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C O N T E N T S

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Research Paper

An Investigation on the Removal of Heavy Metals from Contaminated Soils with Ornamental Plants

Feran Aşur[1,*], Suzan Karagöz[2],

[1]Department of Landscape Architecture, Faculty of Architecture-Design, Yuzuncu Yil University, Zeve Campus, 65090 Tuşba, Van, Turkiye; [2] Environmental Problem Research Center, Yuzuncu Yil University, Zeve Campus, 65090 Tuşba, Van, Turkiye. suzankaragoz@yyu.edu.tr

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Abstract: Pollution caused by heavy metals is one of the important issues that spreads rapidly in urban, rural, and industrial areas and has great environmental impacts. Although it is possible to remediate soils contaminated with heavy metals using chemical, physical or biological techniques, physical and chemical methods of remediating areas contaminated with heavy metals are costly, time-consuming, and environmentally damaging. Therefore, in recent years, scientists and engineers have tried to design and develop biological techniques that can clean and replace places contaminated with heavy metals without causing negative effects on soil fertility and biodiversity, and as a result, they have introduced "Phytoremediation Systems". Many ornamental plants can extract several toxic metals from the soil and store them in large amounts in their organs, and at the same time survive without showing signs of toxicity. This article aims to explain the potential use of ornamental plants for phytoremediation of polluted environments and their effects on the landscape. This study focuses on phytoremediation and ornamental plants used in landscape architecture according to the type of pollution. Through a comprehensive literature review, it has been revealed that these plants can be used and that they form an important basis in purifying environmental pollution in landscaping works. According to the results obtained, while making rearrangements in the relevant areas in the future, they will provide greenery to the environment with ornamental plants, as well as providing healthy, aesthetic, and visual living spaces that are open to people's use.
Keywords: *Heavy metals, ornamental plants, contaminated soil, phytoremediation*

Introduction

Heavy metals are compounds naturally found in the earth's crust. Recently, because of the development of the industry and mining activities, pollution caused by heavy metals has become an important issue attracting worldwide attention. The toxicity of heavy metals and their accumulation in food chains is one of the main environmental and health problems of modern societies. Soil, water, and air pollution creates environmental pollution in nature in the form of a triple circle and affects all ecosystems, including humans. Pollution that cannot be transformed and eliminated in nature is soil pollution. Agriculture cannot be done in polluted lands and these lands remain idle. Soil pollution is the ultimate source of water pollution and air pollution in nature. Today, heavy metal pollution in soil is one of the important environmental problems (Çağlarırmak & Hepçimen, 2010).

Heavy metals are among the environmental pollutants found everywhere in industrial societies (Lasat, 2002). In terms of their physical properties, the term heavy metals refer to metals and semimetals with a density of more than 5 gr cm^{-3}. Lead (Pb), Zinc (Zn), Copper (Cu), Cadmium (Cd), Nickel (Ni), Arsenic (As), Iron (Fe), Manganese (Mn), Molybdenum (Mo), Cobalt (Co), Magnesium (Mg), mercury (Hg), chromium (Cr), silver (Ag) and selenium (Se) are among these metals. The toxicity of heavy metals and their accumulation in food chains is one of the main environmental and health problems of today's societies (Adriano, 2001; Baba et al., 2009; Çağlar Irmak & Hepçimen, 2010; Al-samman et al., 2022). Soil pollution caused by heavy metals differs from water or air pollution because heavy metals remain in the soil longer and are more durable and persist in the soil than in other parts of the biosphere (Lasat, 2002). In the research conducted in Hungary, the effect of soil pollution caused by heavy metals on microorganisms in the soil was investigated. While heavy metal pollution was detected at low levels in polluted soil, Cr and Cd rates were determined to be high according to the Hungarian Soil Pollution Regulation. Cr and Cd rates in polluted soils were found to be significantly high (Mathe Gasper et al.,

**Corresponding: E-Mai: feranekasur@gmail.com; Tel: +90 5058867677.*

2005). In the research conducted in China; Heavy metal contents of 268 vegetable samples grown in soil contaminated by different reasons such as mining, agriculture, industrial activities, and traffic density were determined. It has been determined that the Pb, Cd, Cr, Hg and as levels in celery, carrots, cabbage, tomatoes, asparagus, lettuce, and red peppers are higher than the level that does not pose a risk to health as stated by the Environmental Protection Agency (EPA), and the contamination rate varies according to vegetable types (Liu et al., 2013). Heavy metal levels in alcohols and wines made from fruits produced in certain areas in Italy, Poland and Bulgaria and using pesticides and fertilizers were higher than the level legally permitted by the European Union (Formicki *et al*., 2012).

Factors that cause heavy metals to spread into the environment are primarily industrial activities, pesticides and fertilizers used in agriculture, urban waste, motor vehicle exhaust fumes, mining operations and volcanic activities (Stresty & Madhava, 1999). Heavy metals accumulated in the soil not only affect soil fertility and ecosystem functions, but also have significant effects on human and animal health through the food chain. Heavy metals can contaminate the environment in various ways, such as meat and milk from animals fed on grass contaminated with metals, grains from the environment, fish caught from polluted waters, or from tools and equipment used during food production. They can pass into industrial wastes, drinking water, groundwater, air, and soil (Erkmen, 2010).

In this study, information was given about the important effects of heavy metals on human health and ornamental plants used in soil reclamation in landscape architecture were investigated according to the type of pollution. In this regard, concerns have been raised about the potential effects of heavy metals on vegetation and the phytoremediation potential of ornamental plants, soil pollution in urban areas and plant breeding technology.

Material and Method

The main material of the study consists of the data obtained because of literature searches to find the answer to the question of what ornamental plants can be used by landscape architects to provide visual living spaces in the reclamation of soils contaminated with heavy metals and healthy landscaping. The method of the study consists of analysis, synthesis and evaluation of the data obtained through extensive literature reviews on this subject. The results of research and investigations on the subject are presented in the following order.

Effects of Heavy Metals on Human Health

If the concentrations of heavy metals exceed a certain level in soil, water, and atmosphere, they can cause serious problems for all living things. Heavy metals cause different diseases, especially cancer, in humans, depending on factors such as the person's immune resistance, general health status, genetics, nutritional level and age, as well as the dose they are exposed to. Protecting natural resources and the environment against contamination is very important in preventing environmental pollution (Wu et al., 2018; Yasin et al., 2021). However, purifying contaminated areas is of great value in solving existing environmental pollution. Removal of heavy metals found in soil and water, which are harmful to human health, by using classical physicochemical techniques is a method that is costly and limited in use. Plants are considered important tools for soil and water remediation (Prasad, 2007; Poddar, 2023). For this reason, it is of great importance to remove heavy metals in soil and water by using the phytoremediation technique, which is easy and cheap to apply and allows the removal of heavy metals from the soil by natural methods, with the help of different hyper accumulator plants that can vary depending on the concentration and type of heavy metal in the soil.

Heavy metals are non-biodegradable, bio accumulative, and are ubiquitous in nature. They can enter the food chain and cause various diseases and disorders in plants, humans, and animals (Erkmen, 2010; Yasin *et al.*, 2021; Siddique *et al.*, 2013). According to a report published by USEPA (2016), there are approximately ten million people worldwide affected by metal-contaminated soils. Similarly, excessive amounts of heavy metals in the soil restrict the growth of vegetation due to phytotoxic effects and make the soil prone to erosion, causing pollutants to disperse to new areas (Deepika & Harikash, 2023). Table 1 lists the main effects of heavy metals on humans.

The types of heavy metals that accumulate in the soil and the effects they cause are also different: Lead: Grains, vegetables, fruits, seafood and meat, some types of beverages, water and spices may contain Pb, both in natural and contaminated form (Tayfur, 2009). It has been determined that foods

contain Pb in an average amount of 0.065 mg kg^{-1} (Food Standard Agency, 2009). Lead exposure can cause acute proximal renal tubular damage, chronic nervous system disorders, anemia, colic, chronic renal failure, blindness, and damage to vitamin D metabolism (Ärup, 2003).

Table 1. Main effects of heavy metals on humans (Jorge et al., 2005; Wu et al.,2016; Siddique & Al-Samman, 2022; Deepika & Harikash, 2023).

