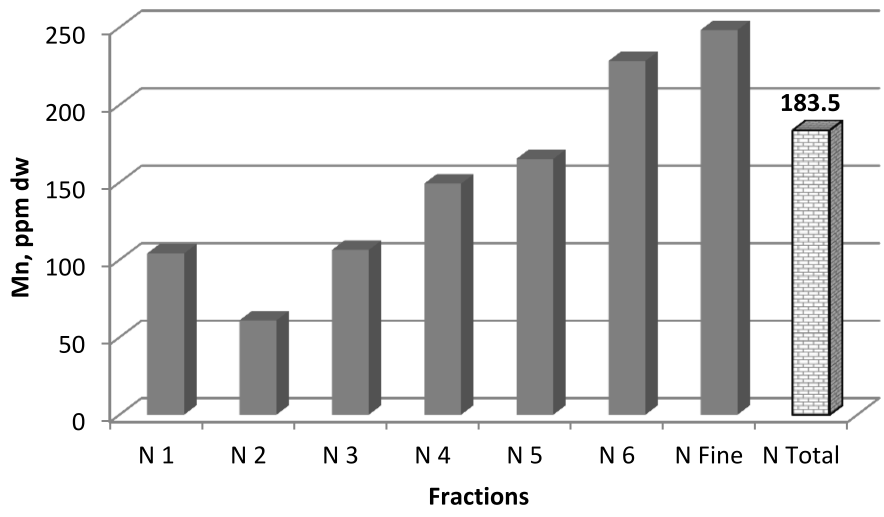

Figure 4.51 Manganese content of Naldoken

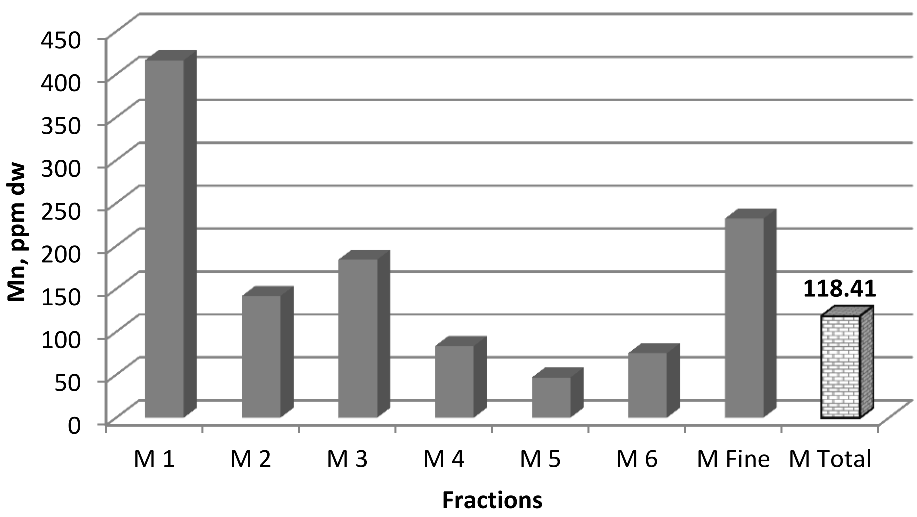

Figure 4.52 Manganese content of Mavisehir

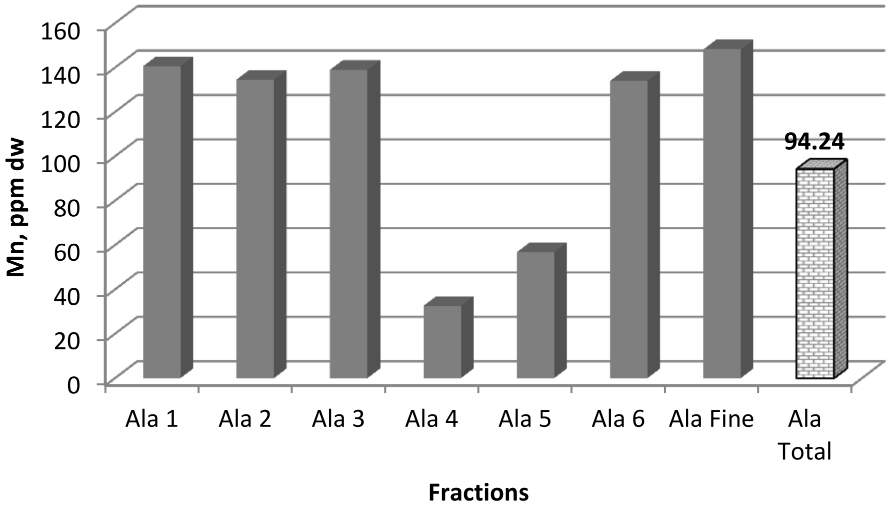

Figure 4.53 Manganese content of Alaybey

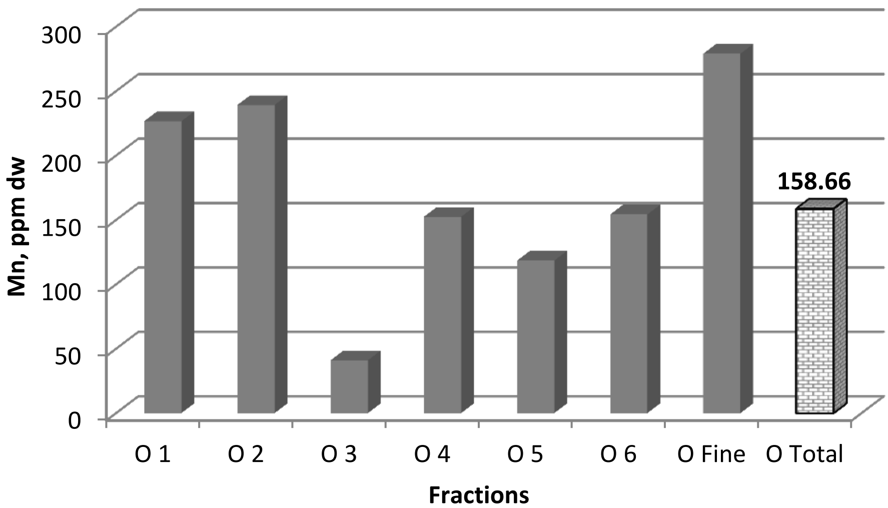

Figure 4.54 Manganese content of Ornekkoy

According to limit value defined by Italy, the manganese values of 2nd fraction of Alsancak and fine fraction of Mavisehir exceed the limit.

4.6.1.6 Sodium Content

Sodium content graphs of the districts starts from the Figure 4.55 to 4.63. No limit value for sodium is determined in the statement of RDF.