Metal	Effects
Arsenic (As)	Cancer, chromosomal abnormalities, diabetes, cardiovascular disease, liver and kidney damage, pulmonary disease, anaemia, peripheral neuropathy and skin irritations
Cadmium (Cd)	May cause kidney damage, lung disease, hepatocellular injuries, cancers, as well as diabetic complications, hypertension and osteoporosis, gastroenteritis
Chromium (Cr)	Allergic dermatitis, kidney damage, respiratory and stomach cancer, neurological and cardiovascular disorders, premature death, ulcer, liver necrosis
Copper (Cu)	Gastrointestinal upset, liver, or kidney damage
Mercury (Hg)	inorganic Kidney damage, neuropsychiatric disorders, birth defects, insomnia, weight loss, gingivitis, delusions and hallucinations
Nickel (Ni)	Lung, nose, lung, throat and stomach cancer, dermatitis, lung fibrosis, cardiovascular and kidney disease due to inhalation of nickel
Lead (Pb)	Delays physical and mental development in children, Kidney damage and high blood pressure problems, miscarriages and birth defects in adults, DNA damage and neurological disorders, hypertension, encephalopathy in both children and adults.
Zinc (Zn)	Excessive zinc intake (150 mg/day-1-2 g/day) causes sideroblastic anaemia, hypochromic microcytic anaemia, leukopenia, neutropenia and gastrointestinal bleeding.

Potential Effects of Heavy Metals on Vegetation

Increasing heavy metal concentration in soil affects plant growth and fertility. Increased metal concentrations in plant tissue could bring various biochemical, physiological, and morphological toxic effects. In non-resistant plant species, heavy metals affect a wide range of plant cellular activities, including photosynthesis, respiration, mineral nutrition, cell membrane properties and structure, and gene expression (Majer et al., 2002). Cadmium is one of the most dangerous soil pollutants with adverse effects. Metal toxicity in plants interrupts water and nutrient uptake and transport, changes nitrogen metabolism, restricts plant growth by reducing photosynthetic activity, and causes stomatal closure due to malfunction of the photosynthetic mechanism of plants (Athar et al., 2018). Conversely, some plants have evolved the ability to grow in metallic soil, as observed in mining sites (Gardea-Torresdey *et al*., 2005), and the concept of developing tolerance to metal exposure is referred to as 'adaptation'.

Plants require some heavy metals in very low concentrations, but when the concentration of these metals is higher than the plant's need, it causes metabolic disorders and inhibits the growth of most plant species (Majer *et al*., 2002). A summary of the effects of heavy metals Arsenic, cadmium, chromium, copper, mercury, nickel, lead, and zinc on plants is available in Table 2.

Table 2. Main effects of heavy metals on plants (Jorge *et al*., 2005; Deepika & Harikash, 2023).

Metal	The effects
Arsenic (As)	Chlorosis, inhibition of growth process, oxidative stress
Cadmium (Cd)	Reduction of seed germination, lipid content and plant growth; causes browning of root tips and chlorosis and eventually plant death,
Chromium (Cr)	Reduction of enzyme activity and plant growth; Damage to the cell membrane and root of the plant, yellowing of the leaves
Copper (Cu)	Inhibition of photosynthesis, plant growth and reproduction processes, leaf yellowing
Mercury (Hg) inorganic	Reduction of photosynthetic activity, water absorption and antioxidant enzymes; Phenol and proline accumulation interferes with Mitochondrial activity, oxidative stress, binding to water channel proteins,
Nickel (Ni)	Reduction of seed germination, dry matter accumulation, protein, chlorophyll, and enzyme production; Increase in free amino acids
Lead (Pb)	Decreased chlorophyll production and plant growth; Production of reactive oxygen species, water imbalance, disruption of membrane permeability and mineral nutrition, toxic effects on the morphology, growth and photosynthetic processes of plants.
Zinc (Zn)	Chlorosis, Delayed growth, aging and inhibition of metabolic functions.

Phytoremediation Potential of Ornamental Plants

Phytoremediation removes heavy metals, organic pollutants, petroleum by-products, etc. from the soil. Plants with shorter life cycles that are economically important in groundwater are persuading researchers to engage in phytoremediation to remove hazardous substances from the environment. Although it has been used for many years, phytoremediation is still a relatively new technology (Kristanti & Hadibarata, 2023). The concept of phytoremediation was first proposed in 1983 and the process is still evolving. It is the best approach to deal with moderately metal-contaminated sites and can be applied along with other conventional remediation technologies for effective removal of pollutants (Deepika & Harikash, 2023). Plant breeding is a cost-effective and ecologically benign alternative to traditional breeding methods. Phytoremediation is a sustainable method of cleaning up polluted areas as it helps restore ecosystems and biodiversity. Third, environmental managers and policymakers should consider using phytoremediation to address widespread contamination (Poddar, 2023). Wu et al., (2018) stated that approximately 721 hyperaccumulator species were reported, including 59 from the Phyllanthocin and 83 from the Brassicaceae family. Despite numerous types of research, phytoremediation is not effectively used commercially due to the plants' long growing seasons, low biomass production, risk of entering the food chain, poor disease resistance, and shallow root systems (Wei et al. 2008; Liu et al., 2011). Ornamental plants are herbaceous plants that have the advantages of short growth period, high biomass, high adaptability, wide distribution, and low toxicity risk. In addition, these plants can provide economic benefits and improve the aesthetic appearance of the contaminated area (Deepika & Harikash, 2023).

Ornamental plants provide a different aspect to the phytoremediation of polluted terrestrial and aquatic environments. Ornamental plants are grown for aesthetic reasons and include a wide variety of plants of different sizes, colours and shapes that grow in different types of land and climate. Ornamental plants generally include different types of plants, from low to high, from herbs to shrubs, and from marine to terrestrial. Additionally, since ornamental plants are not eaten, the risks of hazardous substances, especially heavy metals, have less chance of entering the food chain. In addition to cleaning the environment, ornamental plants also have additional benefits such as increasing environmental aesthetics and providing additional income as well as additional employment opportunities (Işık, 2004; Kaushal *et al*., 2023).

According to Poddar (2023), it is a green technology that uses plants to clean, stabilize and eliminate environmental toxins. In Poddar's study, use of *Helianthus annuus* to remove radioactive contaminants from water in Chernobyl, Ukraine; *Salix* Spp. to stabilize and reduce heavy metals in soil in Silver Bow Creek, Montana. use: and discussed the use of *Alpine pennycress* to remove heavy metals from contaminated soil in Bunker Hill, Idaho, USA. Large-scale phytoremediation projects at Chernobyl, Silver Bow Creek, and Bunker Hill demonstrate the promise of this approach to dealing with pollution at the landscape scale. Phytoremediation involves several specific processes discussed below:

In phytostabilization, plants immobilize or stabilize pollutants in contaminated areas by accumulating them on roots or root hairs, causing adsorption on the root surface, or precipitation in the rhizosphere of a plant (Muthusaravanan et al. 2018), thereby reducing the bioavailability of pollutants in the environment (Lee, 2013). Various reports indicate that plants from the Fabaceae and Brassicaceae families are often involved in the phytostabilization process (Tordoff et al., 2000). *Festuca rubra, Agrostis tenuis, Zygophyllum fabago, Lupinus angustifolius, Horedeum vulgare, Brassica juncea, Secale cereale, Helianthus annuus* (Ghosh & Singh, 2005).

Phytoextraction is a process by which a plant's roots absorb pollutants from soil or water, then transfer and store these pollutants into aboveground tissues such as shoots and leaves. Plants used to perform phytoextraction must have the ability to produce high biomass to accumulate pollutants without visible symptoms. This method is only applicable to areas with low to moderate levels of metal contamination. Aquatic plant species that could remove heavy metals from water resources; It consists of *Eichhornia crassipes, Hydrocotyle umbellata* L, *Lemna minor* L. and *Pistia stratiotes* (Prasad & Freitas, 2003).

Phytovolatilization, also known as Phytoevaporation, is the process by which pollutants are taken up and assimilated into the air spaces of the plant and then released into the atmosphere in the same or modified/less toxic form due to the metabolic and transpiration of the plants (USEPA 1999). The process is beneficial as it causes significant dilution and photochemical degradation of pollutants in the

atmosphere (Ghosh & Singh, 2005). Some aquatic plants, such as *Typha latifolia* L., also could volatilize selenium into the atmosphere (Pilon-Smits, 2005).

Rhizofiltration removes pollutants or pollutants from aqueous waste streams, nutrient recycling systems, etc. It refers to the use of plant roots to filter, adsorb, precipitate, and concentrate excess nutrients (Lee, 2013). In general, terrestrial plants such as *Brassica juncea* (Dushenkov et al. 1995) and *Helianthus annuus* (Dushenkov et al. 1997) are considered more suitable for rhizofilteration because they produce longer, more extensive, and fibrous root systems that contain greater surface area for metal accumulation.

Phytodegradation, also known as Phytotransformation, is the use of plants and related microorganisms to break down organic pollutants. Certain pollutant-metabolizing plant enzymes are released into the rhizosphere, which plays an important role in pollutant transformation. This process can also be used for the degradation of organic compounds such as ammunition, chlorinated solvents, herbicides, insecticides, and inorganic nutrients (Schnoor et al., 1995).

In recent years, potential hyperaccumulators have become a very important and popular area of research. 'Hyperaccumulators' are plant species that can grow in metal-contaminated soil without exhibiting any phytotoxic symptoms and without accumulating significant amounts of heavy metals in aboveground tissues. To date, approximately 721 hyperaccumulators have been reported from 52 families (Huang et al., 2020).

Ornamental plants are considered potential material for phytoremediation programs due to their shorter growth cycles. These plants have beautiful forms, colors and patterns and have the potential to be used frequently for landscaping in urban and suburban areas. The fact that ornamental plants can be used to prevent pollution in urban areas and at the same time to beautify the environment represents the advantage of ornamental plants over other plants for plant breeding (Poddar, 2023; Deepika & Harikash, 2023). Such plants also represent higher biomass, rapid growth, diversity of plant species, vitality, economic benefits, and ultimately quality visual effects that increase landscape aesthetics. In addition, since these plants are not used as foodstuffs, they reduce the risk of contaminants entering the food chain (Vural, 1993; Prasad & Freitas, 2003; Li et al., 2020).

Metal concentration in ornamental plants may not always be high enough to be classified as a hyperaccumulator, as higher biomass yield may compensate for lower metal accumulation. For example, *Amaranthus hypochondriacus* and *Celosia argentea* are frequently used for phytoremediation because of their higher biomass yields and ability to grow under adverse conditions (Huang et al. 2020). Similarly, despite not being a hyperaccumulator, *Godetia grandiflora* accumulated 1014, 1180, and 1021 mg Pb/kg dry root weight in 1000, 1500, and 2000 mg Pb/kg soil, respectively (Manzoor et al. 2018).

Some ornamental plants such as *Urtica, Thlaspi, polygonum sachalase, Chenopodium*, and *Alyssum* could accumulate zinc, lead, cadmium, nickel, and copper in their bodies. The use of these plants is accepted as an indirect method of purifying polluted soils (Mulligan et al., 2001). Use of ornamental plants such as *Tagetes patula, Chlorophytum comosum*, *Limoniastrum monopetalum* (L.), T*agetes erecta, Helianthus annuus, Gladiolus grandiflorus, Chrysanthemum indicum, Calendula officinalis,* etc. has been reported for phytoremediation of heavy metal contaminated soils without showing any significant adverse effects on plant health (Poddar, 2023; Deepika & Harikash, 2023). In their study, Manios et al., (2003) examined the heavy materials collected by *Typha latifolia* from water and, because of the analysis, provided information about the heavy metals (Cu, Zn, Ni) collected in the highest amounts by the roots, stems and leaves of *Typha latifolia.* It has been determined that heavy metals are successfully removed from the environment thanks to some plants. For example; *Myripphyllum spicatum* (Cu, Pb, Cd, Ni, Zn), *Brassica Juncea* (Cu, Pb, Cd, Sr, Cr, Ni, Zn) and *Helianthus annuus* (Mn, U, Co, Cu, Cs, Cr, Cd, Ni, Zn), *Lemna minor*, *Eichornia crassipes* and *Hydrocotyle umbellata* species were successfully grown in a short time against many pollution factors (Meers et al., 2005; Epa, 2014). In their studies, heavy metals (Cd, Cu, Pb, Cr, Ni, Zn) accumulation and accumulation capacities were investigated. Willow species selected for research; *Salix triandra* 'Noir de Villaines', *Salix dasyclados* 'Loden', *Salix purpurea* × Salix daphnoides 'Bleu', *Salix fragilis* 'Belgisch Rood' and *Salix schwerinii* 'Christina'. According to Brooks et al., (1998), various plant species are used to neutralize various factors that create environmental pollution. Accordingly, *Thlaspi caerulescens* plant species for cadmium and chromium removal, *Haumaniastrum robertii* plant for cobalt removal, *Haumaniastrum katangense* plant for copper removal, *Macadamia neurophylla* for manganese removal, *Thlaspi*

ratundifolium subsp for lead removal, *Alyssum bertoloni* and *Berkheya coddii* plant species for nickel removal, *Astragalus pattersoni* for selenium removal. *Iberis in removing* thallium *Atriplex confertifolia* plant species can be used for intermedia and uranium removal.

It has been determined that *Althaea rosea* and *Calendula officinalis*, which are ornamental plants that can be used outdoors, are tolerant to cadmium and these plants can be used in phytoremediation (Liu et al., 2008a). *Impatiens balsamina* (henna flower), *Calendula officinalis* and *Althaea rosea* alone were found to be tolerant to Cd and Pb pollution and could accumulate these metals effectively (Liu et al., 2008b). *Syngonia* sp. and *Tagetes patula* plants have been found to be usable in removing Arsenic pollution in the soil (Imamul, 2005). *Helinathus annuus* L. has been particularly successful in removing radioactive metals found in Chernobyl. After the Chernobyl disaster, sunflower fields were planted to collect these radioactive metals from the ground, and when the sunflowers were fully grown, they were harvested via pyrolysis and disposed of safely (Prasad, 2007). The list of some ornamental plants that can be used against heavy metals in green breeding is given in Table 3.

Table 3. Some ornamental plants that can be used against heavy metals (Brooks *et al*., 1998; Manios *et al.*, 2003; Ghosh & Singh, 2005; Meers et al., 2005; Liu *et al.*, 2008a; Epa, 2014).

Ornamental Plants	**Heavy Metals That Can Remove**
Althaea rosea	Cadmium, Lead
Calendula officinalis	Cadmium, Lead
Impatiens balsamina	Cadmium, Lead
Syngonia sp.	Arsenic
Tagetes patula	Arsenic
Pistia stratiotes	Silver, Cadmium, Copper, Chrome, Mercury, Lead, Nickel, zinc
Helianthus indicus	Mercury
Sesbania drummondii	Mercury
Lemna gibba	Arsenic
Alyssum SPP.	Nickel
Solanum nigrum	Cadmium
Thlaspi caerulescens	Cadmium, Chrome
Thlaspi ratundifolium	Lead, Nickel
Haumaniastrum robertii	Cobalt
Haumaniastrum katangense	Copper
Macadamia neurophylla	Manganese
Alyssum bertoloni	Nickel
Berkheya coddii	Nickel
Astragalus pattersoni	Selenium
Iberis intermedia	Talyum
Atriplex confertifolia	Uranium
Myripphyllum spicatum	Zinc, Copper, Lead, Cadmium, Nickel
Brassica Juncea	Zinc, Copper, Lead, Cadmium, Nickel, Strontium
Helianthus annuus	Zinc, Copper, Lead, Cadmium, Nickel, Manganese, Uranium

In order to prefer a plant to be used in a breeding method; It is necessary to have the ability to accumulate the heavy metal that is desired to be removed from the soil, and to have a high tolerance level to the concentration of heavy metal in the soil. Especially with the increase in pollution in urban areas, the use of ornamental plants in eliminating soil pollution should be taken into consideration by choosing the right species from ornamental plants, which have an important role in improving the beauty of the environment and at the same time.