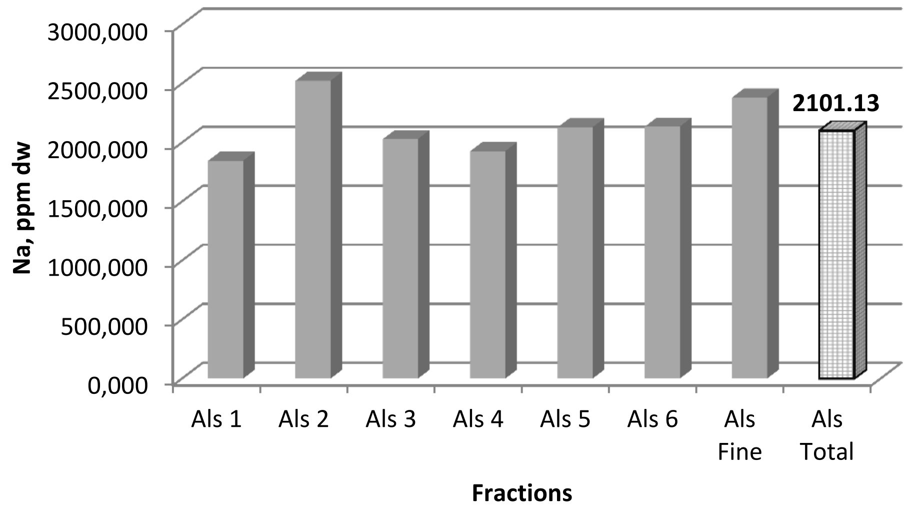

Figure 4.55 Sodium content of Alsancak

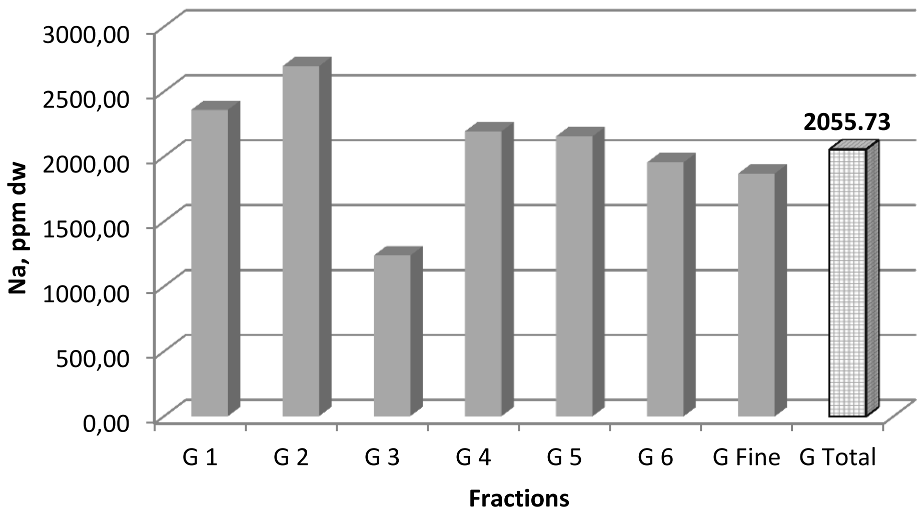

Figure 4.56 Sodium content of Guzelyali

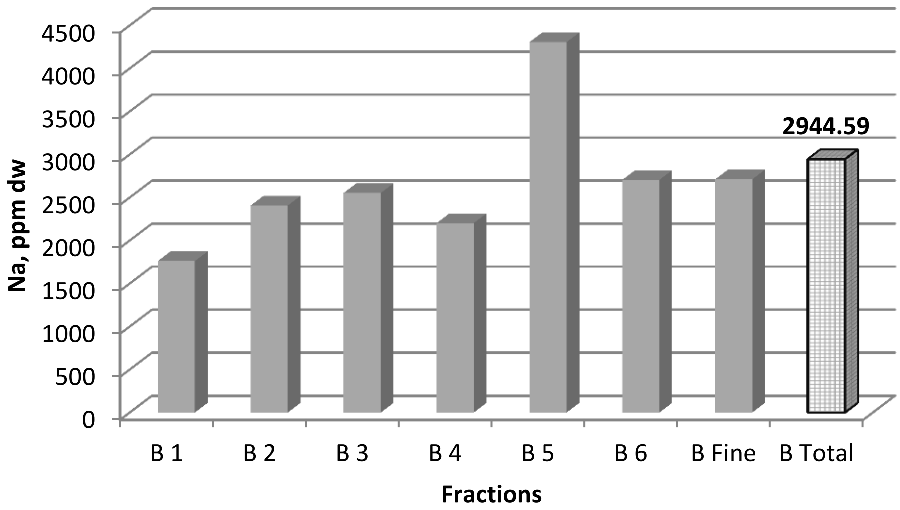

Figure 4.57 Sodium content of Basmane

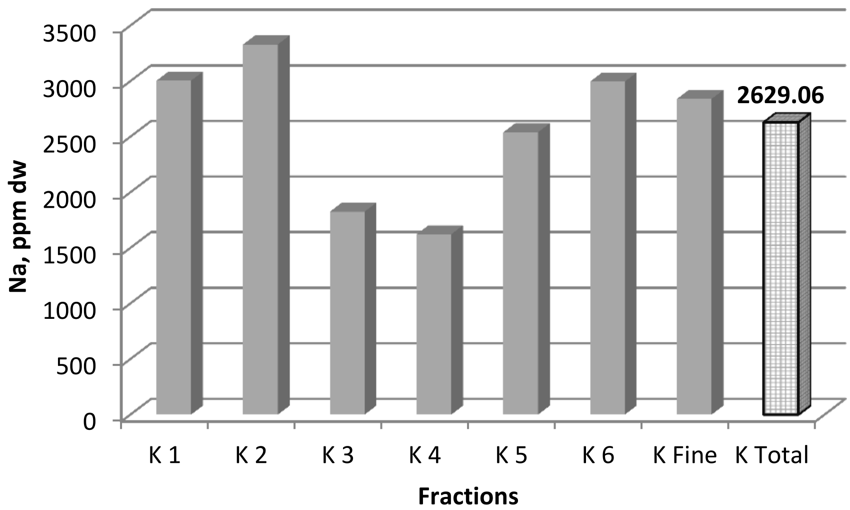

Figure 4.58 Sodium content of Kizilay

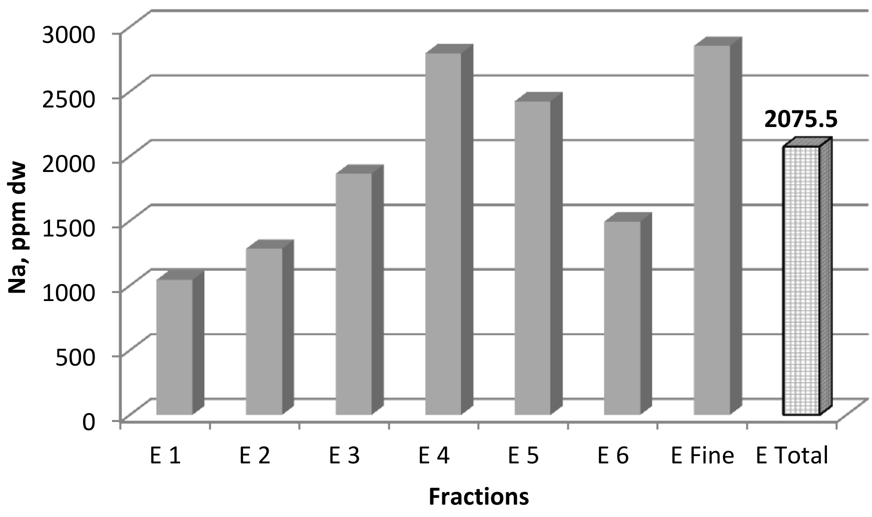

Figure 4.59 Sodium content of Erzene

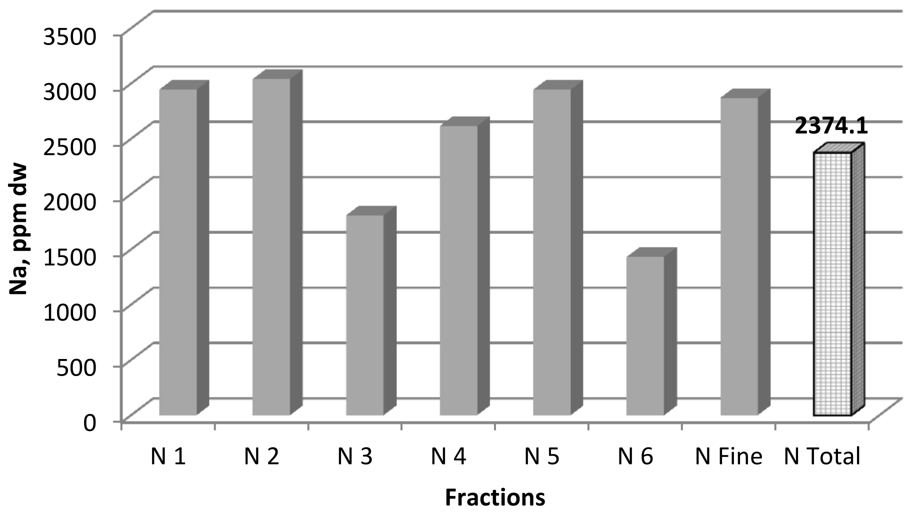

Figure 4.60 Sodium content of Naldoken

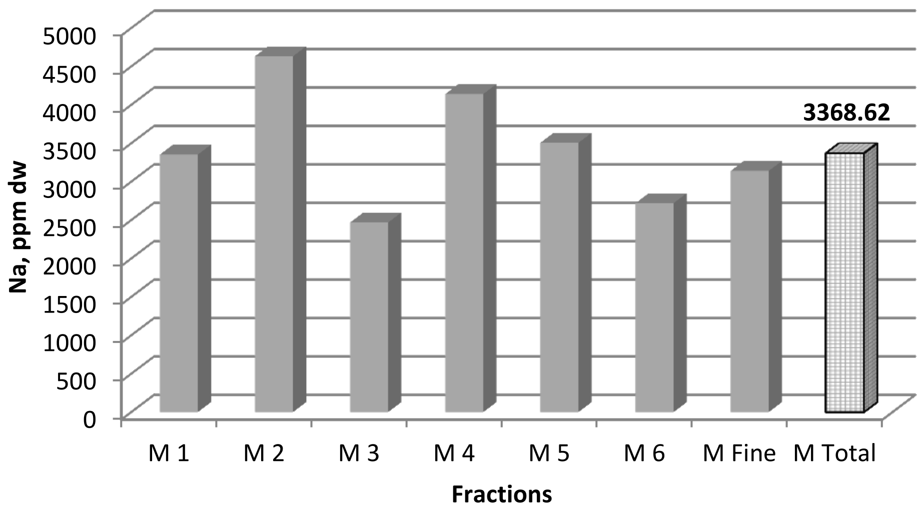

Figure 4.61 Sodium content of Mavisehir

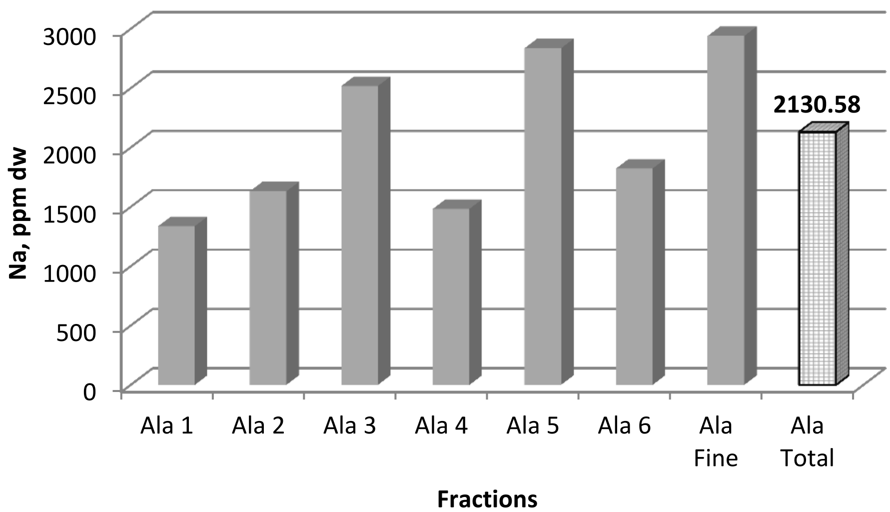

Figure 4.62 Sodium content of Alaybey

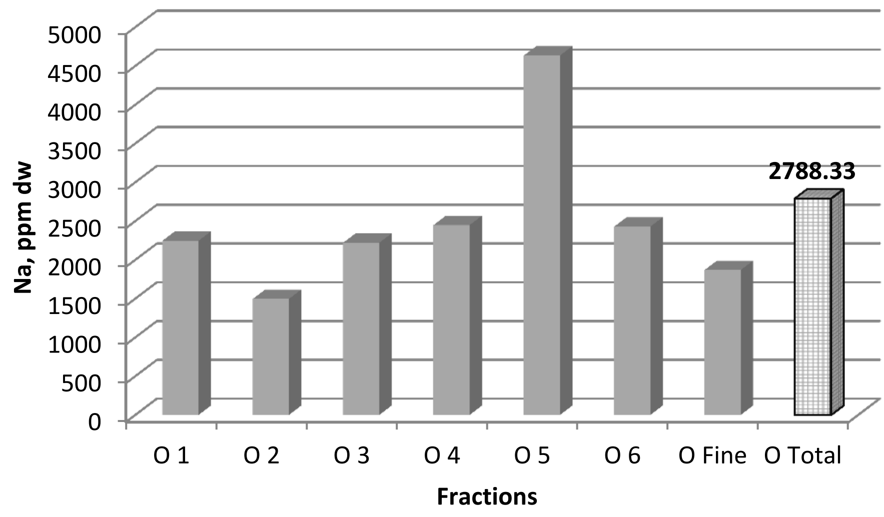

Figure 4.63 Sodium content of Ornekkoy

4.6.1.7 Nickel Content

Nickel content graphs of the districts are between the Figure 4.64 and 4.72. The limit value defined for nickel in the Statement of RDF is 300 ppm.

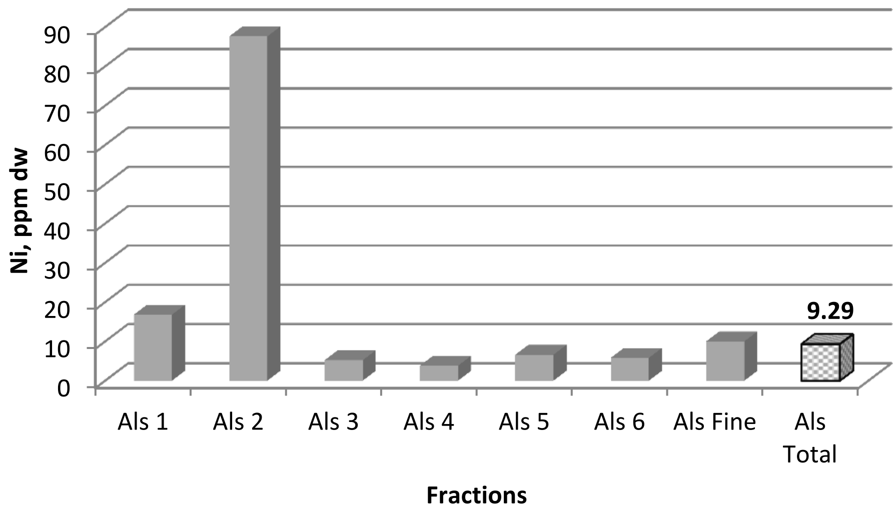

Figure 4.64 Nickel content of Alsancak

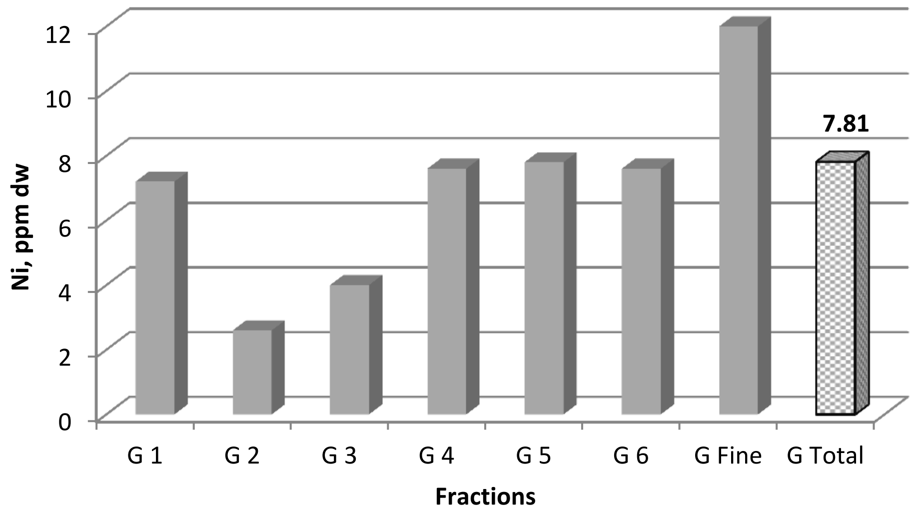

Figure 4.65 Nickel content of Guzelyali

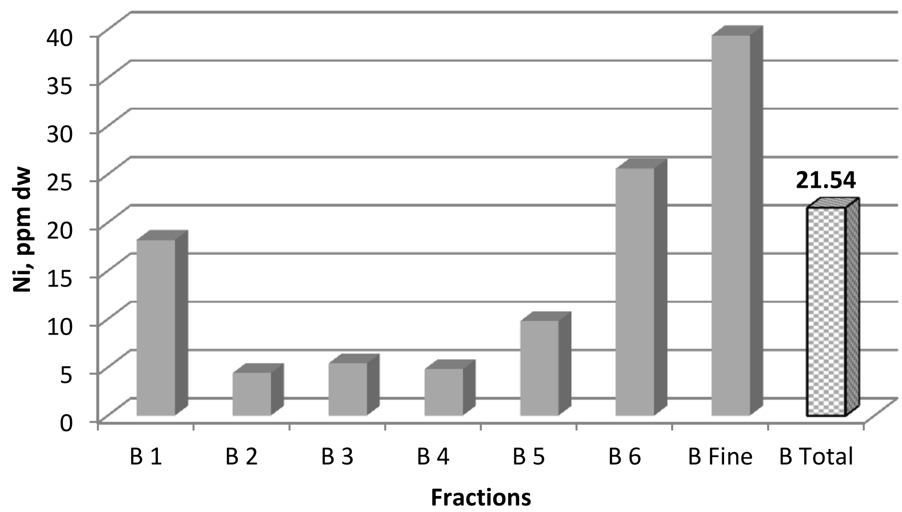

Figure 4.66 Nickel content of Basmane

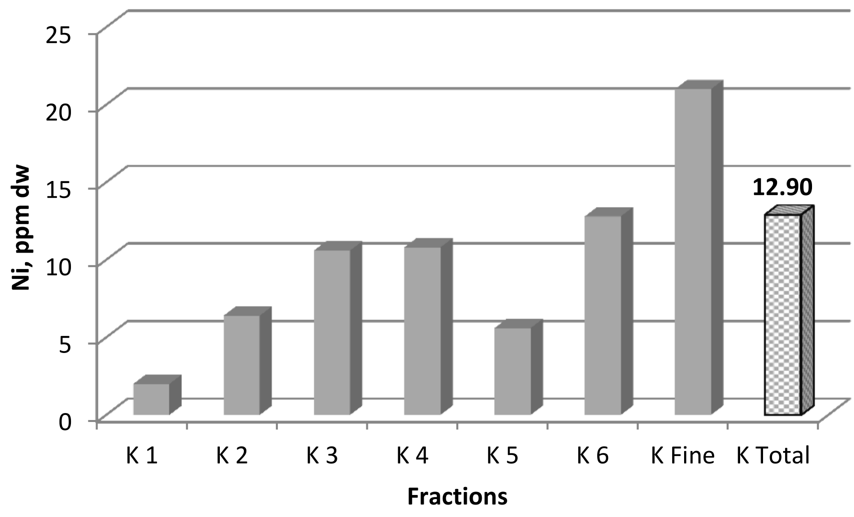

Figure 4.67 Nickel content of Kizilay

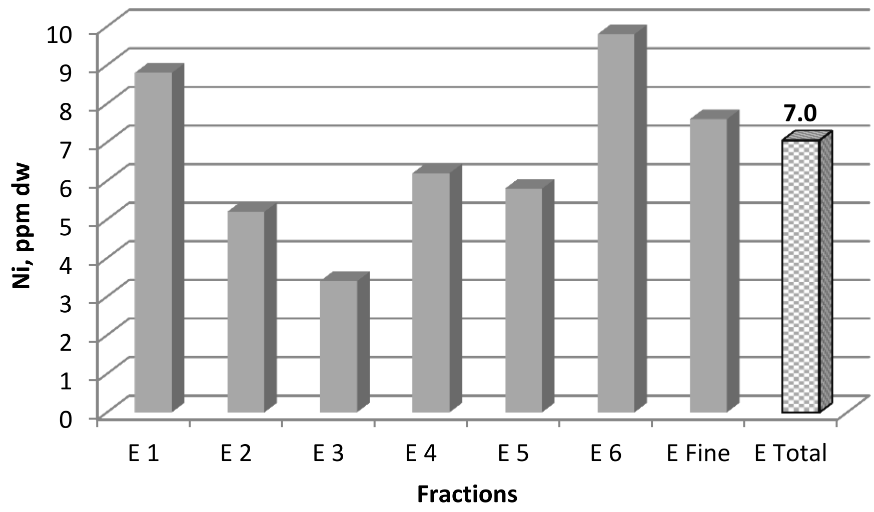

Figure 4.68 Nickel content of Erzene

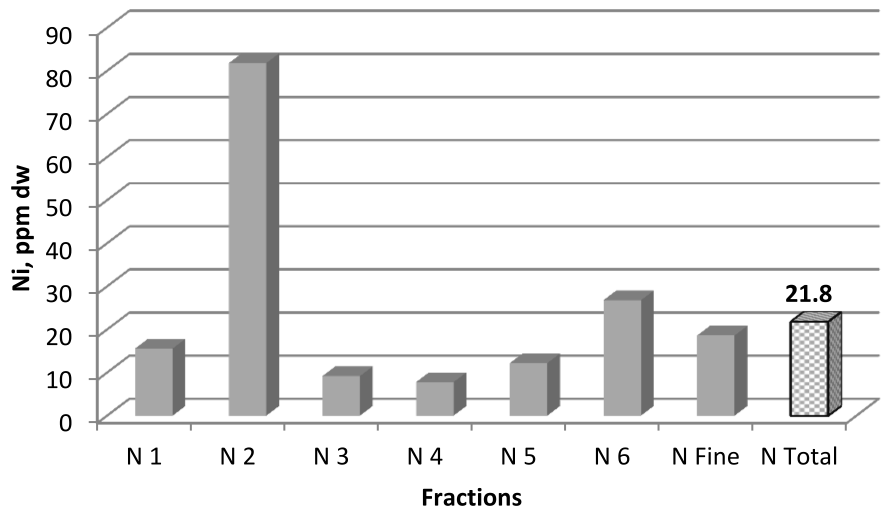

Figure 4.69 Nickel content of Naldoken

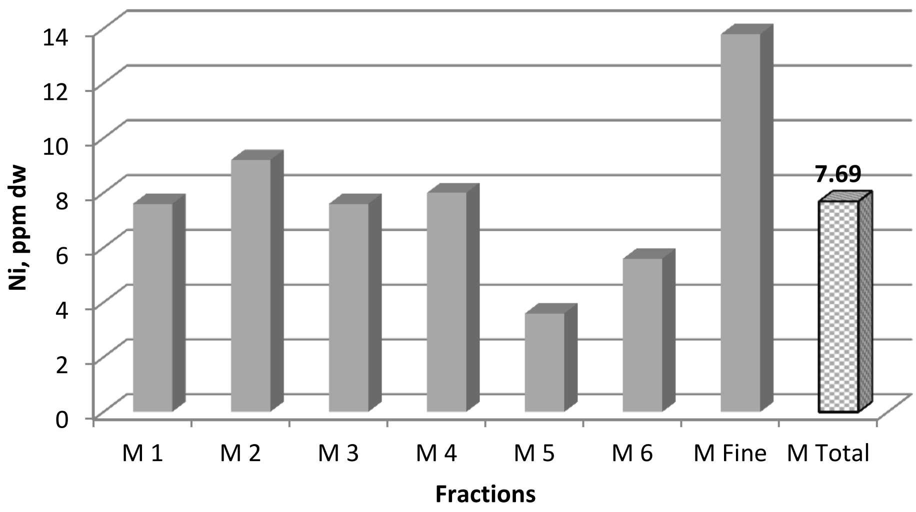

Figure 4.70 Nickel content of Mavisehir

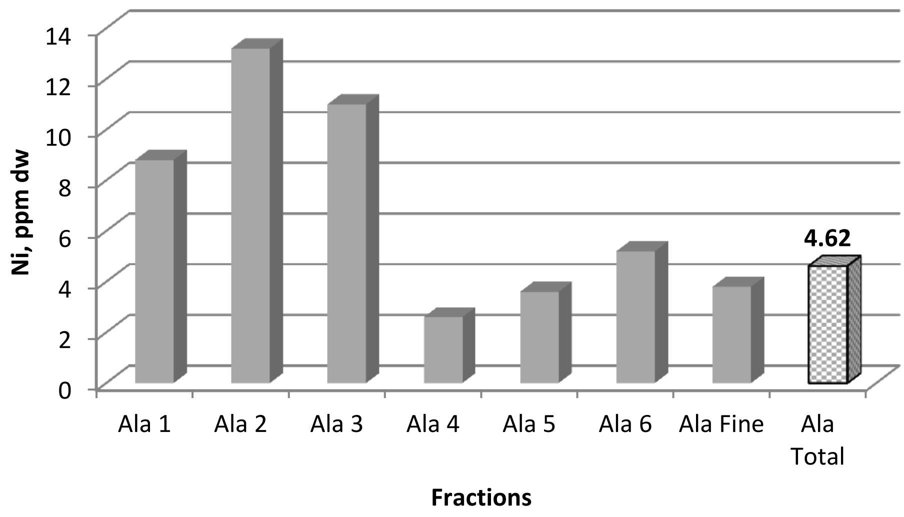

Figure 4.71 Nickel content of Alaybey

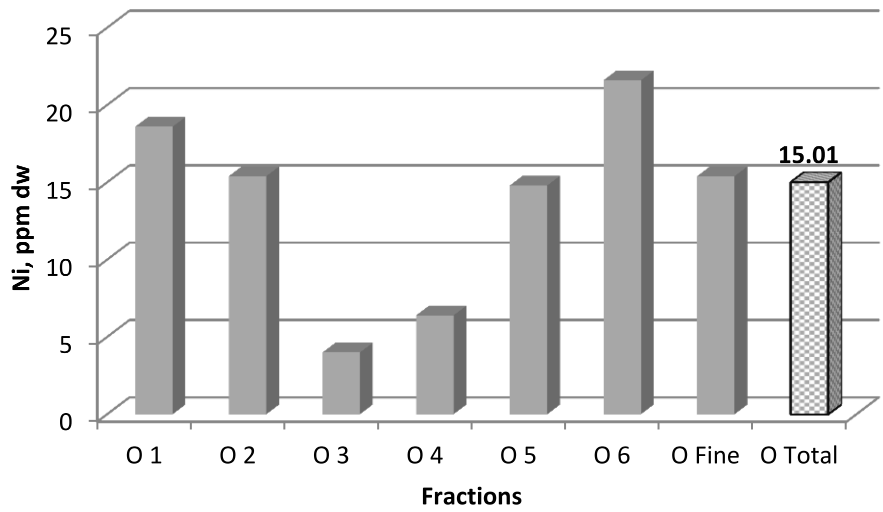

Figure 4.72 Nickel content of Ornekkoy

4.6.1.8 Lead Content

Lead content graphs of the districts starts from the Figure 4.73 to 4.81. The limit value for lead indicated in the statement is 600 ppm.