Soil Pollution and Plant Breeding in Urban Areas

According to the United Nations, approximately 70 percent of the world's population will live in cities by 2050. Cities will face new challenges in sustainable development and seek different solutions. In urban areas, heavy metals such as Fe, Cu, Zn, Cd, Pb, Cr and Ni are generally found in the top layer of soil on the edges of streets and in the roots and leaves of plants growing in such areas (Athanasopoulou & Kollaros, 2016). This is mostly due to road traffic (Hercer *et al*. 2016; Rolka *et al*., 2020), combustion of fuels, consumption of motor vehicle oils, wear of tires and asphalt (Hołtra & Zamorska-Wojdyła,

2016) and maintenance work on the roads (Athanasopoulou & Kollaros, 2016). Due to the increasing flow of motor vehicles, both public transport and private vehicles, pollution with heavy metals caused by road traffic is one of the most serious dangers for the environment (Acar & Özkul, 2020). Higher metal content may have a negative impact on roadside vegetation (Khalilova & Mammadov, 2016), while hypersalinity of soils along roads may additionally worsen (Czerniawska-Kusza et al., 2004). In addition, such elements can pollute surface and groundwater (Athanasopoulou & Kollaros, 2016; Halilova & Memmedov, 2016) and accumulate in the environment and threaten human health (Önder et al., 2007; Halilova & Memmedov, 2016; Yap et al., 2022). The accumulation of heavy metals in roadside areas depends on various factors such as intensity of traffic flow, duration of exposure, age of vehicles (Athanasopoulou & Kollaros, 2016), distance from the road, depth of the soil profile, speed, and direction of the wind (Athanasopoulou and Kollaros, 2016; Rolka et al., 2020) and land aid (Rolka et al., 2020). Heavy metal emissions are compounded by the presence of industrial facilities that are potential emitters of such pollutants, often in the form of dust or smoke (Athanasopoulou & Kollaros, 2016).

In their study in Pakistan, Umer and Hüseyin (2023) revealed that the highest lead levels in the existing fuel and exhaust bodies of automobiles are present in the summer season, associated with increased wear and tear of automobile parts due to the high temperature of summer. Eight ornamental plant species commonly grown in various urban areas of Pakistan were tested for their lead hyperaccumulation potential and revealed *Bismarckia nobilis* and *Conocarpus erectus* plants as effective lead hyperaccumulator plant species.

Considering the harmful effects of heavy metals, precautions must be taken to minimize their effects on the environment and human health. In urban areas, especially along transportation routes, it is very important for landscaping to choose plants that can play a phytomediator role as well as fulfilling an aesthetic function (Widłak *et al*., 2017; Capuana, 2020; Rolka et al., 2020; Khan *et al*., 2021; Yasin *et al*., 2021). The success of phytoremediation depends on the volume of biomass produced, plant species, and bioavailability of metals (Sheoran et al., 2016). Moreover, successful implementation of the phytoremediation strategy depends on careful selection of genotypes, adjusting them to the contaminants therein. Great care should be taken in the selection of ornamental plants in an urban landscape (Capuana, 2020). Selection of multifunctional species is important in purifying the environment and improving the visual landscape value (Akpınar Külekçi, 2019; Capuana, 2020; Sezen and Akpınar Külekçi, 2020). In this direction, it is recommended to use local plants and consciously integrate them into the urban landscape.

However, the phytoremediation potential of plants is not considered, while their selection is often based on habitat conditions and aesthetic value. Thanks to their well-developed root systems, grasses are better than herbaceous plants at improving soil stability and forming compact vegetation, which means that they can be recommended for soil improvement purposes (Kompała-Bąba *et al*., 2021). The literature provides rich information about different plant species used for phytoremediation (Boros-Lajszner et al., 2021; Yasin et al., 2021). Considering that urban soils are exposed to a constant emission of pollutants, including trace elements, along transport routes, the choice of plants should be determined by their phytoremediation abilities. In this context, Rolka *et al*., (2022) determined in their study the phytomediator role of *Calamagrostis acutiflora* in heavy metal-polluted urban soils in Polnya and its adaptation to urban soils, revealing that this grass species could be an interesting choice in the landscaping of urban areas due to its high aesthetic value. Factors affecting phytoremediation of heavy metals; It consists of a few relevant factors such as soil properties, heavy metal type, and plant species (Deepika & Harikash, 2023).

Concerns About Plant Breeding Technology

One of the major concerns with phytoremediation technology is the low speed of this process compared to physical and chemical methods for remediating contaminated soils. Due to their slow growth, depending on climatic limitations and species diversity, it is possible that cleaning of a polluted area by plants may require many growing seasons. Plants with shallow roots can only cleanse the soil or surface water sources but cannot clean and improve the groundwater table and deep soil horizons (Sykes et al., 1999). There is also a risk of contamination of food chains by plants that absorb toxic substances because animals living in contaminated areas may feed on these plants (Moffat, 1995). Due to the strong adhesion of hydrophobic pollutants to soil particles, the phytoextraction technique is less

effective for them (Bizily *et al*., 1999). On the other hand, evaporation of polluting compounds can turn a water or soil pollution problem into an air pollution problem. But the biggest concern is with the reclamation facility: what will happen to the metal-rich contaminated plants once they are harvested? It is possible that biodegradation or use of contaminated plants may fully or partially return contamination to the soil (Gratao *et al*., 2005). The answer to this question is still unclear.

Conclusions

The current situation of environmental pollution caused by heavy metals will affect all components of the ecosystem. Various techniques are used to treat contaminated soil. To restore the balance of the environment, the phytoremediation technique has many benefits, such as low cost compared to physical and chemical soil modification methods, no impact on soil biodiversity, and reduction of soil erosion. Therefore, it is one of the most suitable methods to deal with the problem of accumulation of heavy metals in the environment.

Some ornamental plants have a high potential for phytoremediation of many pollutants and remediation of polluted environments because they have many and diverse species, tolerate very high pollutant concentrations, and can grow in many soils and polluted environments. These plants have the feature of cleaning polluted environments, having economic and ecological values, and improving the quality of landscapes. They can also serve as a warning indicator for atmospheric pollutants and the growth environment. These excellent plants do not enter the human food chain and therefore do not pose any health problems to humans. Research shows that copper, cadmium, nickel, lead, zinc, mercury, arsenic, and chromium are among the heavy polluting elements and some ornamental plants can accumulate these metals in high amounts. In developed countries, a natural treatment system was planned by taking these negativities into consideration and as a result, "Phytoremediation Systems" were introduced. The biomass of ornamental plants produced after such activities can be used and sold as raw materials in the production of potted plants, cut flowers, essential oils, perfumes, air fresheners, and silk production.

In this study, information was given about the negative effects of heavy metals on human health, and ornamental plants used in soil reclamation in landscape architecture were investigated according to the type of pollution. The potential effects of heavy metals on vegetation and the phytoremediation potential of ornamental plants, concerns about soil pollution in urban areas and plant reclamation technology. has been revealed. As a result of the study, it is recommended that the mentioned ornamental plants be used in landscaping works of both urban and rural areas in order to eliminate heavy metal pollution, taking into account the climatic conditions and usage areas. Ultimately, these recommendations also highlight the importance of expanding the reach of phytoremediation through research, marketing, and funding so that it can fully realize its potential to make the world a cleaner, greener place. To design and select a scientific, accurate and comprehensive strategy, considering the type of metal ions presents in the soil or water, the geographical location and climatic conditions of the target area and the potential, the effectiveness of the mentioned method depends on the characteristics of the plant in removing pollutants from the environment.

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Research Paper

Evaluation of Solid Waste Management in Mamak District Centre of Ankara Province

Esra Gümüş[1, *], Şükrü Dursun[2],

[1]*Konya Technical University, Institute of Graduate Studies Department of Environmental Engineering, Konya Turkiye, esratorun185@gmail.com;* [2]*Konya Technical University, Environmental Engineering Department, Konya, Türkiye, sdursun@ktun.edu.tr;*

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Abstract: Due to the increasing population and the concentration of population especially in metropolises, the solid waste problem is gradually increasing. Most of the solid wastes that arise as an important environmental problem consist of materials with recycling and recovery properties. It is important for solid waste generators to reduce the amount of solid waste or contribute to recycling. In this study, in order to determine the behaviours, attitudes, knowledge levels and sensitivities of individuals who play the most important role in solid waste management, a WEB-based questionnaire with 30 questions was applied to total 204 people aged 18 and over residing in Mamak. SPSS analysis was applied to the survey results and the margin of error of the study is 6.86 and the confidence interval is 95%. Normality analysis, ANOVA analysis, correlation and regression analyses were performed on the data obtained and frequency tables were created. As a result, it has been determined that most of the individuals participating in the survey, 44.60%, do not collect waste separately, do not attach enough importance to the separate collection of solid wastes at home and would like to have more information about reducing the waste generated in their daily lives. The 31.4% of the individuals participating in the survey stated that they would like to have a share in the recycling economy and that financial rewards would encourage them to separate waste and contribute to recycling. In this respect, it is important to make the society more conscious and sensitive by disseminating the zero waste approach and solid waste management studies.

Keywords: *Solid Waste Management, Zero Waste, Mamak, Ankara.*

Introduction

People's lifestyles, daily routines, consumption habits, socio-economic models and development levels have a significant impact on the amount and type of solid waste. Due to population growth, industrialisation, urbanisation and development of industry, the environmental impact of wastes has reached dangerous dimensions. Excessive production and consumption have also led to a significant increase in resource consumption. This situation increases the pressure on nature and disrupts the ecological balance. Since resources are not infinite and wastes have negative effects on personal health and the environment, it has been felt that important steps should be taken in waste management (Anonymous, 2019). Citizens of society are those who make decisions and act in ways that have a direct or indirect impact on their environment. Citizens need to be knowledgeable about environmental problems, understand potential solutions and be willing to implement effective solutions in order to make efficient decisions (Stapp, 1969).

The environmental sociology literature, which examines social-environmental relations at the point of explaining the causes of environmental problems, can empirically examine issues such as environmental attitudes and behaviours, environmental movements and environmental policies with a holistic perspective, as well as the effects of environmental events (such as the relationship between exposure to air pollution and social class as an independent or control variable) on social structure, or conduct conceptual and theoretical studies on the environment. In this context, dealing with issues such as garbage production, garbage content, sorting behaviour, recycling awareness depending on social status and/or class position also falls within the field of study of environmental sociology. For example, when saying "Tell me what you throw away, I'll tell you who you are!" (Baudrillard 2013), the reality that the amount and content of garbage, as well as environmental awareness, can change depending on social status / class position can be put forward sociologically (Aygül, 2018).

**Corresponding: E-Mail: esratorun185@gmail.com,*

Depending on a country's socioeconomic status, income sources, education and development level, culture and lifestyle, attitudes and behaviours towards waste management can vary significantly. In Turkey, which is among developing countries, there is an increase in interest in waste separation and recycling (Arı & Yılmaz, 2016).

Factors such as the rapid growth of our country in recent years and today in terms of economic conditions, developing industrialisation, urbanisation, increasing population and welfare level have led to a significant increase in the amount of waste produced. The problems encountered with the increase in waste amounts have made "sustainable waste management approach", which aims to create zero or minimum waste, a necessity (Ulaşlı, 2018).

In sustainable waste management, separation of wastes at source is very important for reuse, recycling, and recovery processes. Mixed collection of wastes leads to contamination of wastes and materials, weakening of reuse, recycling, and recovery conditions, decrease in the material value of waste, increase in waste residues in waste processing facilities, *etc*. It leads to problems. It is important to prevent these problems from the beginning of the waste management process (Topal, 2012).

The aim of this study is to determine the level of awareness of individuals in solid waste management and to evaluate and interpret solid waste management according to the research results. The problems encountered in solid waste management were determined and the studies that can be done for an integrated and conscious waste management were evaluated.

Material and Method

Characteristics of the research area

This research was conducted in Mamak district centre of Ankara province, located in the Central Anatolia region of the Republic of Turkey. Mamak district, 39° 56' 31"N and 32° 55' 23" D (Çakmak, 2016). The district borders Altındağ in the north, Elmadağ in the east, Çankaya and Elmadağ in the south, Çankaya and Altındağ in the west. There are 65 neighbourhoods in Mamak district. The district has a typical continental climate, winters are rainy and cold, summers are hot and dry. The annual rainfall in the region is around 360 to 420 kg/m2 (Çakmak, 2016). Ankara city centre is 3.5 km away from the district. Its height above sea level is 899 m and its surface area is 308 km2. Kökpınar hill, which is 1503 metres above sea level, is the highest point of Mamak district. The lowest point in the region is Dikimevi, which is 899 metres above sea level. Mamak district has a hilly geography (Mamak Municipality Introductory Booklet, 2021). There are Blue Lake (Bayındır Dam) and Hatip Stream within the district borders. Service, mining, agriculture, industry, and trade sectors play an important role in the district economy. The main economic activities of the district are civil service, craftsmanship, private sector and construction labour. In addition, slums and infrastructure, unemployment, lack of education, security and transport are considered as the main problems of the district (Mamak Municipality, 2022).

Mamak has been one of the most important symbols of squatting, uncontrolled urbanisation and environmental destruction since the 1950s. The most important cause of environmental destruction is the Mamak landfill (Özaslan, 2014). Mamak landfill is a large solid waste landfill with an area of 26.6 hectares (Güngör and Torunoğlu, 2022). Since it was thought that the Mamak landfill could cause negative impacts such as epidemics, natural resource pollution, visual pollution, bad odours, greenhouse gas emissions to the atmosphere and explosion risks, the improvement work was urgently implemented. The Mamak landfill was transformed into a solid waste reclamation centre thanks to the project implemented by Ankara Metropolitan Municipality in cooperation with ITC, which started operations in 2002.

The average amount of solid waste collected daily in Ankara is 5.000 tonnes. There are 13 private transfer stations in the province. There are two solid waste landfill sites in Mamak and Sincan districts of Ankara. Leachate collection systems are used in both locations (Ankara Provincial Directorate of Environment, Urbanisation and Climate Change, 2021). The figure shows the characteristics of solid wastes in Ankara province as of 2021. According to Figure 1, 52.58% of the wastes are biodegradable wastes. Table 1 shows the numerical values of solid waste potential generated in Mamak district from 2013 to 2022.

Mamak is the 4th largest district of Ankara in terms of population density. According to the 31 December 2022 Address Based Population Registration System results, Mamak district has a population of 687,535 people (TUİK, 2022). The total female population of Mamak district is 346,420 and the total male population is 340,915. In percentage terms, 50.38% of the total population is female and 49.62%

is male. It is seen that the population of Mamak has increased in recent years until today. The population statistics of Mamak between 2007 and 2022 are shown in Table 2.

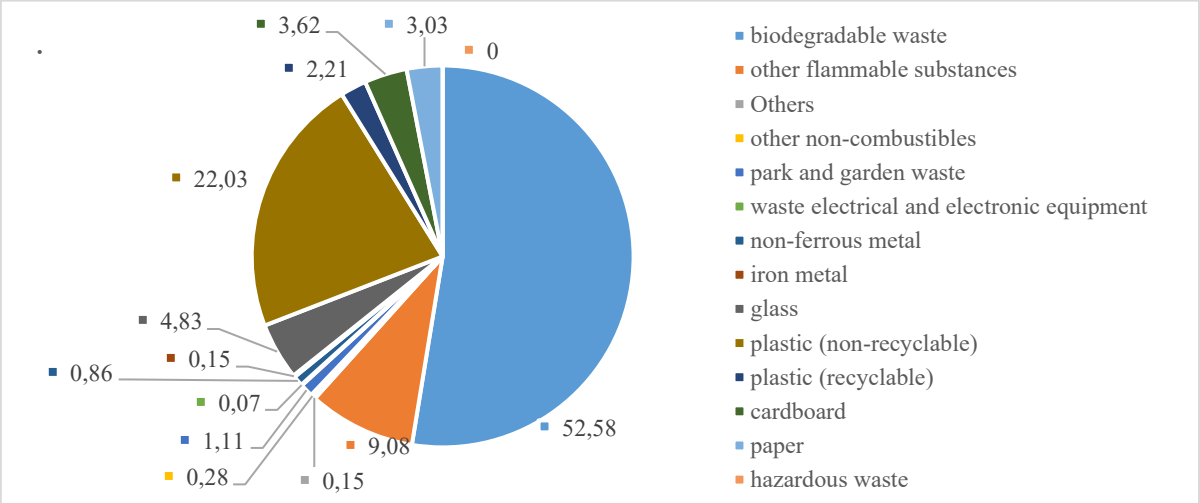

Figure 1. Waste characterisation of Ankara province in 2021 (Ankara Provincial Directorate of Environment, Urbanisation & Climate Change, 2021)

Table 1. Mamak district solid waste amounts collected between 2013-2022 (Mamak Municipality Directorate of Cleaning Affairs, 2022)