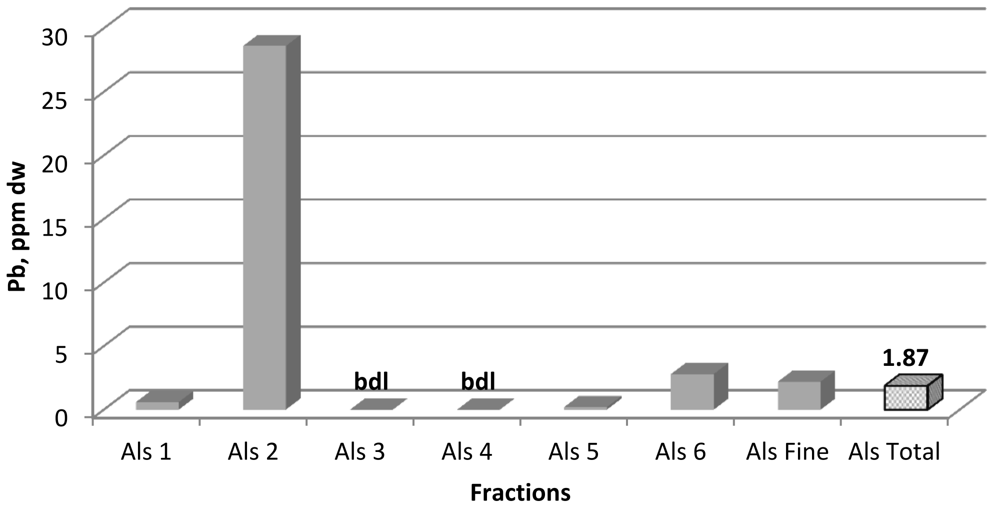

Figure 4.73 Lead content of Alsancak

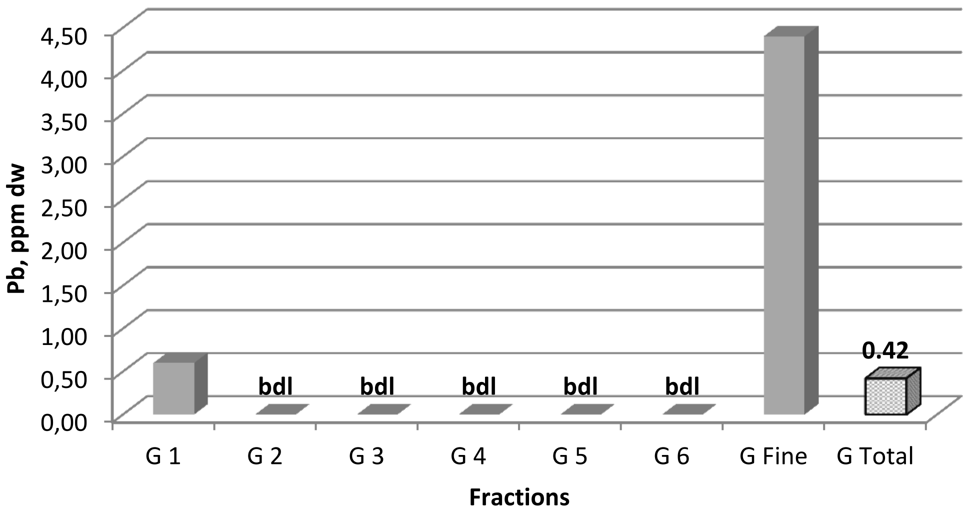

Figure 4.74 Lead content of Guzelyali

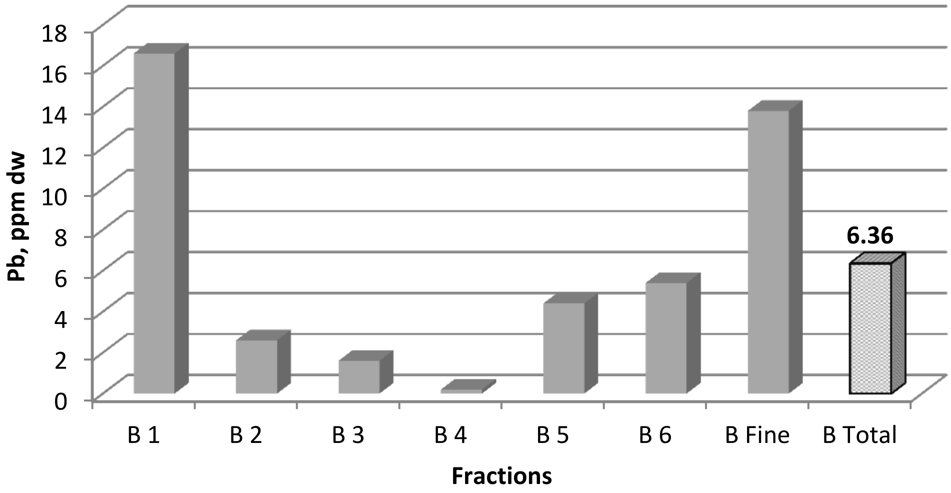

Figure 4.75 Lead content of Basmane

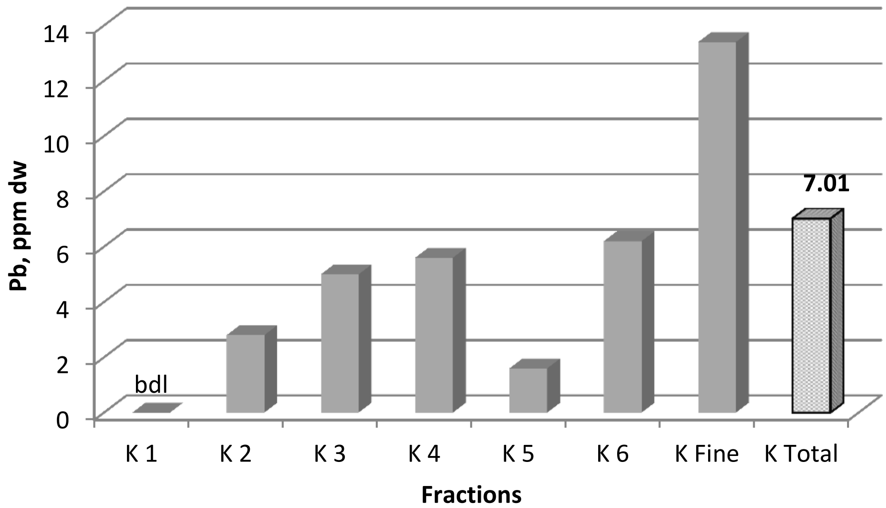

Figure 4.76 Lead content of Kizilay

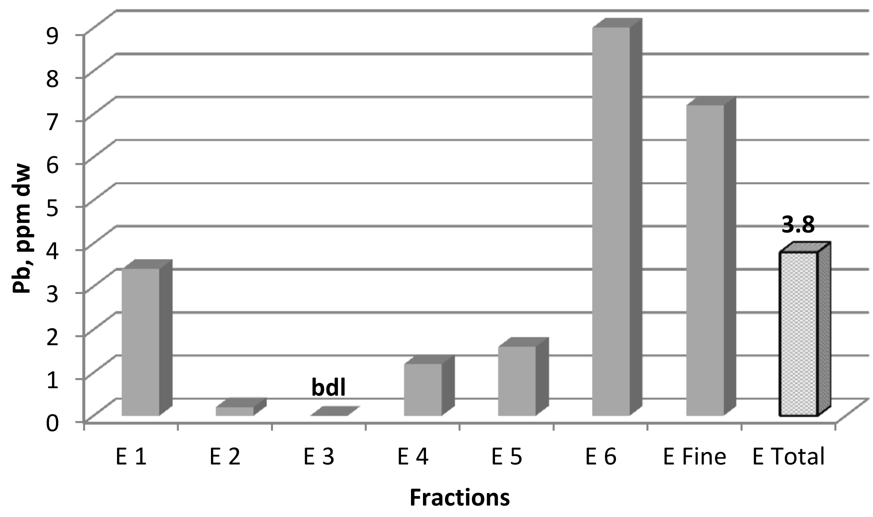

Figure 4.77 Lead content of Erzene

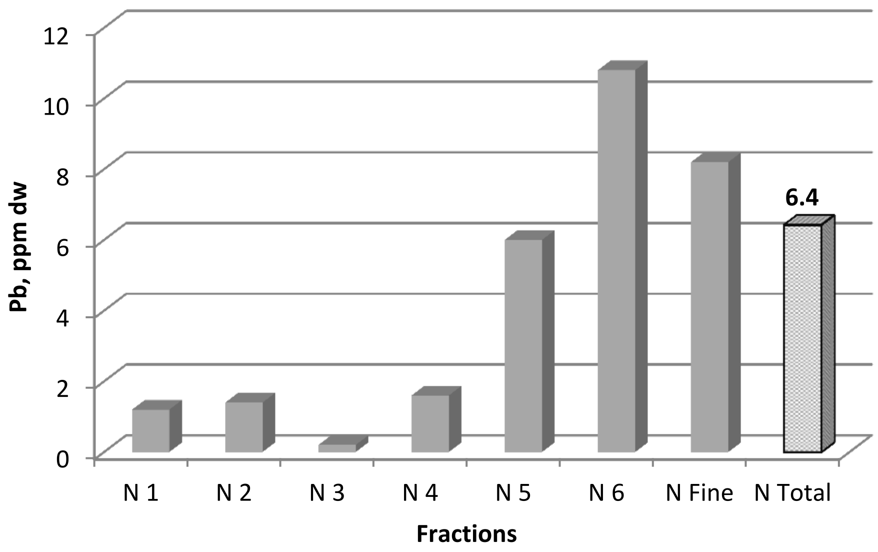

Figure 4.78 Lead content of Naldoken

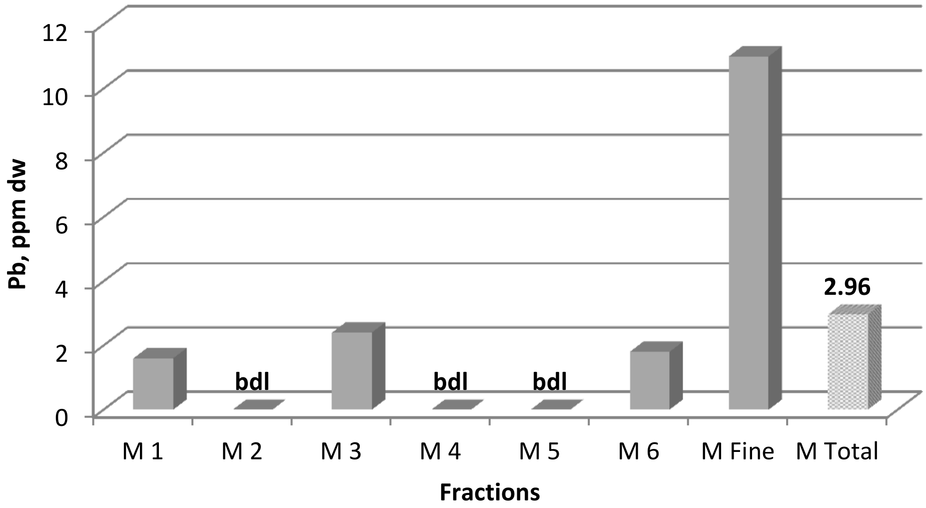

Figure 4.79 Lead content of Mavisehir

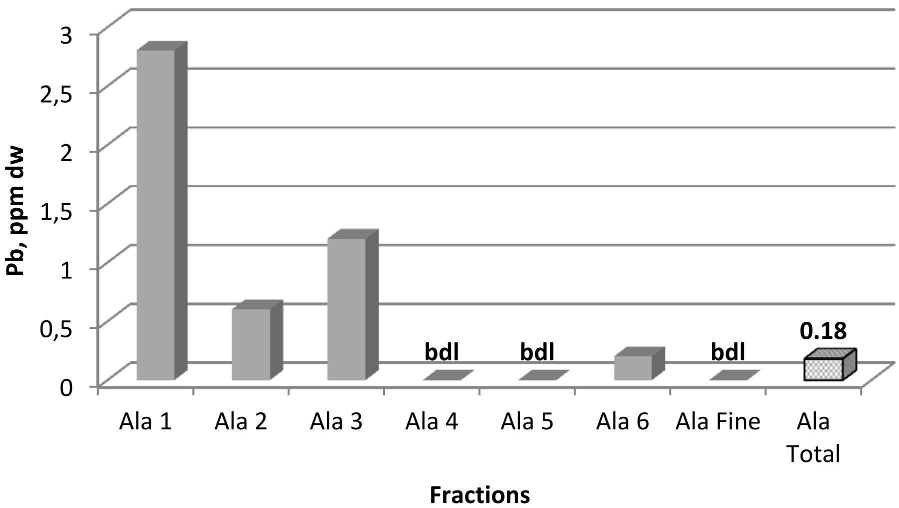

Figure 4.80 Lead content of Alaybey

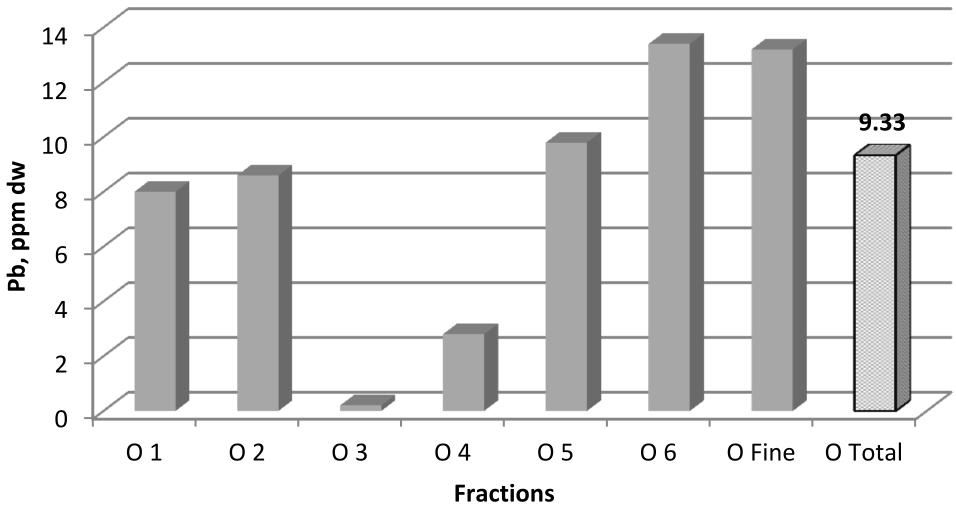

Figure 4.81 Lead content of Ornekkoy

4.6.1.9 Zinc Content

Zinc content graphs of the districts are from the Figure 4.82 to 4.90. 4000 ppm is defined as the limit value of zinc in the Statement.

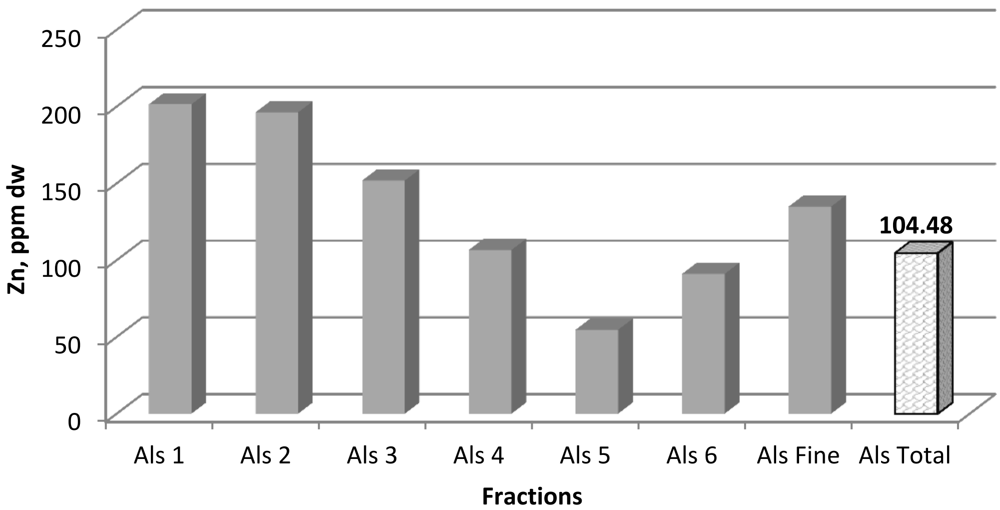

Figure 4.82 Zinc content of Alsancak

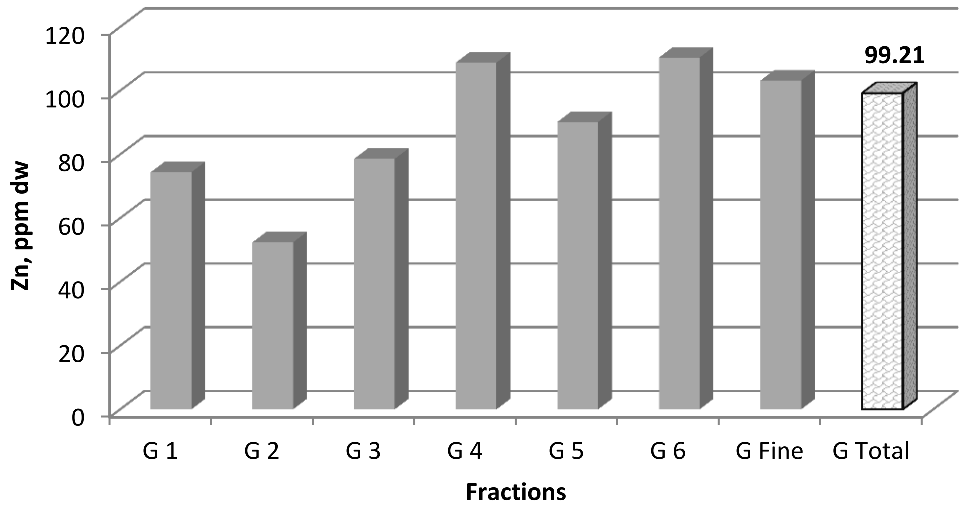

Figure 4.83 Zinc content of Guzelyali

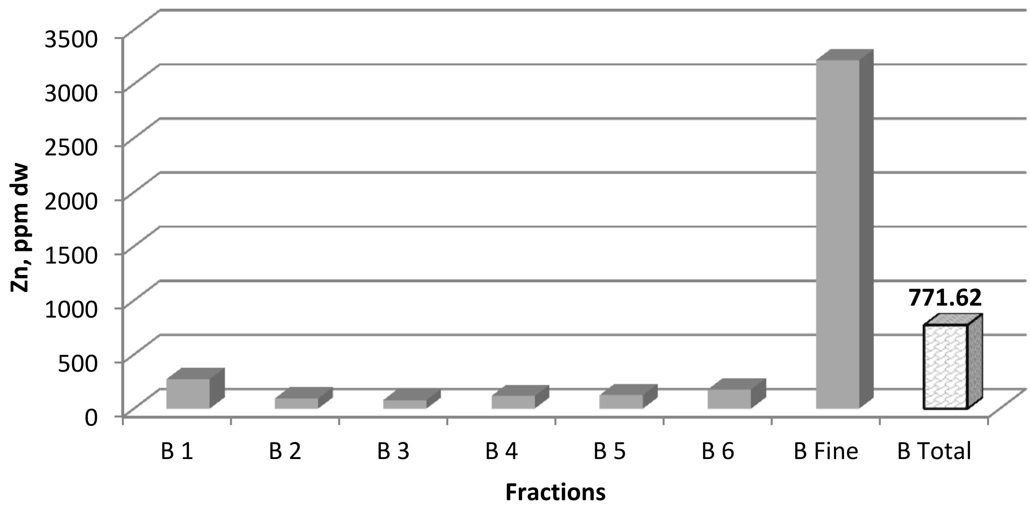

Figure 4.84 Zinc content of Basmane

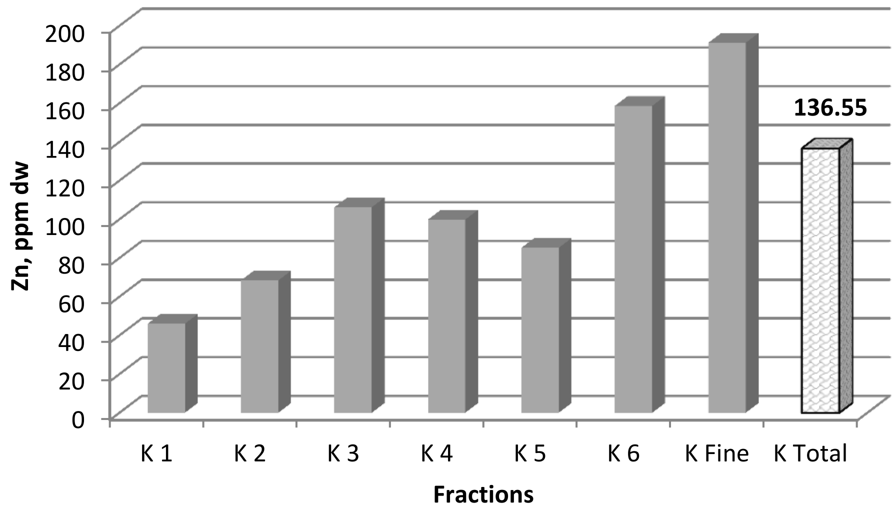

Figure 4.85 Zinc content of Kizilay

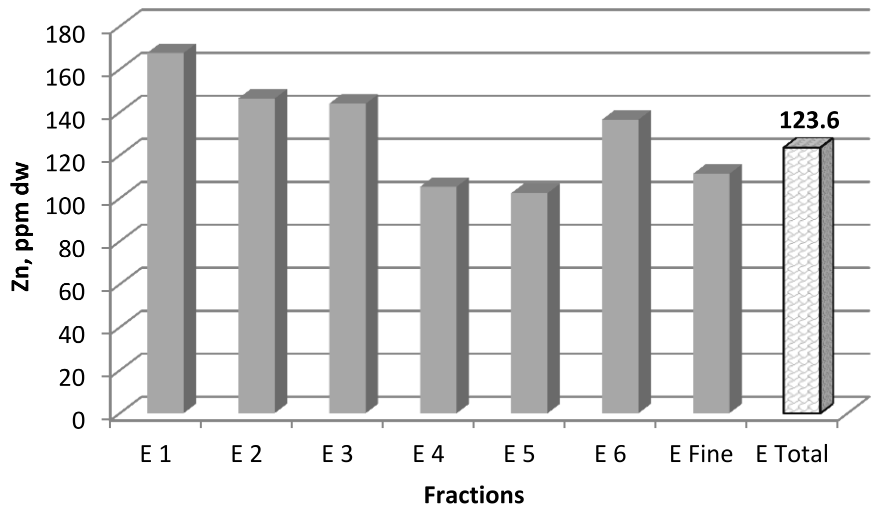

Figure 4.86 Zinc content of Erzene

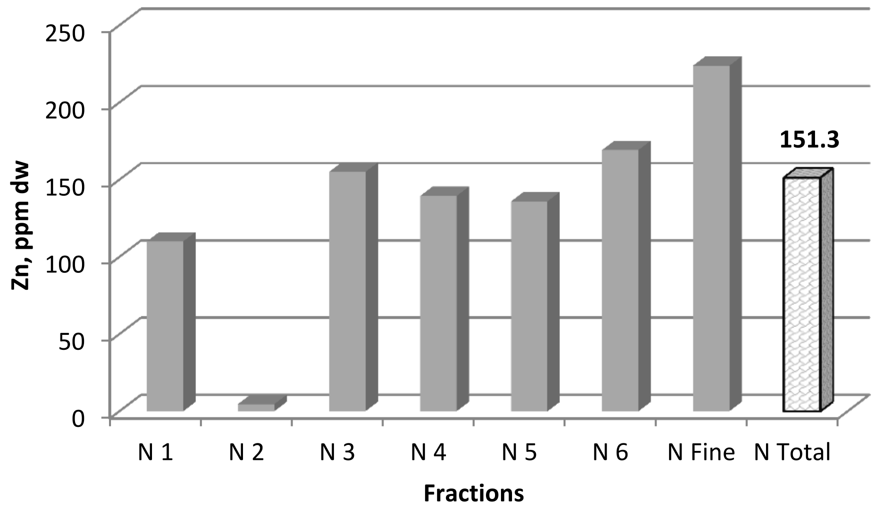

Figure 4.87 Zinc content of Naldoken

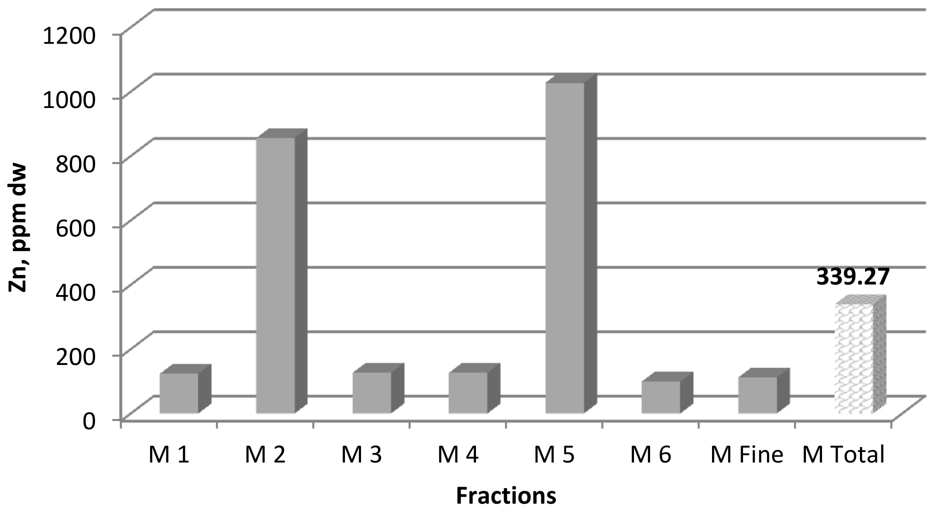

Figure 4.88 Zinc content of Mavisehir

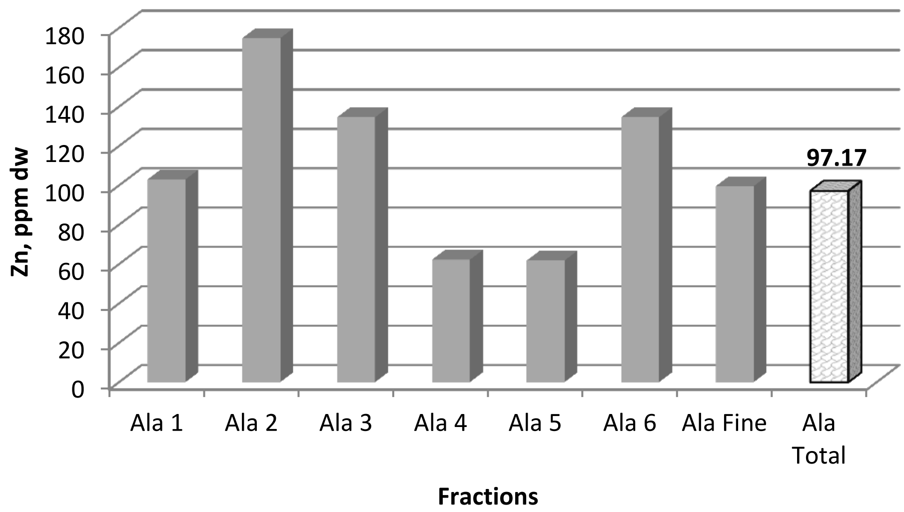

Figure 4.89 Zinc content of Alaybey

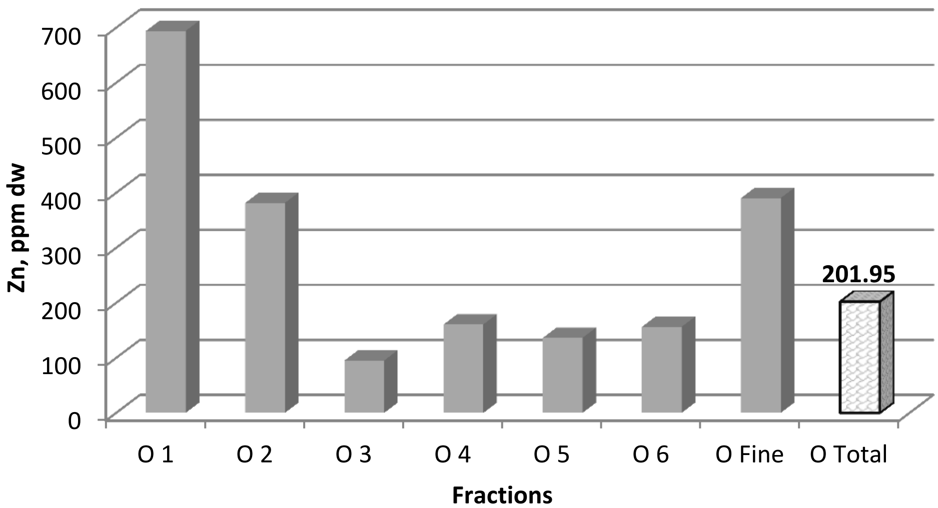

Figure 4.90 Zinc content of Ornekkoy

The zinc contents of the samples are under the limit defined in the statement.

4.6.1.10 Aluminum Content

Alumium content graphs of the districts are between the Figure 4.91 and 4.99. There is no defined Al limit in the statement of RDF.