Amount of Waste Collected between 2013-2022 (Mamak Municipality Directorate of Cleaning Affairs, 2022)									
Year	**Domestic waste kg**	**Packaging waste kg**	**Textile kg**	**Vegetable oil waste kg**	**Pharmaceutical waste kg**	**Batterykg**	**Electronic waste kg**	**Hazardous waste fluorescents kg**	**Hazardous waste cartridges kg**
2013	No data	2.795.017,00		8.770,00					
2014	No data	4.075.430,00		17.480,00					
2015	160.220.480,00	4.120.660,00		3.100,00		2.730,00			
2016	160.480.830,00	5.631.480,00				1.759,00			
2017	162.980.010,00	6.903.120,00				469,50			
2018	179.601.600,00	12.620.680,00				5.057,90			
2019	175.378.585,00	7.102.020,00				560,19			
2020	191.306.170,00	1.225.320,00				1.338,20			
2021	184.018.310,00	2.505.740,00	17.172,00	1.947,00	239,00	253,00	77,00	550,00	50,00
2022	172.796.800,00	818.710,00	363.400,00	3.372,00	6,00	20,00	15,00	-	350,00
Total	1.386.782.780,00	47.971.377,00	380.572,00	34.669,00	245,00	12.187,79	92,00		400,00

Table 2. Mamak district population between 2007-2022 (TUIK, 2022)

Year	Mamak Population	Male population	Female Population
2022	**687.535**	340.915	346.620
2021	**682.420**	340.018	342.402
2020	**669.465**	333.567	335.898
2019	**665.978**	332.512	333.466
2018	**647.252**	323.710	323.542
2017	**637.935**	318.309	319.626
2016	**625.083**	313.174	311.909
2015	**607.878**	304.502	303.376
2014	**587.565**	394.672	292.893
2013	**568.396**	284.830	283.566
2012	**559.597**	282.464	277.133
2011	**558.223**	284.649	273.574
2010	**549.585**	281.036	268.549
2009	**532.873**	271.531	261.342
2008	**520.446**	263.156	257.290
2007	**503.663**	254.647	249.016

Evaluation of Solid Waste Management

In the research, quantitative research method and primary data analysis, field research and secondary data research were applied. A survey was conducted to determine the behaviours and attitudes of individuals residing in Mamak district centre of Ankara province on solid waste, their approaches to solid waste management, their sensitivity and knowledge levels on environment and waste management.

The survey content was created with Google Survey Forms tool. Thirty questions were prepared to serve the purpose of the research. Within the scope of the study, within 2 months (January-March 2023), a WEB-based 30-question survey was applied by delivering the relevant link and QR code to the participants without any special information of the individuals. For the survey study, a letter of approval was obtained from Konya Technical University Scientific Research and Publication Ethics Committee dated 08.12.2022. The data obtained from the research were analysed using SPSS analysis, margin of error and reliability level. Normality analysis, ANOVA analysis, correlation and regression analyses were performed, and frequency tables were created and interpreted.

A survey consisting of demographic and scale questions was designed to learn the waste awareness of individuals residing in Ankara Mamak district. After receiving survey answers from people with or without awareness and conducting research using the quantitive method, analyses and tables were created with the licensed SPSS 29 version package.

Here according to the number of people residing in Mamak district and based on a margin of error of 6.86%, the population of the research was determined as a minimum of 204 people in the research with the Raosoft Sample Size Calculation program, using the unknown sample size formula. (Raosoft,2004)

It is possible to state that this study is based on academic and practical knowledge. The sample size of the research was determined by taking into account the type of the research, the design of the research, the number of variables, the data analysis method to be applied, and the confidence interval accepted for estimation. 204 people aged 18 and over, living in Mamak district, were surveyed. The margin of error of the study is 6.86 and the confidence interval is 95%.

Findings

The results of the survey applied to 204 participants residing in Mamak district, demographics, frequencies and breakdowns and tables are shown below and explained in detail. In the survey conducted in Mamak district, 45.1% of the respondents were male and 54.9% were female (Table 3).

Table 3. Gender distribution of the participants

Gender		
	Number of answers (N)	**Per cent (%)**
Male	92	45,1
Female	112	54,9
Total	204	100

Table 4 shows the age distribution of the participants of the research conducted in Mamak district. It is stated that the age group that constitutes most of the survey is between 26-35 years old with 49%. Since this survey is a web-based survey, it is necessary to use a smartphone or computer with internet access. Accordingly, the proportion of respondents aged 60 and over is also low.

Table 4. Age distribution of the participants

Age range		
	Number of answers (N)	**Per cent (%)**
18-25	42	20,6
26-35	100	49
36-45	45	22,1
46-59	16	7,8
60 years and older	1	0,5
Total	204	100

Table 5. Distribution of education level of the participants

Education level		
	Number of answers (N)	**Per cent (%)**
primary school	12	5,9
postgraduate	18	8,8
high school	46	22,5
university	128	62,7
Total	204	100

The education levels of the people who participated in the study conducted in Mamak district are shown in Table 5. It is seen that 62.7% of the respondents are university graduates and 5.9% of them are primary school graduates. It is seen that as the level of education increases, the willingness and sensitivity to participate in the research also increases.

In the study conducted in Mamak district, 78.9% of the participants stated that they had a medium level of income (Table 6).

Table 6. Income level distribution of the participants

Income Level		
	Number of answer(N)	**Per cent(%)**
	1	0,5
low	36	17,6
medium	161	78,9
high	6	2,9
Total	204	100

Table 7. Distribution of duration of residence of the participants in Mamak district

Duration of Residence in Mamak District		
	Number of answers (N)	**Per cent (%)**
	1	0,5
11-15 years	17	8,3
16 years and over	63	30,9
Less than 5 years	88	43,1
5-10 years	35	17,2
Total	204	100

In Mamak, 43.1% of the respondents have been residing in the district for "less than 5 years". In addition, the number of those who have been living in the district for "16 years and more" is also quite high (Table 7). A very high rate of 97.1% of the respondents use the natural gas system (Table 8).

Table 8. Distribution of the participants heating system

Heating System of the House		
	Number of answers (N)	**Per cent (%)**
Natural gas	198	97,1
Electric Home Heating System	2	1
Air Conditioner	2	1
Stove	2	1
Total	204	100

Table 9. Distribution of the most important environmental problems in Mamak district according to the participants

Which environmental problem do you consider the most important in the district where you live?		
	Number of answers (N)	**Per cent (%)**
Noise pollution	24	11,8
Air pollution	17	8,3
Drinking water pollution	28	13,7
Insufficiency of sewerage-treatment facilities	11	5,4
Solid waste (rubbish) problem	57	27,9
Insufficient green areas	67	32,8

32.8 per cent of the participants stated that the most important environmental problem within the borders of Mamak district is the lack of green areas and 27.9 per cent stated solid waste and garbage problems (Table 9). It is seen that the participants of the survey conducted in Mamak district centre are disturbed about the lack of green areas and solid waste. In the research conducted by Yapıcı and Yaman (2020) by applying a questionnaire to 680 people residing in Karabük, it was determined that solid waste was evaluated as an important environmental problem and the residents of the region were not actively

involved in activities and it was concluded that individuals should play an active role. In a study conducted by Gül and Yaman (2021) on 648 people in Altındağ, Çankaya, Etimesgut, Sincan, Pursaklar, Yenimahalle, Keçiören and Mamak districts of Ankara, it was concluded that individuals consider solid waste as an important environmental problem in Ankara. The results of these studies support the findings of Mamak and it was revealed that individual opinions were similar.

Table 10. Participation in Training on Environmental Problems, Zero Waste and Solid Waste

Have you received any training on environmental issues, zero waste and solid waste?		
	Number of answers (N)	**Per cent (%)**
Yes	56	27,5
No	148	72,5
Total	204	100

As can be seen in the table, the majority of the people who participated in the research conducted in Mamak district were disturbed by the insufficiency of green areas and solid waste problems. When the same people were asked whether they had participated in any training on this subject, the majority (72.5%) stated that they had not (Table 10). In the survey conducted by Argun (2021), 48.9% of the participants in the questionnaire study on the question of receiving training on the environment did not receive any training on the environment, while the remaining participants received training at least once. When the results of the two studies are compared with each other, it is seen that the rate of participation in environmental education in Mamak is lower.