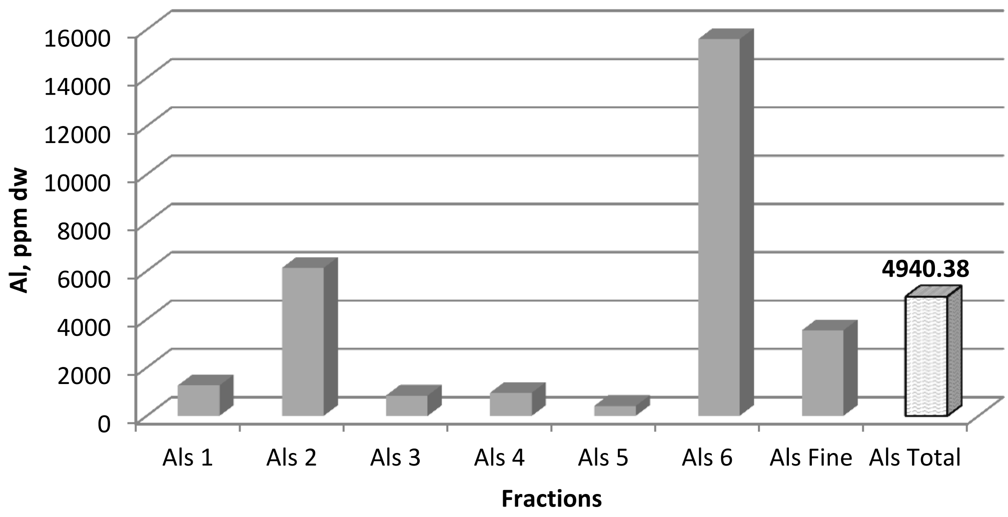

Figure 4.91 Aluminum content of Alsancak

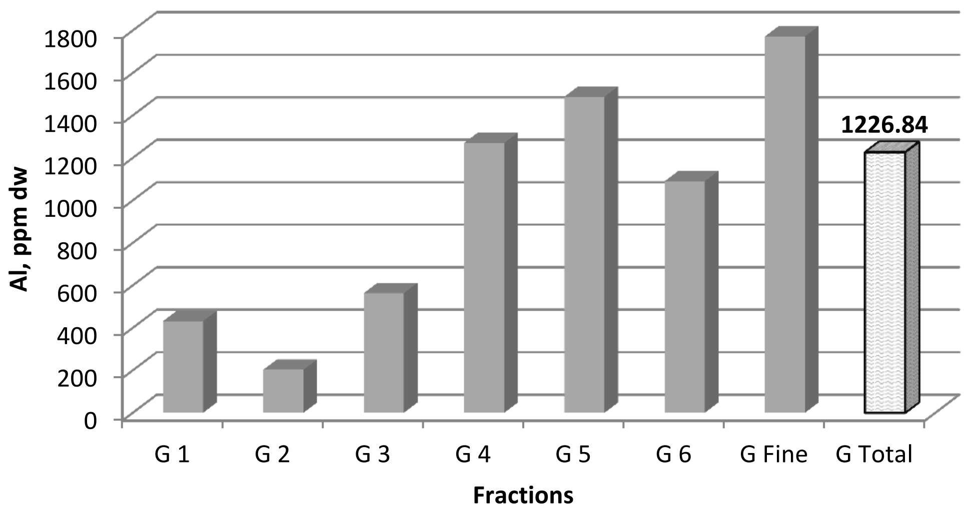

Figure 4.92 Aluminum content of Guzelyali

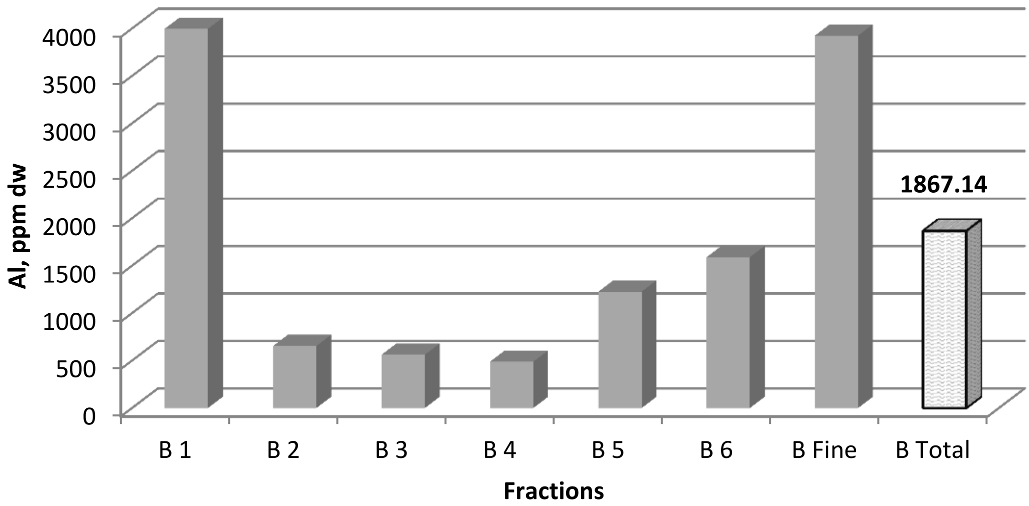

Figure 4.93 Aluminum content of Basmane

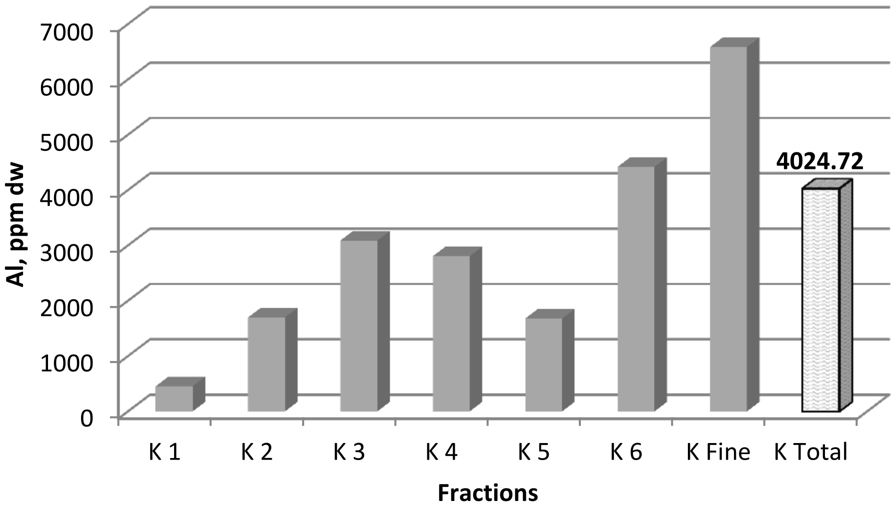

Figure 4.94 Aluminum content of Kizilay

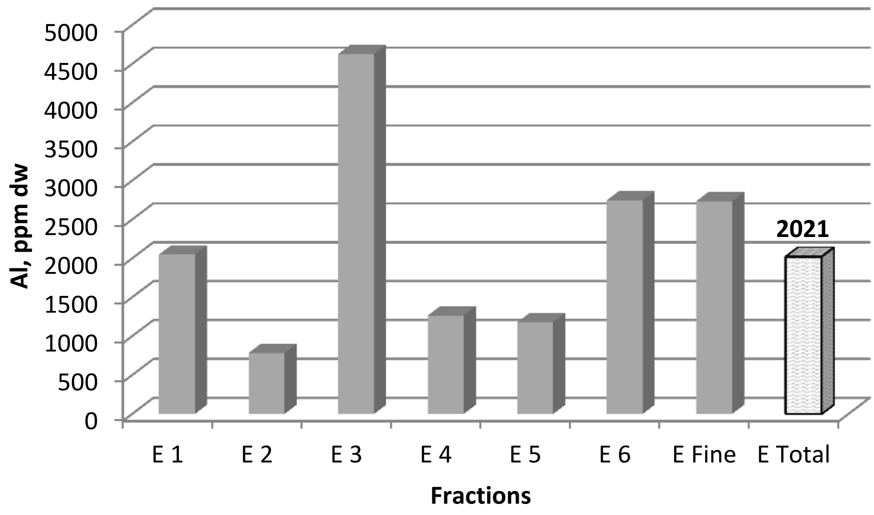

Figure 4.95 Aluminum content of Erzene

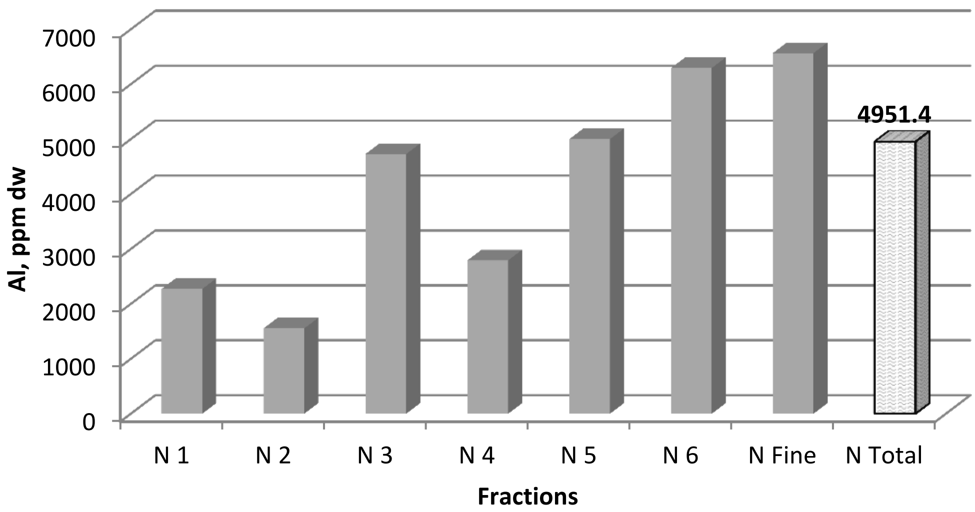

Figure 4.96 Aluminum content of Naldoken

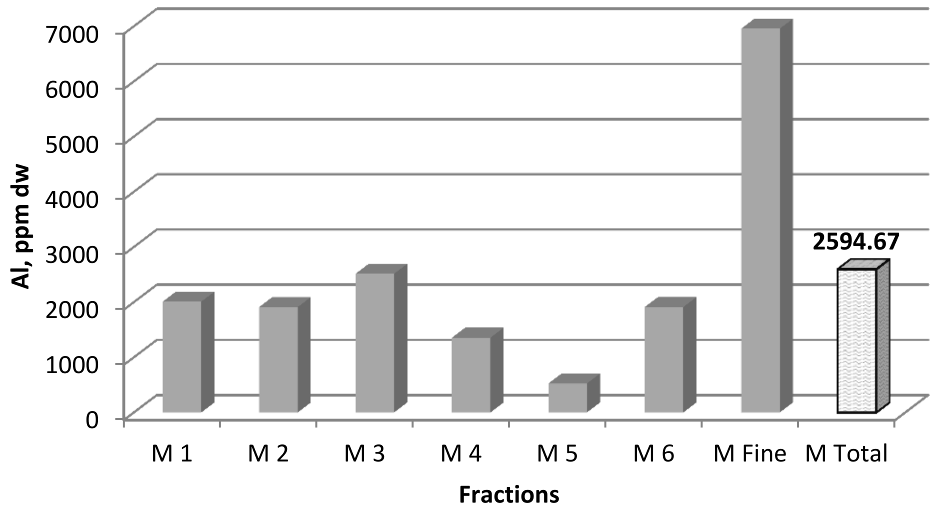

Figure 4.97 Aluminum content of Mavisehir

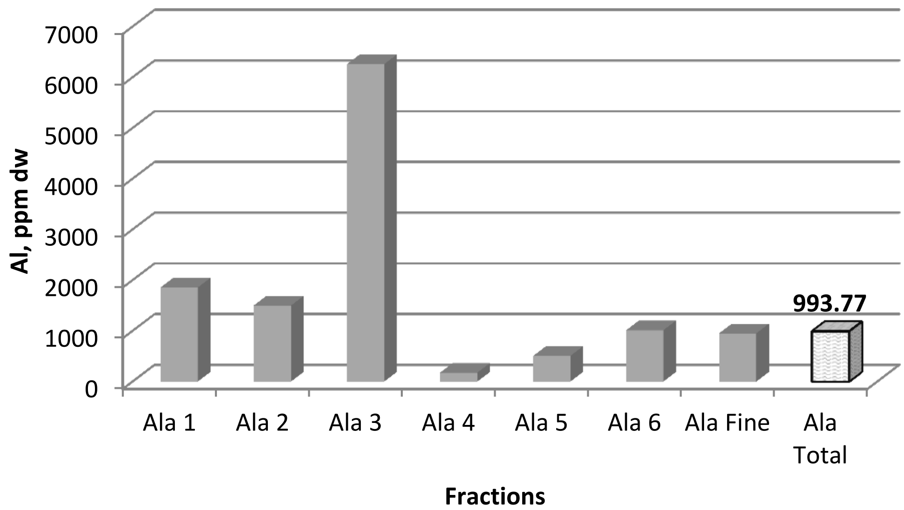

Figure 4.98 Aluminum content of Alaybey

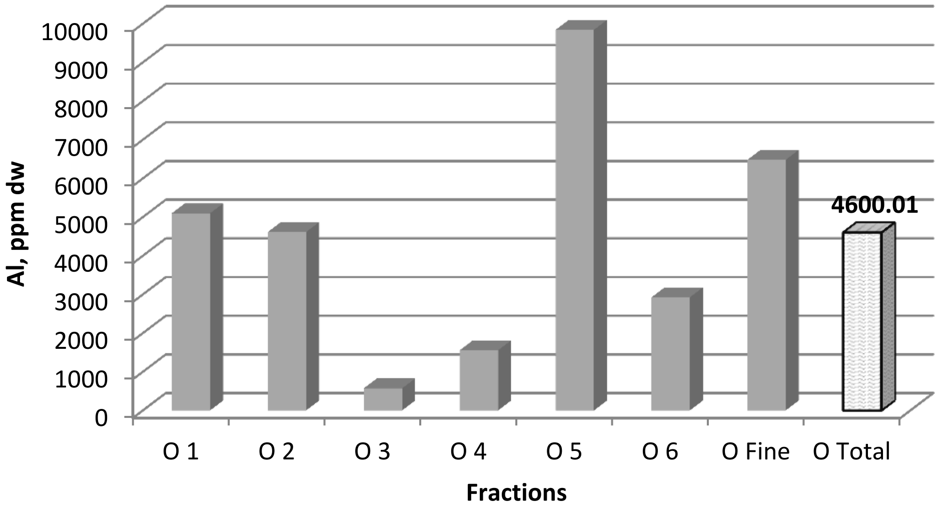

Figure 4.99 Aluminum content of Ornekkoy

4.6.1.11 Calcium Content

Calcium content graphs of the districts starts from the Figure 4.100 to 4.108. No limit is defined in the statement for calcium.

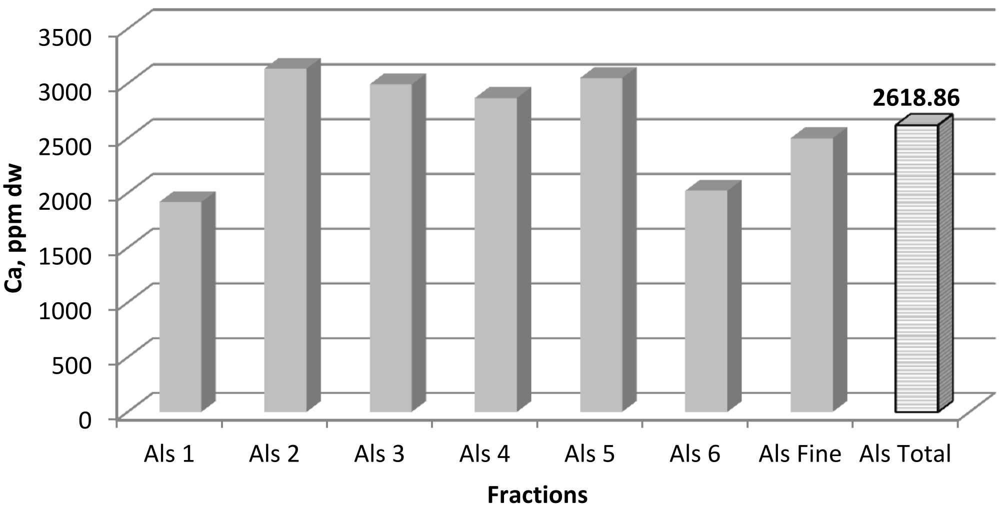

Figure 4.100 Calcium content of Alsancak

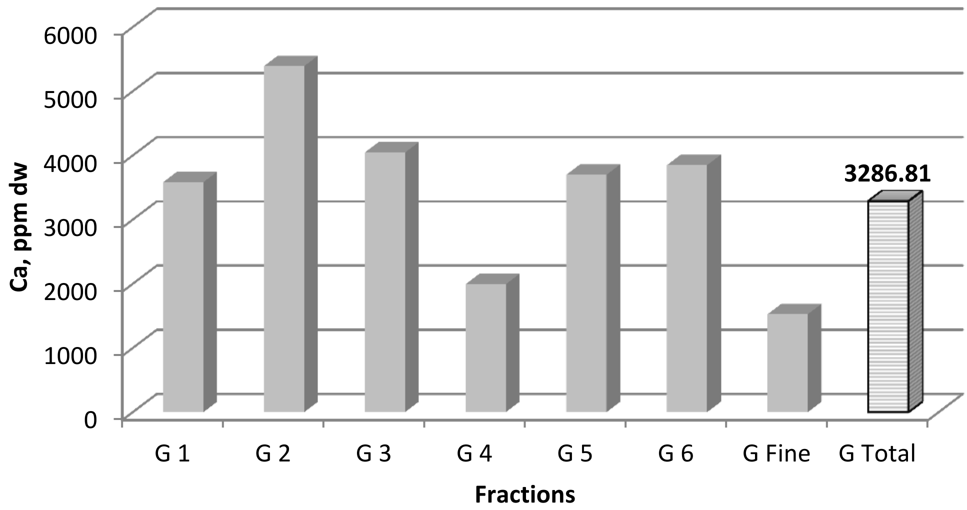

Figure 4.101 Calcium content of Guzelyali

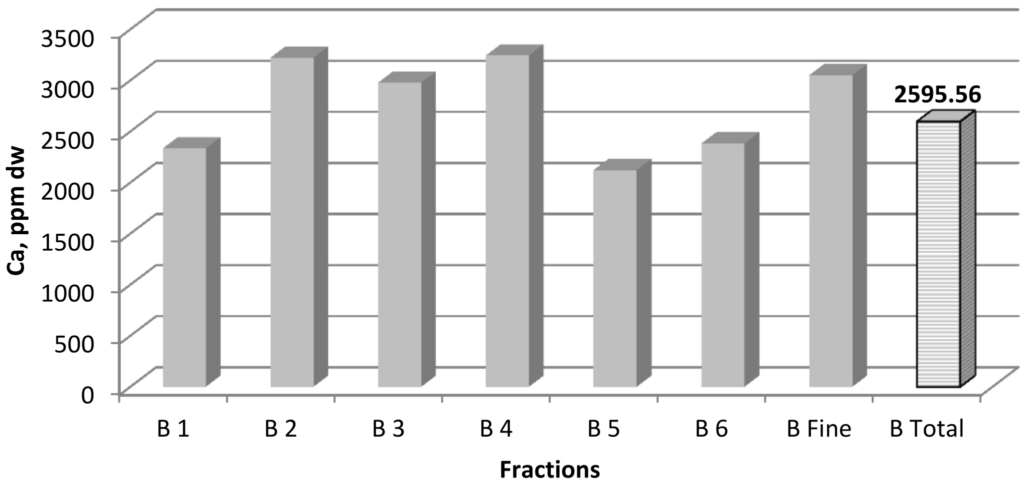

Figure 4.102 Calcium content of Basmane

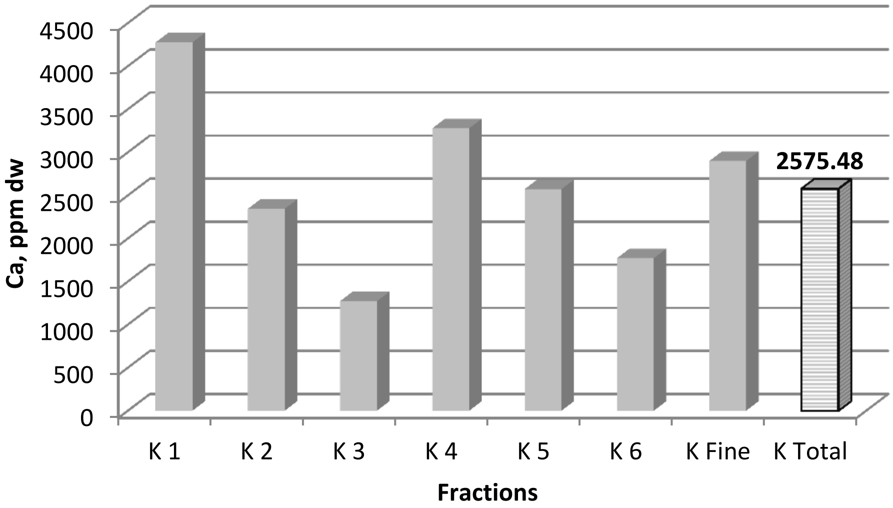

Figure 4.103 Calcium content of Kizilay

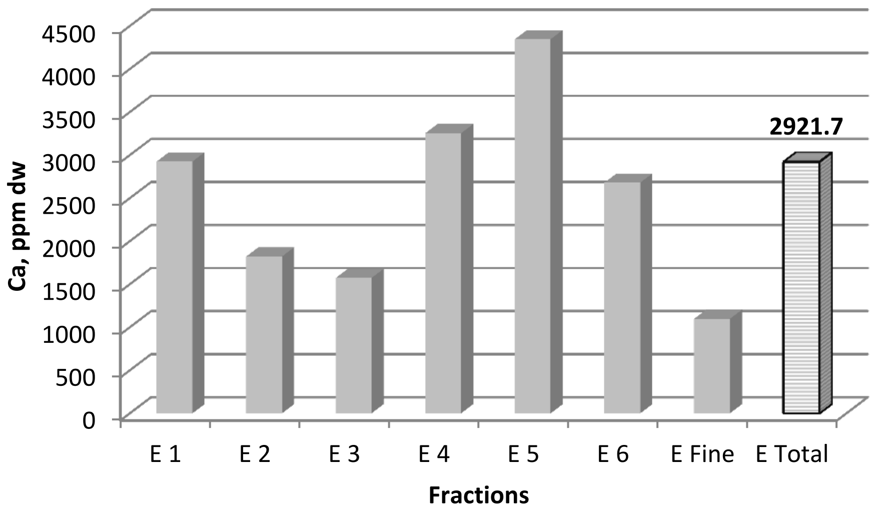

Figure 4.104 Calcium content of Erzene

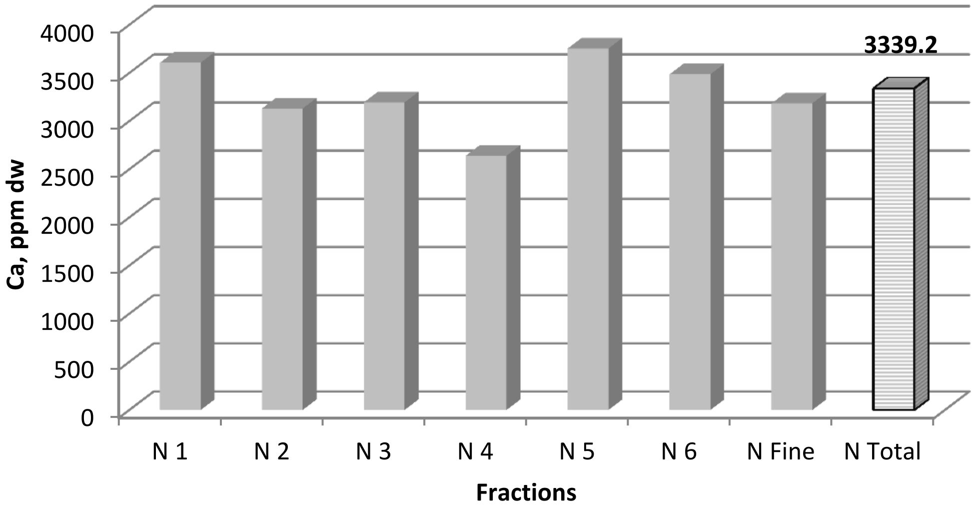

Figure 4.105 Calcium content of Naldoken

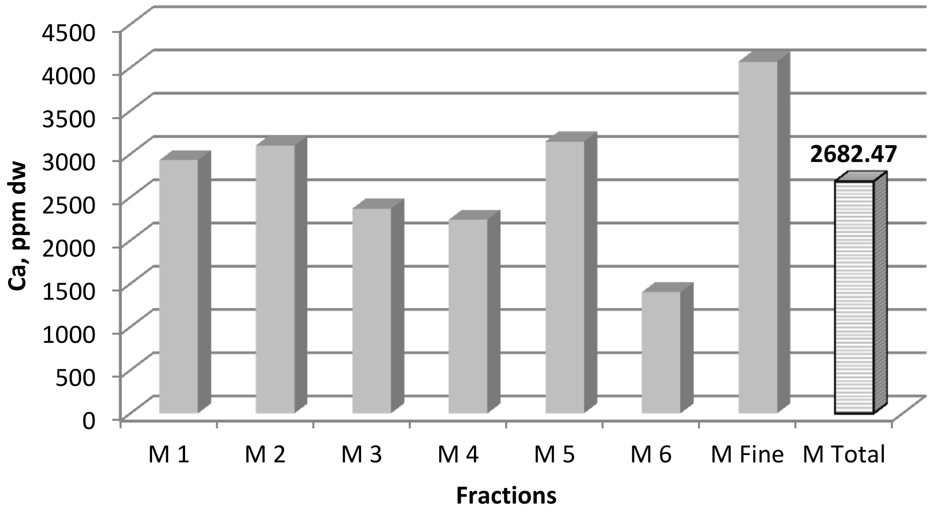

Figure 4.106 Calcium content of Mavisehir

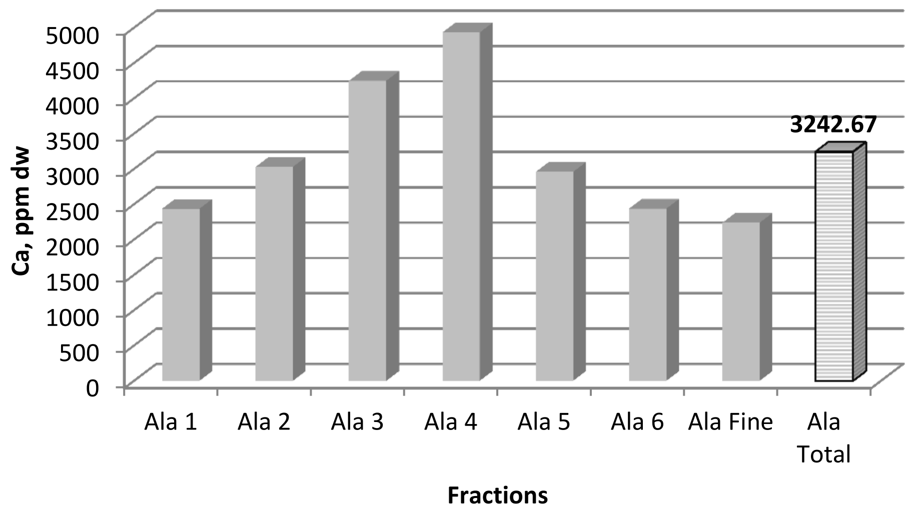

Figure 4.107 Calcium content of Alaybey

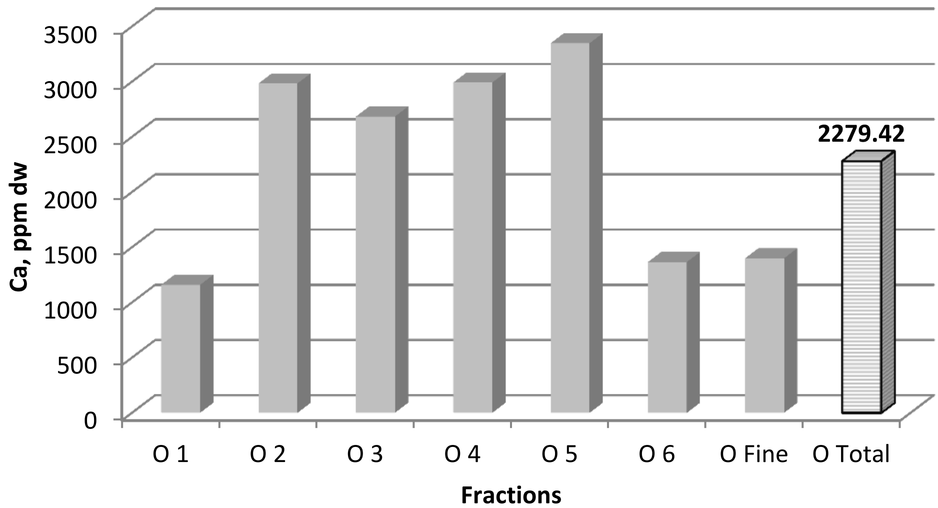

Figure 4.108 Calcium content of Ornekkoy

4.6.1.12 Titanium Content

Titanium concentrations of all districts were found below the detection limit, also the limit defined by The European Union for Responsible Incineration and Treatment of Special Waste as 2 ppm.

4.6.1.13 Arsenic Content

Arsenic content graphs of the districts are between the Figure 4.109 and 4.117. The arsenic limit is defined as 10 ppm by The European Union for Responsible Incineration and Treatment of Special Waste.

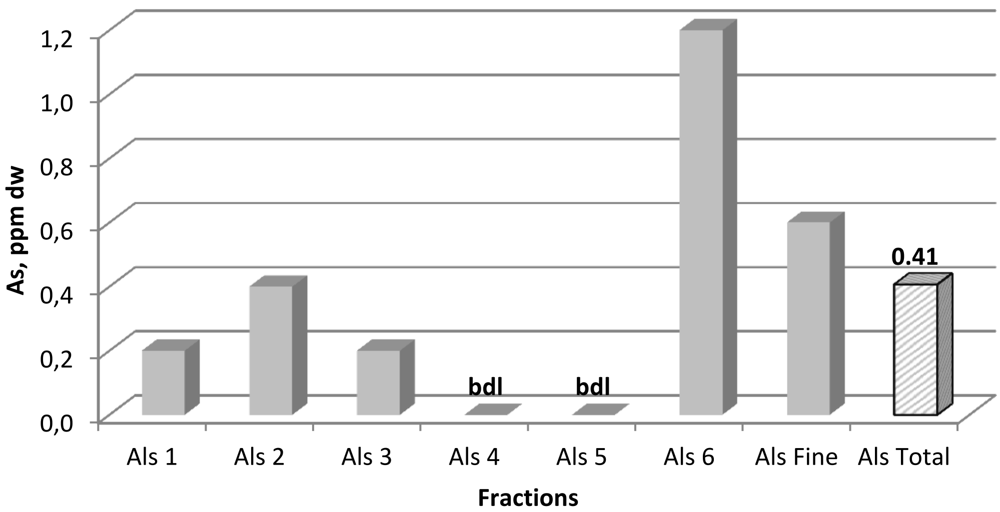

Figure 4.109 Arsenic content of Alsancak

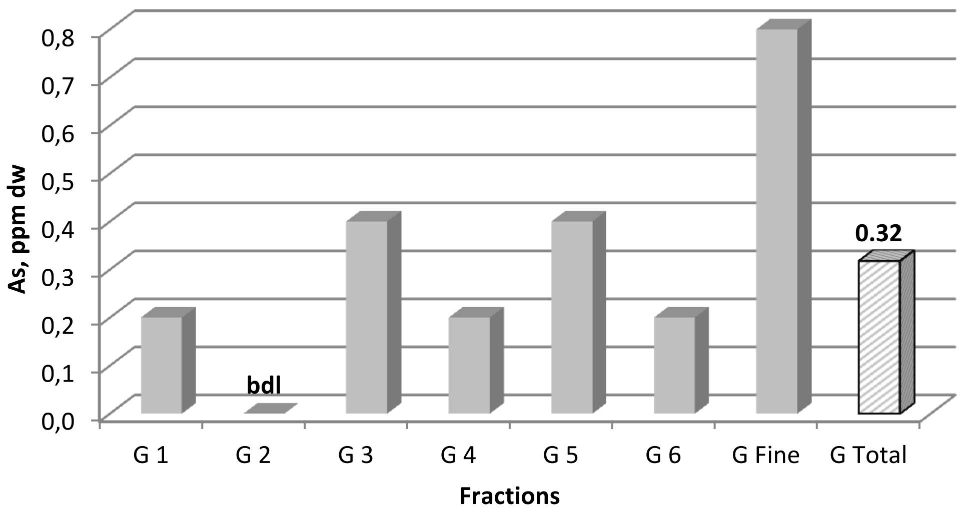

Figure 4.110 Arsenic content of Guzelyali

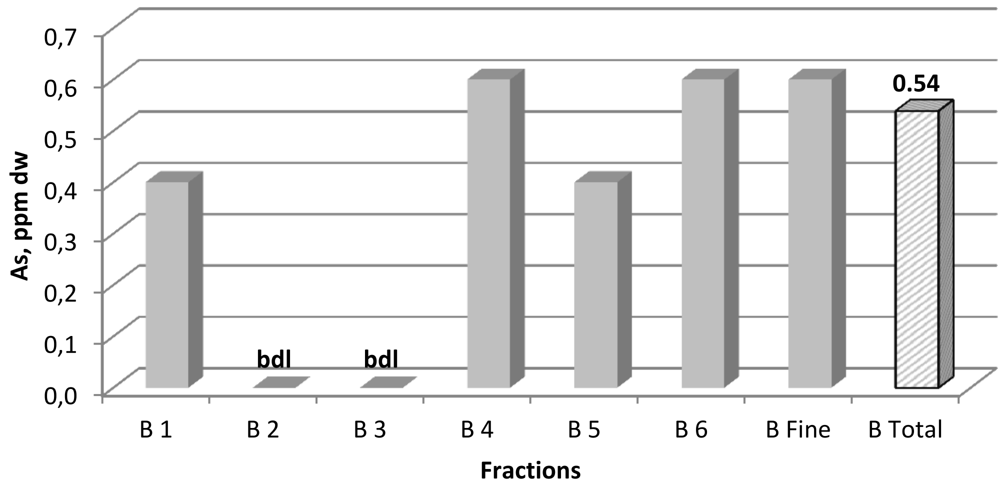

Figure 4.111 Arsenic content of Basmane

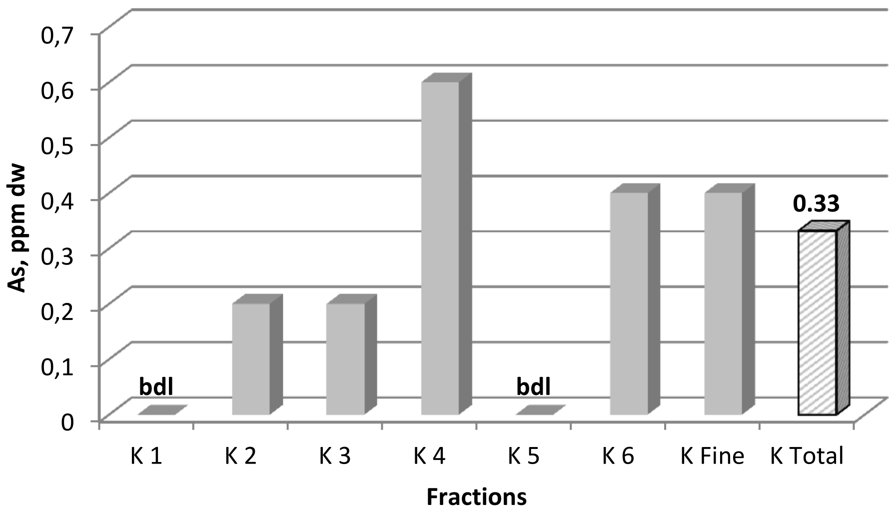

Figure 4.112 Arsenic content of Kizilay

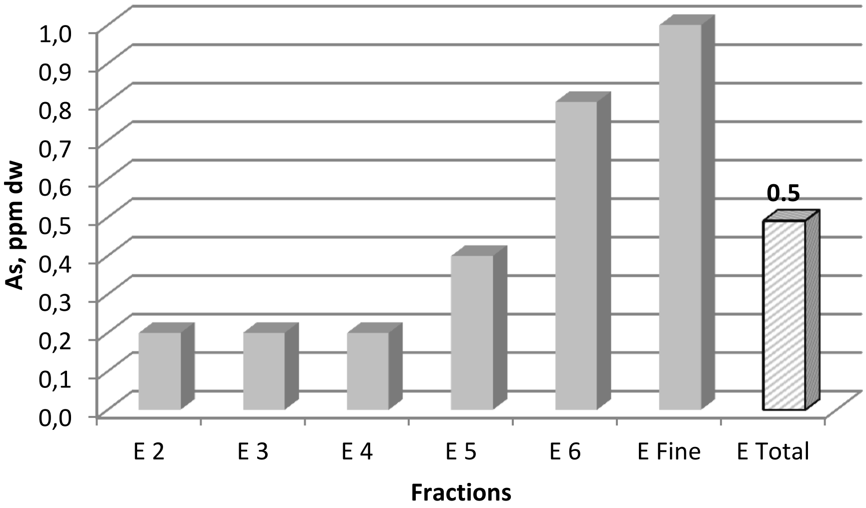

Figure 4.113 Arsenic content of Erzene

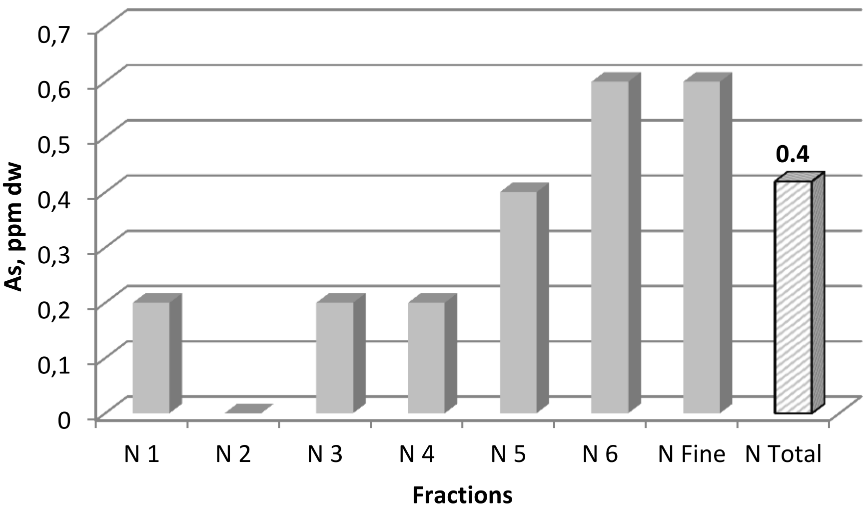

Figure 4.114 Arsenic content of Naldoken

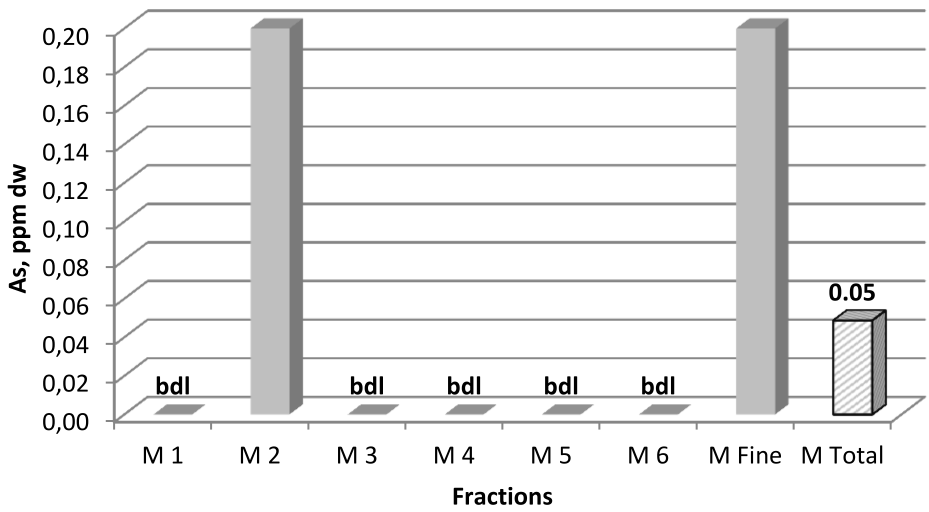

Figure 4.115 Arsenic content of Mavisehir

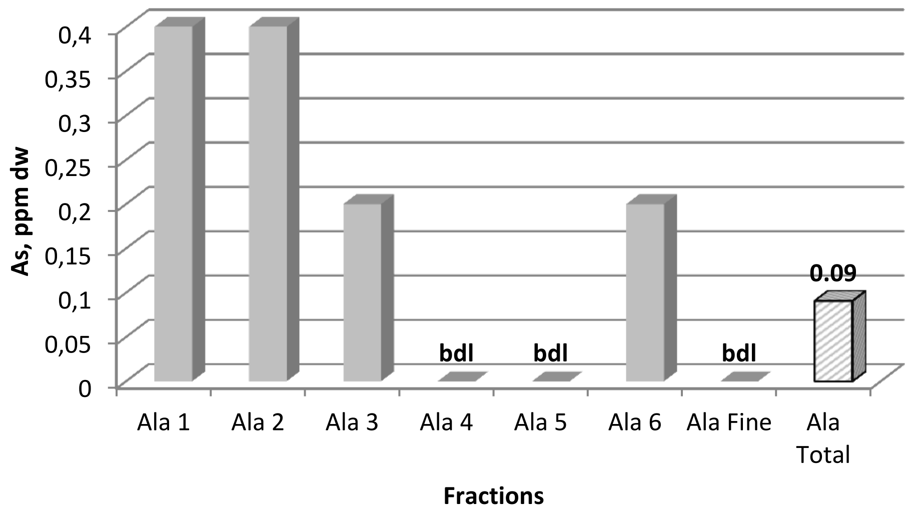

Figure 4.116 Arsenic content of Alaybey

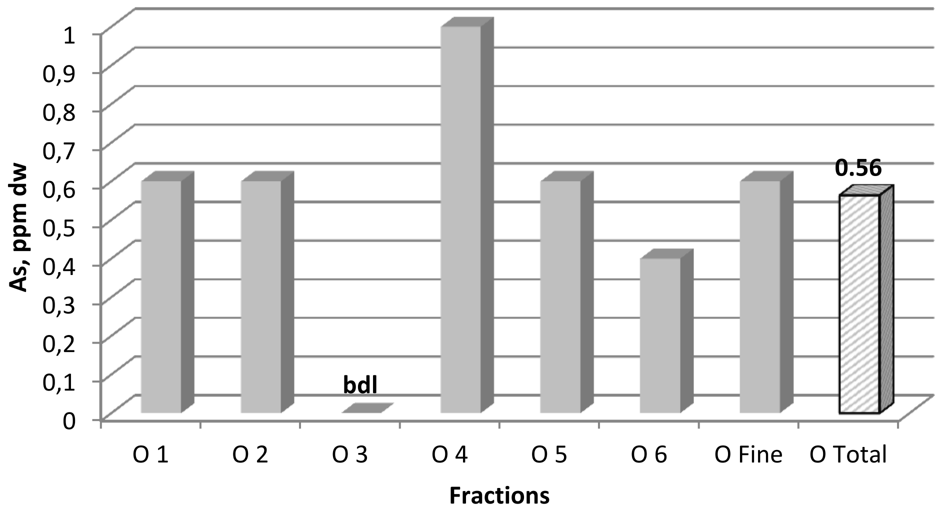

Figure 4.117 Arsenic content of Ornekkoy

4.6.1.14 Mercury Content

Mercury content graphs of the districts are between the Figure 4.118 and 4.126. The limit value defined in the statement is 300 µg/MJ for mercury.