Table 11. Participants Thoughts about Waste

What do you think about waste?	**Number of answers (N)**	**Percent (%)**
Wastes disrupt the balance of the ecosystem when they are released into the environment, they may have harmful effects on human and environmental health, some wastes can be reused as raw materials and brought back to the economy, Some wastes can produce energy.	136	66,7
Some wastes can be reused as raw materials and brought into the economy.	11	5,4
When wastes are released into the environment, they disturb the balance of the ecosystem, they may have harmful effects on human and environmental health, Some wastes can be reused as raw materials and brought into the economy.	7	3,4
It may have harmful effects on human and environmental health, some wastes can be reused as raw materials and brought into the economy.	6	2,9
When wastes are released into the environment, they disturb the balance of the ecosystem.	5	2,5
It may have harmful effects on human and environmental health.	5	2,5
When wastes are released into the environment, they disrupt the balance of the ecosystem and may have harmful effects on human and environmental health.	4	2
Wastes disrupt the balance of the ecosystem when they are released into the environment, they may have harmful effects on human and environmental health, they are useless substances with an expired useful life, Wastes have no economic value.	4	2
It may have harmful effects on human and environmental health, some wastes can be reused as raw materials and brought back into the economy, some wastes can be used to produce energy.	4	2
When wastes are released into the environment, they disturb the balance of the ecosystem. Some wastes can be reused as raw materials and brought back to the economy; some wastes can produce energy.	3	1,5
Wastes disrupt the balance of the ecosystem when they are released into the environment, they may have harmful effects on human and environmental health, some wastes can be reused as raw materials and brought back to the economy, they are useless substances with an expired useful life.	3	1,5
Some wastes can be reused as raw materials and brought back into the economy; some wastes can be used to produce energy.	2	1

In the survey carried out in Mamak, the respondents were asked about the ideas about waste and their level of agreement with these ideas. Each participant has the right to give more than one answer. It is possible to say that the idea of "Wastes disrupt the balance of the ecosystem when they are left to the environment", "Wastes can have harmful effects on human and environmental health", "Some wastes can be reused as raw materials and brought back to the economy", "Some wastes can be used as raw

materials and brought back to the economy" are the most accepted ideas with a participation rate of 66.7% (Table 11). Considering the amount of solid waste (garbage) produced by households, 42.2% of the participants stated that the amount of solid waste (garbage) produced by their households is between 1 and 2 kg per day (Table 12). According to the 2021 State of Environment Report of Ankara province, the average amount of waste generated per person in Ankara province is 1.03 kg/day (Ankara Provincial Directorate of Environment, Urbanisation and Climate Change, 2021).

Table 12. Distribution of the approximate amount of waste generated in the house during the day

Approximately how many kilograms of solid waste (rubbish) are generated daily in your household?	Number of answers (N)	Per cent (%)
1 kg and less	61	29,9
1-2 kg	86	42,2
2-3 kg	37	18,1
3-4 kg	14	6,9
4-5 kg	6	2,9

According to the data of the Turkish Statistical Institute in 2021, the average household size in Ankara is 2.96 people and each household produces an average of 3.05 kg of waste. According to the results, most of the participants think that they create less waste in their homes. In the study conducted by Argun (2021) in Karaman, 1263 participants were asked a question to evaluate the amount of waste generated at home daily. 41.3% of the participants answered 1-2 kg. According to this result, the opinions of the individuals participating in the survey in Mamak district regarding the amount of waste generation are similar to the opinions of the individuals participating in the research in Karaman. In the research conducted by Kılıç (2017), in response to the question "Approximately how many kg of solid waste is generated daily where you live?", 27% in Yıldırım and Nilüfer and 28% in Osmangazi stated that 2-3 kg of solid waste can be generated from their homes, although the people living in all three districts do not know how much solid waste they generate daily. Although this amount varies depending on the eating and drinking habits of the people, the rate of those who produce less than 1 kg solid waste varies between 14-23%.

In response to the question "Which wastes are mostly generated in your household?", 80.4% of the participants answered, as "Kitchen wastes" (Table 13). The amount and content of household waste also depends on industrialisation, urbanisation, geographical location, socio-economic structure, seasonal changes, and dietary habits. According to the findings, to reduce and properly manage kitchen waste, participants should improve their consumption habits and adopt a zero-waste approach to cooking and food. In the survey conducted by Argun (2021), 93% of the participants answered the question of what kind of wastes are generated in your home (more than one marking can be made) as organic wastes, 51% as recyclable wastes and 23% as vegetable waste oils. In this context, it is seen that waste generators do not know the types of wastes they generate.

Table 13. Distribution of the most common wastes at home

Which wastes are mostly generated in your household?	Number of answers (N)	Per cent (%)
Paper waste (file papers, paper towels, magazines and newspapers, note papers)	5	2,5
Kitchen waste (napkins, leftover food, tin cans, grocery bags)	164	80,4
Plastic waste	13	6,4
Food packaging	22	10,8

Table 14. Distribution of participants opinions on separate collection of waste

What is your opinion on collecting waste separately (separation at source)?	Number of answers (N)	Per cent (%)
I think it will not help waste management.	6	2,9
It is not necessary to separate waste at source, waste can also be deposited in mixed form.	8	3,9
I have no information.	16	7,8
I think it will increase efficiency in recycling.	174	85,3

85.3% of the respondents in Mamak region accept and are aware of the idea that separation of wastes at source increases recycling efficiency (Table 14).

Table 15. Attitudes of participants towards separate collection of household waste

Do you collect your household waste (recyclable waste, food waste, hazardous waste, waste oil) separately?	Number of answers (N)	Per cent (%)
I collect waste oil separately from other waste.	5	2,5
Sometimes I save.	59	28,9
Saving.	22	10,8
I don't save.	91	44,6
I only collect recyclable waste separately from other waste.	20	9,8
I only collect hazardous waste separately from other waste.	7	3,4

The majority (44.6%) of the residents living in Mamak district who participated in the survey stated that they do not collect their wastes separately (Table 15). Kılıç (2017) conducted a survey among 600 people living in Yıldırım, Osmangazi and Nilüfer districts of Bursa. In this survey, the question "Do you separate your solid waste from home?" was asked. While most of the residents of Yıldırım and Osmangazi reported a positive opinion on waste separation, 51.1% of Nilüfer residents stated that they do not separate waste. As a result, the results obtained in Mamak are like these results. It is seen that individuals mostly do not spare time for separate waste collection.

Table 16. Distribution of **s**olid wastes outside the house

In general, what do you put solid waste (rubbish) in when you take it out of your home?	Number of answers (N)	Per cent (%)
I put them in shopping bags.	64	31,4
Other	2	1
I put it in a special rubbish bag.	133	65,2
I put it in the rubbish bin without using a bag.	5	2,5

The 65.2% of the residents of Mamak district who participated in the survey stated that they throw their solid waste and garbage into special garbage bags. In addition, there are also people who use shopping bags. According to the findings, it was concluded that more than half of the participants accumulate their solid waste and garbage in special garbage bags obtained from the markets (Table 16). In the study conducted by Kılıç (2017), when the survey participants were asked how they accumulate their solid wastes, 48% of the residents of Yıldırım district stated that they accumulate their solid wastes in special plastic garbage bags, 51% of the residents of Nilüfer and 50% of Osmangazi residents stated that they accumulate them in shopping bags. In both studies, the use of special rubbish bags and shopping bags is high.

Table 17. Distribution of participants time of taking their rubbish out of the house

Between which hours do you take your rubbish out of the house?	Number of answers (N)	Percent (%)
16.30-18.00	97	47,5
No specific time.	30	14,7
I'll take it out when the bin's full.	47	23
Whenever I want	16	7,8
On the way to work and school in the morning	14	6,9

These findings can be interpreted as that the participants, who are assumed to live in an apartment with natural gas, take out their rubbish at regular intervals in accordance with the rules of the apartment. 47.5% of the individuals take out their garbage between 16.30 and 18.00 (Table 17). It was concluded that garbage collection services are generally available in the evening hours in Mamak district, and accordingly, individuals take out their garbage in the evening hours.

58.8% of the participants use the plastic bags, which they buy from the market for 25 kuruş, to carry and store the products they buy from the market. 35.3% of the individuals take cloth bags or net bags to the market to carry and store the products (Table 18). Since 2019, the practice of making grocery bags paid in our country has led many individuals to use reusable cloth bags and nets.