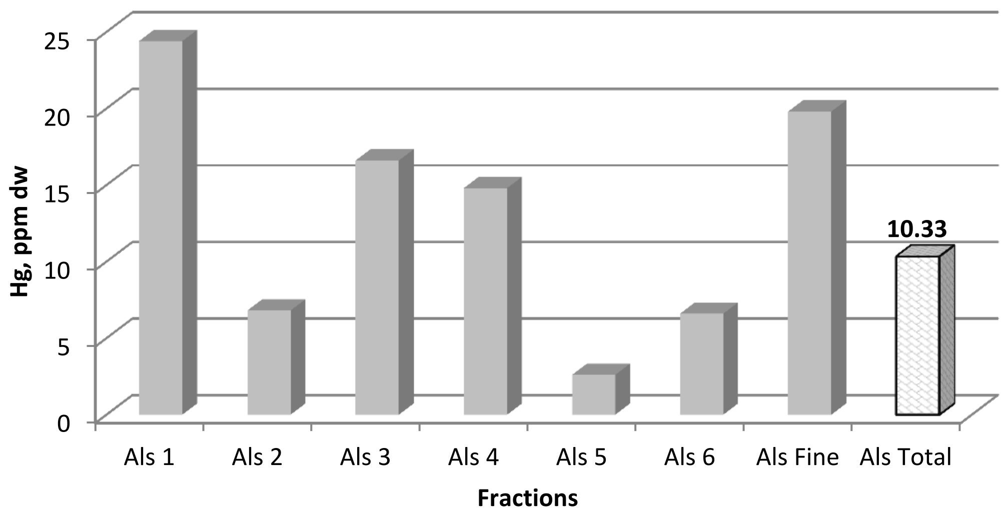

Figure 4.118 Mercury content of Alsancak

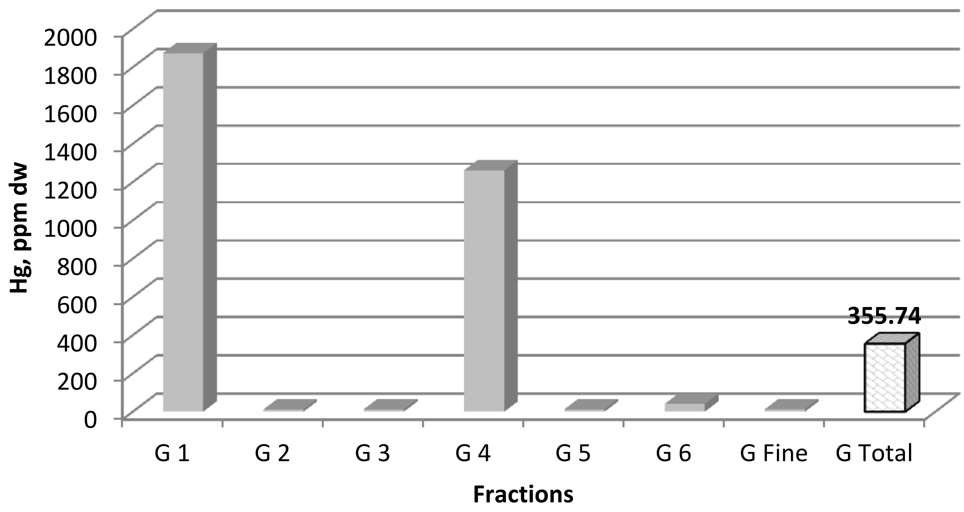

Figure 4.119 Mercury content of Guzelyali

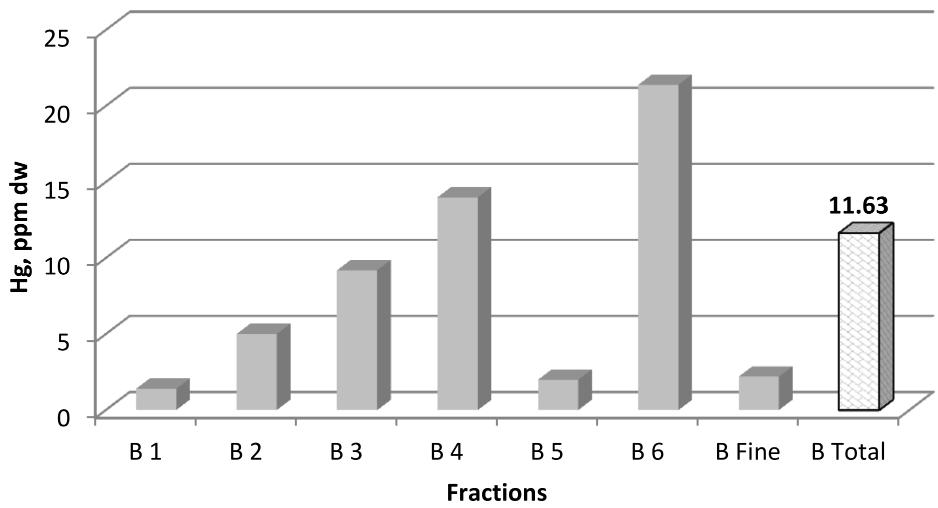

Figure 4.120 Mercury content of Basmane

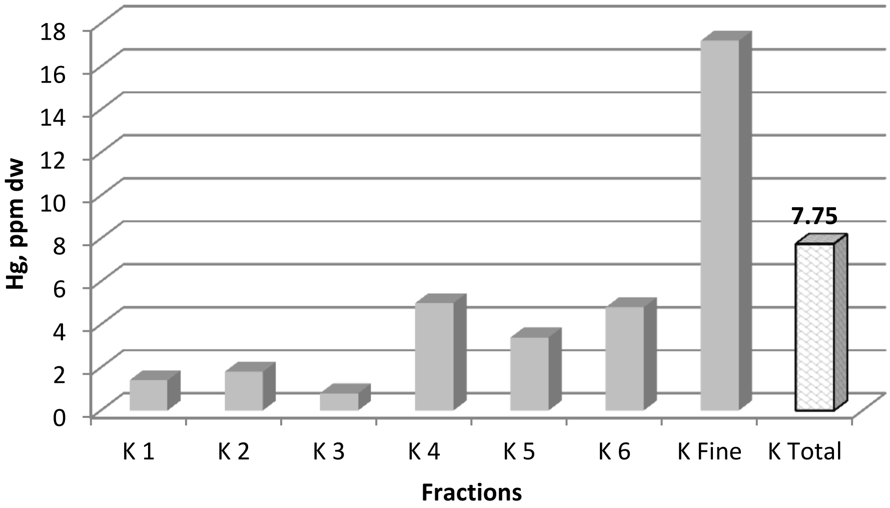

Figure 4.121 Mercury content of Kizilay

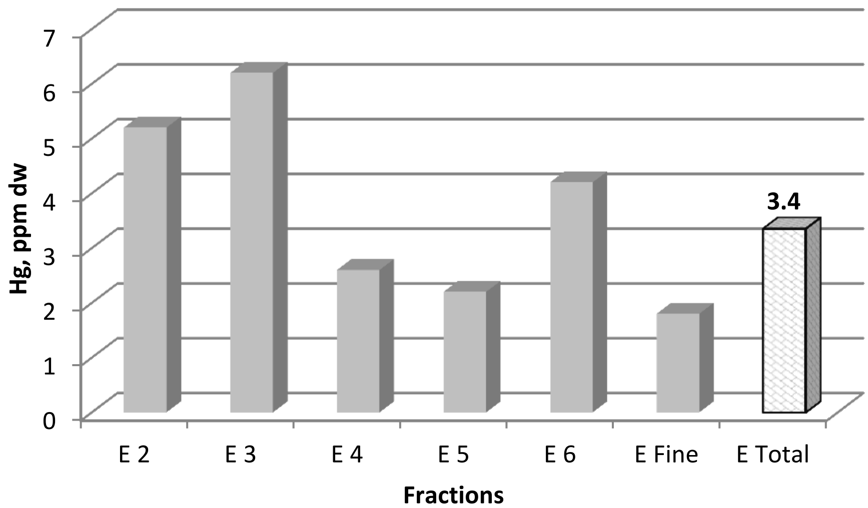

Figure 4.122 Mercury content of Erzene

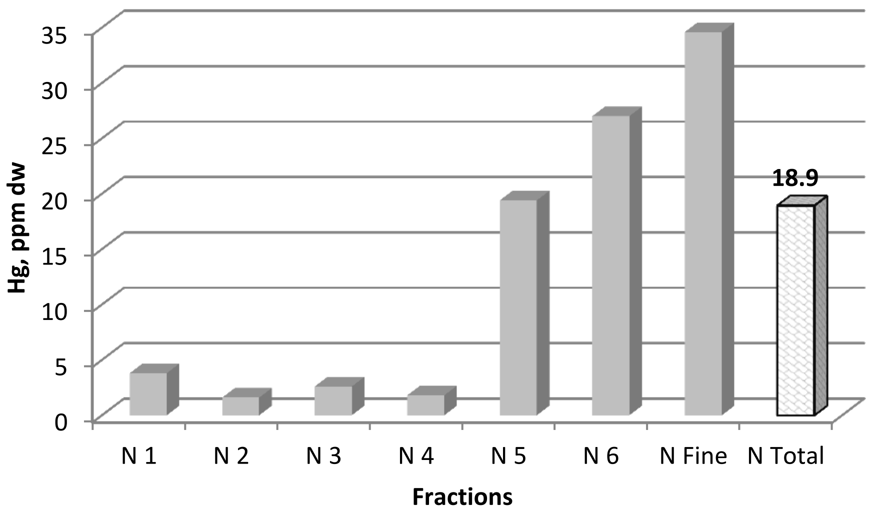

Figure 4.123 Mercury content of Naldoken

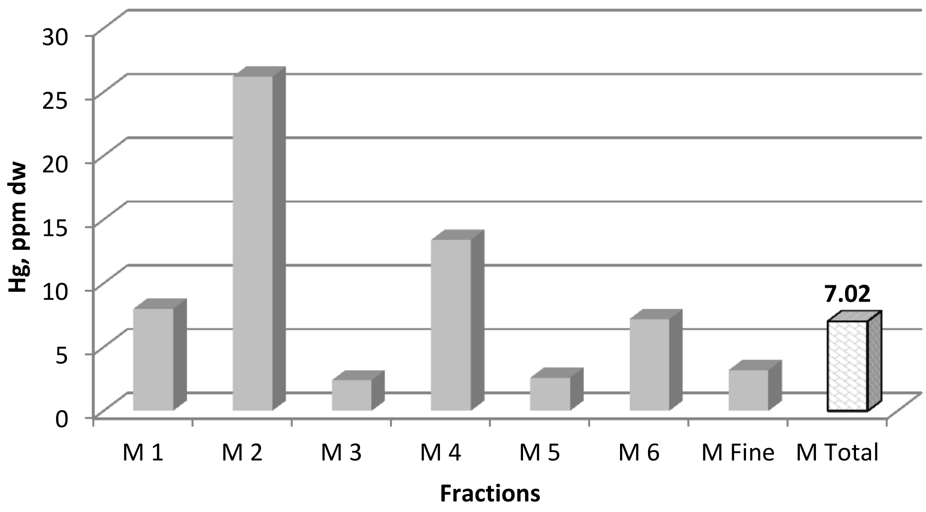

Figure 4.124 Mercury content of Mavisehir

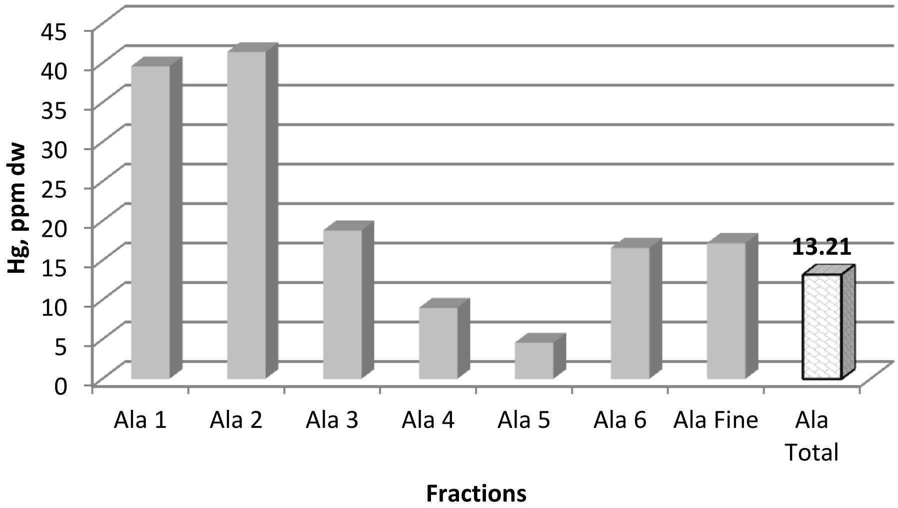

Figure 4.125 Mercury content of Alaybey

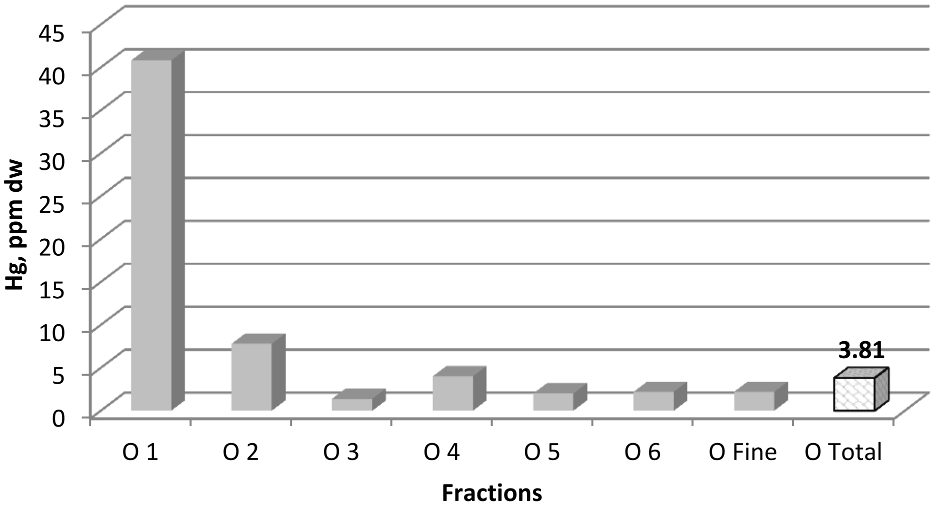

Figure 4.126 Mercury content of Ornekkoy

The biggest Hg value found was 1873.4 ppm which is 0.131 μg/MJ; therefore, it is less than the limit value defined in the statement as 300 μg/MJ.

4.6.2 Possible Sources and Comparison of Heavy Metal Contents

The correlation of all results can be seen in the Table 4.27. In the table it can be understood that Ni-Cr, Pb-Cr, Al-Cr, Zn-Cu and Al-Mn have relationships in the fractions. Mn-Cr, Ni-Mn, Pb-Mn, Pb-Ni and Al-Pb have stronger relationships.

Table 4.27 The correlation values of all heavy metals' results

R Value											
	Cr	**Cu**	**K**	**Mn**	**Na**	**Ni**	**Pb**	**Zn**	**Al**	**Ca**	**Hg**
Cr	1										
Cu	0,252151	1									
K	0,082836	0,092916	1								
Mn	**0,667958**	0,312182	-0,06933	1							
Na	-0,00021	0,326168	-0,00664	-0,00658	1						
Ni	**0,432517**	0,231569	-0,03723	**0,538961**	0,078602	1					
Pb	**0,454054**	0,187043	-0,09915	**0,705314**	0,009771	**0,63002**	1				
Zn	0,264695	***0,361083***	-0,09579	0,138325	0,132026	0,219586	0,267581	1			
Al	***0,304461***	0,105424	-0,12713	**0,48472**	0,079068	0,250016	**0,52081**	0,088206	1		
Ca	-0,06411	0,010474	0,12213	-0,16165	0,042634	-0,0204	-0,16898	-0,03404	-0,14084	1	
Hg	0,009081	-0,03459	0,051943	-0,00627	-0,03892	-0,06064	-0,12278	-0,05366	-0,13138	0,023491	1

Table 4.28 The correlation of average concentrations of the fractions

R Value											
	Cr	Cu	K	Mn	Na	Ni	Pb	Zn	Al	Ca	Hg
Cr	1										
Cu	0,178457	1									
K	-0,61749	-0,02818	1								
Mn	0,868417	0,462887	-0,72572	1							
Na	-0,28784	0,142968	0,421612	-0,09951	1						
Ni	0,444774	0,913689	-0,13273	0,675738	0,127152	1					
Pb	0,769977	0,371708	-0,52831	0,883676	0,16899	0,667672	1				
Zn	0,528836	0,247404	-0,64646	0,77314	0,389484	0,399887	0,812171	1			
Al	0,504902	-0,10146	-0,54434	0,529023	-0,04411	0,215818	0,768765	0,579332	1		
Ca	-0,71594	0,230275	0,707461	-0,57738	0,486662	-0,07611	-0,62749	-0,38304	-0,85542	1	
Hg	0,299181	-0,25533	-0,02555	0,057763	-0,32643	-0,26723	-0,26671	-0,22702	-0,51794	0,103728	1

The correlation of weight based averages can be seen in the Table 4.28. Mn-Cr, Pb-Cr, Ni-Cu, Ca-K, Ni-Mn, Pb-Mn, Zn-Mn, Pb-Ni, Zn-Pb and Al-Pb have strong relation with respect to this table. Moreover, Ni,Cr, Zn-Cr, Al-Cr, Mn-Cu, Na-K, Al-Mn, Ca-Na, Zn-Ni and Al-Zn have logical relation.

According to Veeken & Hamelers (2001), the heavy metal content of foods are generally low especially Cd and Pb concentration. The heavy metal contents of garden wastes are expected to be more than vegetables due to anthropogenic contamination such as traffic, pesticides and fertilizers.

Vegetables can uptake the heavy metals via roots and foliage. The most possible uptake way is root for the many vegetables. Metals can be transferred into the plants via soil pore water as dissolved ions. Moreover, as the pH of soil decreases, the concentrations of Fe^{+2}, Mn^{+2}, Zn^{+2} and Ca^{+2} decrease in the soil (Chang, Yu, Chen, Li, Zhang & Liu, 2013).

Soils in urban areas consist of Pb, Zn, Cd and Cu due to traffic, paint and other non-specific sources. Decomposition of long- distance, atmospherically transported aerosol particles caused by combustion of fossil fuels and contaminants in the fertilizers are important (Alloway, 2013).

In this study for the heavy metal concentrations of organic wastes can be caused by traffic emissions where vegetables grow. Johansson, Norman & Burman (2008) said that Cu emissions are generally caused by brake wear, while Ni emissions are caused exhaust and also this is valid for Zn.

The Pb, Zn, Cd and Ni concentrations in soils decrease as moving away from the road. Moreover, the metals in soil and the vegetation have positive correlation between each other. The metal concentrations in soils and vegetation have also positive relation with traffic densities (Amusan, Bada & Salami, 2003).

Besides traffic, fertilizers, pesticides and other factors, the irrigation water has a significant effect on the metal concentrations. Applying the wastewater varies the physicochemical characteristics of soil and so heavy metal uptake by vegetables. For Fe, Zn, Mn and Cu, the maximum accumulation is observed in the vegetables irrigated with wastewater, as the minimum accumulation is seen in ones irrigated with freshwater (Arora, Kiran, S. Rani, A. Rani, Kaur & Mittal, 2008).

In the study, vegetables which form significant part of the organic wastes can be irrigated both with the wastewater via channels and the freshwater via the wells. Moreover, the properties of the freshwater are important to determine the effects on the metal concentrations.

Shyamala & Belagali (2012) expressed that the main sources of Ca in the solid wastes can be food and vegetable wastes, animal wastes and fine earth. Moreover, they indicated that As contamination in the soil can be caused by pesticide application and As contaminated manure.

Hg can emit to atmosphere due to the combustion of coal, natural gas and petroleum and eventually Hg can deposit in soil or into water bodies. Besides atmospheric release mercury can remain in the bottom ash, hence Hg can transfer to solid wastes (Jasinski, 1995). Moreover, pesticides consist of mercury. Products such as batteries, thermometers, lamps and electronic equipments are significant sources for mercury (Mukherjee, Zevenhoven, Brodersen, Hylander & Bhattacharya, 2004).

4.7 Water Soluble Chlorine Content

Water soluble chlorine contents of Konak, Bornova and Karsiyaka can be observed in the Tables 4.29, 4.30 and 4.31, respectively.

Table 4.29 Chlorine content of Konak

	Alsancak		Guzelyali		Basmane	
Size Fraction	Cl (ppm)	Cl (%)	Cl (ppm)	Cl (%)	Cl (ppm)	Cl (%)
1	13964.42	1.40	30148.55	3.01	13745.74	1.37
2	2061.86	0.21	11210.81	1.12	8602.60	0.86
3	12139.09	1.21	19493.96	1.95	9597.02	0.96
4	7041.29	0.70	8747.29	0.87	7597.64	0.76
5	6475.26	0.65	9854.09	0.99	10496.75	1.05
6	4284.39	0.43	6972.84	0.70	8929.05	0.89
Fine	6708.45	0.67	7888.86	0.79	8247.44	0.82

Table 4.30 Chlorine content of Bornova

	Kizilay		Erzene		Naldoken	
Size Fraction	Cl (ppm)	Cl (%)	Cl (ppm)	Cl (%)	Cl (ppm)	Cl (%)
1	13589.54	1.36	5414.99	0.54	8068.93	0.81
2	10246.82	1.02	13495.82	1.35	12371.16	1.24
3	6747.91	0.67	8330.75	0.83	13852.85	1.39
4	10139.71	1.01	12296.19	1.23	15942.42	1.59
5	9934.42	0.99	4261.84	0.43	8365.83	0.84
6	6972.84	0.70	10887.93	1.09	10023.21	1.00
Fine	3544.36	0.35	11450.99	1.15	5411.37	0.54

Table 4.31 Chlorine content of Karsiyaka

	Mavisehir		Alaybey		Ornekkoy	
Size Fraction	Cl (ppm)	Cl (%)	Cl (ppm)	Cl (%)	Cl (ppm)	Cl (%)
1	8207.98	0.82	26991.63	2.70	2999.07	0.30
2	7576.60	0.76	9497.06	0.95	6073.12	0.61
3	3998.76	0.40	7497.68	0.75	7997.52	0.80
4	3998.76	0.40	8997.21	0.90	8568.77	0.86
5	5840.29	0.58	19868.84	1.99	4665.22	0.47
6	10271.81	1.03	9896.93	0.99	8606.03	0.86
Fine	6664.60	0.67	6747.91	0.67	6976.10	0.70

The biggest chlorine content has been observed in the 1st fraction of Guzelyali as 3.01 %. The reason can be that plastics consist of more chlorine and the 1st fraction of Guzelyali can include more plastics (left after the separation) than other fractions. The least chlorine was in Mavisehir-3 & 4 as 0.4 %. The chlorine content defined in the statement as the limit value is 1 %. Chlorine contents of 7 samples from Konak, 11 samples from Bornova and 3 samples from Karsiyaka are more than 1 %. However, the weight based average chlorine content is 0.86 %.

As a result of the study, the RDF samples in the Figure 4.127 have been produced as fluff.

Figure 4.127 The RDF samples produced in the study

CHAPTER FIVE
CONCLUSIONS

- The carbon contents of all fractions are proper with respect to literature value.
- The water content should be less than 35 % according to The Statement about RDF. The water content results in the study were more than 35 %. Therefore, pretreatment was needed; hence bio-drying has been applied. However, required temperature couldn't be reached. For future works, the isolation of the reactor should be provided more precisely to reach required temperature for bio-drying process.
- Moreover, the ash content changed between 3-86 %. The required ash content in the literature is generally about 20 %. Hence a part of solid wastes are suitable according to ash content, while the other part doesn't meet the values in the literature. The ash content of lignite in Turkey is between 30 % and 40 %. Therefore, RDF produced in the study has more or less same ash content with the lignite in Turkey.
- The calorific values have found between 1394 - 4170 kcal/kg. The standard calorific value required in the Statement should be more than 2500 kcal/kg. Hence, the results meet the standards. Moreover, the calorific values in the literature change from 2000 kcal/kg to 4100 kcal/kg. The RDF produced in the study can be used in the precalciner of clinker process in the cement industry or in the fluidized bed incinerator. Furthermore, the calorific value of lignite in Turkey is about 3000 kcal/kg, so RDF has approximately same value.
- The heavy metal contents generally meet the standards of the Statement. Moreover, the results were found less than the values in the literature.
- The values of Cd, Cr, Cu, Ni, Pb and Zn were found below the limits in the Statement about RDF.
- The Mn values of Als-2 and M-1 were more than the limits of the European Union; however, the weight based averages of Alsancak and Mavisehir were less than the limit.
- Na contents of the samples were less than the limits in the literature.
- The titanium limit value is 2 ppm; however, no titanium was detected in the samples.

- The limit of As is given by the European Union and the results were below this limit.
- The biggest Hg value detected was 1873.4 ppm, when it is converted to µg/MJ, it was 0.131. This value is below the limit in the Statement about RDF which is 300 µg/MJ.
- Exceptionally some samples' chlorine contents are less than 1 % as defined in the statement; however, the general of the samples are proper with regard to chlorine content. Hence, the samples cannot cause corrosion in the clinkers.
- The RDF in this study was produced as fluff which can be seen in next figure, pelletizing process hasn't been applied.
- To conclude, RDF produced from the solid wastes of Izmir is appropriate if the water content is decreased fewer than 35 %. To decrease water content, the bio-drying process should be improved.
- In order to improve the bio-drying process, mixing period should be more frequent and the collection of leachate should be in a more organized way. Therefore, by means of bio-drying, the water content of solid waste can be decreased in environment friendly and cheap way.
- As a result, the solid waste obtained from Izmir is suitable for RDF production if the water content is decreased fewer than 35 % by proper bio-drying application and necessary chlorine content adjustments are conducted.
- Moreover, if analysis of ash and emission which are outputs of RDF incineration are conducted, more detailed results can obtain and more accurate interpretations can be made.
- Furthermore, for Izmir case old composting facilities can be used as bio-drying unit in order to prepare RDF by removing the moisture.

REFERENCES

Alloway, B.J. (2013). Sources of heavy metals and metalloids in soils. *Heavy metals in soils* (3rd ed.) (11-50). Springer Netherlands.

Alp, K. (2011). Refuse derived fuel (rdf). *ÇOB 2011 Atık Yönetimi Sempozyumu*. İstanbul.

Amusan, A.A., Bada, S.B., & Salami, A.T. (2003). Effect of traffic density on heavy metal content of soil and vegetation along roadsides in Osun State, Nigeria. *West Affrica Journal of Applied Ecology, 4,* 107-114.

Arora, M., Kiran, B., Rani, S., Rani, A., Kaur, B., & Mittal, N. (2008). Heavy metal accumulation in vegetables irrigated with water from different sources. *Food Chemistry, 111*, 811-815.

Ataman, T. (n.d). *Türkiye'de liinyit adı altında üretilmekte olan maden kömürlerinin gerçek nitelikleri ve yeni bir sınıflandırma.* Retrieved from http://www.maden.org.tr/resimler/ekler/3451e7ef8755c2a_ek.pdf

Beckmann, M. & Ncube, S. (2007). Characterisation of Refuse Derived Fuels (RDF) in reference to the Fuel Technical Properties. *The International Conference on Incinertaion and Thermal Treatment Technologies. Phoenix.*

Bernard, B., Bernard, H., & Brooks, J. (n.d). Determination of total carbon, total organic carbon and inorganic carbon in sediments. *Tdi-Brooks International*.

Buckley, T., & Domalski, E. (n.d). Evaluation of data on higher heating values and elemental analysis for refuse derived fuels. *Rensselaer Hartford*, 78.

CERTH/ ISFTA. (2011). *Report onrdf/srf utilization applications and technical.* Ptolemais: CERTH/ ISFTA.

Chang, C.Y., Yu, H.Y., Chen, J.J., Li, F.B., Zhang, H.H., & Liu, C.P. (2013). Accumulation of heavy metals I leaf vegetables from agricultural soils and associated potential health risks in the Pearl River Delta, South China. *Environmental Monitoring and Assessment, 186*, 1547-1560.

Chen, M., & Ma, L. (2001). Comprasion of three aqua regia digestion methods for twenty Florida soils. *Soil Science Society of America Journal, 65*(2), 491-499.

Gendebien, A. (2003). *Refuse derived fuel, current practices and pervectives.* Swindon: European Commission – directorate general environment.

Genon, G., & Brizo, E. (2008). Perspectives and limits for cement klins as a destination for rdf. *Waste Management, 28*(11), 2375-2385.

Horttanaien, M., Teirasvuo, N., Kapustina, V., Hupponen, M., & Luoranen, M. (2013). The Composition, heating value and renewable share of the energy content of mixed municipal solid waste in Finland. *Waste Management, 33*(12), 2680-2686.

İzmir Meropolitan Municipality. (2013). *Urban solid waste utiliation methods and selection of proper method for İzmir.*

Jasinski, S.M. (1995). The materials flow of mercury in the United States. *Resources, Conservation and Recycling*, 145-179.

Johansson, C., Norman, M., & Burman, L. (2009). Road traffic emission factors for heavy metals. *Atmospheric Environment,43*(31), 4681-4688.

Kara, M., Günay, E., Tabak, Y., & Yıldız, Ş. (2009). Perspectives for pilot scale study of rdf in Istanbul, Turkey. *Waste Management, 29*(12), 2976-2982.

Ledakowicz, S., Zawadzka, A., & Krzystek, L. (2010). *Biodrying of organic fraction of municipal solid waste*. Retrieved October 13, 2014 from http://archivos.labcontrol.cl/wcce8/offline/techsched/manuscripts/0gqfjc.pdf

Lorber, K., Sarc, R., Pomberger, R., & Erdin, E. (2015). Usage of RDF-SRF as Solid Fuel in Klinker Processes. *Türk Alman Katı Atık Günleri-2015*. Izmir.

Minghua, Z., Xiumin, F., Rovetta, A., Qichang, H., Vicentini, F., Bingkai, L., Giusti, A.& Yi, L. (2008). Municipal solid waste management in Pudong New Area, China. *Waste Management, 29*(3), 1227-1233.

Mukherjee, A.B., Zevenhoven, R., Brodersen, J., Hylander, L.D., & Bhattacharya, P. (2004). Mercury in waste in the European Union: sources, disposal methods and risks. *Resources, Conservation and Recycling, 42*(2), 155-182

Murphy, S. (2007). *General information on solids*. Retrieved May 29, 2014, from http://bcn.boulder.co.us/basin/data/NEW/info/TSS.html

Negoi, R., Ragazzi, M., Apostol, T., Rada, E., & Marculescu, C. (2009). Bio-drying of Romanian municipal solid Waste: an analysis of its viability. *U.P.B. Scientific Bulletin, 71*(4), 193-204.

Reza, B., Soltani, A., Ruparathna, R., Sadiq, R. & Hewage, K. (2013). Environmental and economic aspects of production and utilization of rdf as alternative fuel in cement plants: A case study of MetroVancouver Waste Management. *Resources, Conservation and Recycling, 81*, 105-114.

Sadaka, S., VanDevender, K., Costello, T., & Sharara, M. (2011). *Partial Composting for Biodrying Organic Materials*. Retrieved May 15, 2015, from https://www.uaex.edu/publications/PDF/FSA-1055.pdf

Sarc, R., & Lorber, K. (2013). Environmental and economic aspects of production and utilization of rdf as alternative fuel in cement plants: A case study of Metro Vancouver Waste Management. *Waste Management*, *33*(9), 1825-1834.

Shao, L.M., He, X., Yang, N., Fang, J.J., Lü, F. & He, P.J. (2012). Biodrying of municipal solid waste under different ventilation modes: drying efficiency and aqueous pollution. *Waste Management Research, 30*(12), 1272-1280.

Sharholy, M., Ahmad, K., Vaishya, R.C. & Gupta, R.D. (2006). Municipal solid waste characteristics and management in Allahabad, India. *Waste Management, 27*(4), 490-496.

Shi, D., Wu, W., Lu, S., Chen, T., & Huang, H. (2007). Effect of msw source-classifies collection on the emission of pcdds/fs and heavy metals from incneration in China. *Journal of Hazardous Materials, 153*(1-2), 685-686.

Shyamala, D.C., & Belagali, S.L. (2012). Studies on variations in physico-chemical and biological characteristics at different maturity stages of municipal solid waste compost. *International Journal of Environmental Sciencies, 2*(4), 1984-1997.

The Governorate of İzmir. (n.d). *General information of İzmir*. Retrieved January 01, 2014, from http://www.izmir.gov.tr/default_b0.aspx?content=216

U.S Department of Energy. (2011). *The effect of moisture on heating values.* Retrieved January 01, 2014 from http://cta.ornl.gov/bedb/appendix_a/The_Effect_of_Moisture_on_Heating_Values.pdf

Veeken, A., & Hamelers, B. (2002). Sources of Cd, Cu, Pb and Zn in biowaste. *The Science of The Total Environment, 300*(1-3), 87-98.

Worrel, W. A., & Vesilind, P. (2012). *Solid waste engineering.* Stamford: Cengage Learning.

Zhang, H., He, P., & Shao, L. (2008). Implication of heavy metals distribution for a municipal solid waste management system- a case study in Shanghai. *Science of The Total Environment, 402*(2-3), 257-258.