Table 18. Distribution participants methods of preserving products purchased from the supermarket.

What do you use to transport and store the products you buy from the supermarket?	Number of answers (N)	Per cent (%)
I use the bags I buy from the supermarket for 25 cents.	120	58,8
I'm using a market trolley.	5	2,5
I'm using my rucksack.	6	2,9
I use reusable cloth bags or mesh bags.	72	35,3

According to the findings, 82.4% of the participants were aware that batteries pose a potential danger to human and environmental health (Table 19).

able 19. Participants knowledge of waste materials harmful to the environment

Which of the waste materials is more dangerous for the environment than the others?	Number of answers (N)	Paper (%)
Paper	2	1
Metals	26	12,7
Batteries	168	82,4
Food waste	8	3,9

Table 20. Distribution of the ways of reaching Mamak Municipality for solid waste management requests and complaints

By which means do you convey your complaints and requests regarding solid waste management services to Mamak Municipality?	Number of answers (N)	Per cent (%)
By petition	4	2
Electronic Mail	12	5,9
All of them	51	25
Mamak Municipality Official Website	23	11,3
With Social Media Tools	50	24,5
Telephone	64	31,4

It was concluded that complaints and requests regarding solid waste management were mainly communicated through social media and telephone calls (Table 20). In the study conducted by Solak (2018), 34.9% answered the question "In which ways do citizens convey their complaints and requests to your municipality regarding the provision of solid waste management?" with information phones. Social media has also started to be used at a significant rate as a means of wishes and complaints.

Table 21. Distribution of participants awareness of recycling waste

Do you know about recyclable waste?	Number of answers (N)	Per cent (%)
I know some of them.	85	41,7
I know.	112	54,9
I don't know.	7	3,4

It is seen that half of the participants answered the question "Do you know about recyclable wastes?" as having knowledge, and less than half of the participants answered that they partially know (Table 21). In the survey conducted by Gündüz (2021) among 307 people consisting of Necmettin Erbakan University students, academicians, administrative staff and private sector employees, 69% of the participants strongly agreed with the question "I know that wastes are classified". It can be said that the more people are aware of whether the wastes they produce are within the scope of recyclable waste, the more likely they will contribute to the Zero Waste Project.

Table 22. Participants knowledge about the existence of recycling bins- clothes and shoes

Are there recycling bins close to your home or within your reach where you can leave your old clothes and shoes to deliver them to people in need?	Number of answers (N)	Per cent (%)
I don't know, I haven't seen it.	19	9,3
Yes, I do, but I only see it.	47	23
Yes, there are, but not in sufficient numbers.	31	15,2
Yes, I know where it is and I'm using it.	92	45,1
No, I don't.	15	7,4

45.1% of the residents of Mamak district who participated in the research reported that there are recycling bins for clothes and shoes near or within a close distance of their homes, that they know where these bins are located and that they use these bins. 23% stated that they have seen these bins but have never used them (Table 22). In another study involving 315 students studying in the department of science teaching in Turkey, it was determined that 41.4% of first-year students, 36.2% of second-year students, 48.8% of third-year students, and 51.1% of fourth-year students had a recycling container 250 metres or closer to their residence (Harman & Çelikler, 2018). In a study examining the change in the recycling behaviour of consumers in Turkey over the years, the rate of consumers who thought that recycling containers were too far away was 62.1% in 2006, while this rate was 54.3% in 2012 (Bayraktar and Çobanoğlu, 2016).

Table 23. Participants knowledge about the existence of recycling bins- glass, paper, plastic and battery

Are there recycling bins close to your home or within your reach where you can leave your glass, paper, plastic and battery waste?	Number of answers (N)	Per cent (%)
I don't know if there is. I don't know if there is.	49	24
Yes, I do, but I only see it.	35	17,2
Yes, there are, but not in sufficient numbers.	25	12,3
Yes, I know where it is and I'm using it.	25	12,3
No, I don't.	70	34,3

It is stated that 12.3 per cent of Mamak residents who participated in the research have recycling bins near their houses where they can leave glass, paper, plastic, and battery waste, know where these bins are located and even use these bins. On the other hand, 34.3 per cent of the residents said that there were none (Table 23). In a survey conducted by Gül and Yaman (2021), it was concluded that there are "partially" piggy banks where waste can be collected separately according to type in accordance with zero waste projects. According to these results, it is considered that increasing the number of recycling bins for glass, paper, plastic and battery wastes will contribute to a conscious waste management.

Table 24. Participants knowledge about recycling purposes

Which is not one of the purposes of recycling?	Number of answers (N)	Per cent (%)
Reducing the amount of waste.	11	5,4
Recycling of wastes into second raw materials by various methods and bringing them into the economy.	25	12,3
To ensure the protection of natural resources.	9	4,4
Mixed accumulation of all kinds of waste.	159	77,9

In response to the question "Which of the following is not one of the objectives of recycling?", the answer "Mixed accumulation of all kinds of wastes" was given predominantly (Table 24). It is known by the majority that mixed waste accumulation does not contribute to recycling aims and objectives. However, 10.8% of the participants separate and accumulate their wastes.

Table 25. Distribution of participants opinions on zero waste

What is your opinion on Zero Waste?	Number of answers (N)	Per cent (%)
I have no information.	20	9,8
It will be beneficial for the environment.	34	16,7
When applied correctly, it will reduce waste generation, and if waste is generated, it will ensure that it is collected separately at its source and recycled.	97	47,5
I think that it is not given enough importance by the society.	44	21,6
It is a difficult goal to achieve.	9	4,4

It is seen that 47.5% of Mamak residents who participated in the research answered, "When implemented correctly, it will reduce waste generation, and if waste is generated, it will ensure that it is collected separately at the source and recovered" and a relationship is established that zero waste contributes to recovery (Table 25).

Table 26. Distribution of participants zero waste lifestyle behaviours

What are you doing about Zero Waste lifestyle?	Number of answers (N)	Per cent(%)
I avoid the use of disposable products (such as plastic, cardboard, paper forks, knives, plates, straws).	83	26,4
When I go shopping, I use net or cloth bags instead of plastic bags.	38	12,1
I leave the waste I collect separately in recycling bins or waste collection centres.	9	2,87
I transform stale bread into different flavours by making use of it instead of throwing it away, I think about whether I really need something before I buy it, I donate the things I do not use to charities and charitable organisations.	20	6,37
I collect the waste in my house separately, I transform stale bread into different flavours instead of throwing it away.	30	9,55
When I go to a coffee shop, I take my own coffee cup or flask, I collect the wastes in my house separately, I leave the wastes I collect separately in recycling bins or waste collection centres, I think about whether I really need something before I buy it.	30	9,55
I sell the things I don't use to second-hand shops or people who want to buy them over the internet, I transform stale bread into different flavors by evaluating it instead of throwing it away.	77	24,52
I shop in shops that sell products by weight without packaging, I leave the waste I collect separately in recycling bins or waste collection centers, I transform stale bread into different flavors by evaluating it instead of throwing it away, I think about whether I really need something before I buy it.	24	7,64
I buy some of the things I need second-hand or rent them.	1	0,32
I think about whether I really need something before I buy it, I donate the things I don't use to charities and charitable organizations.	1	0,32
I participate in training and awareness raising activities on environment, waste and zero waste.	1	0,32

Respondents living in the district are not very aware of the zero-waste lifestyle, with only 26.43% saying that they do not use single-use materials (Table 26).

Table 27. Distribution of participants opinions on the reduction of household waste

Do you plan to reduce your household waste?	Number of answers (N)	Per cent (%)
When I know more about reducing waste, I plan to reduce it.	55	27
I don't think so.	17	8,3
Thinking.	132	64,7

In Mamak district, 1 out of every 6 people who participated in the research said that they think about reducing the amount of waste generated at home (Table 27). In the research conducted by Argun (2021), 46 percent of the participants answered, "I think" and 43.6 percent answered "I would think if I had information about how to reduce it" to the question "Do you think about reducing the waste generated in your home?". This means that 90% of the people want to reduce their waste but do not have information on how to do so. In both studies, the opinions of individuals are similar.

Table 28. Participants Awareness of Mamak 1st class waste collection center

Do you know the Mamak Municipality 1st Class Waste Collection Center on Samsun Road, which was opened within the scope of the "Zero Waste" project to prevent environmental pollution and to recycle recyclable waste into the economy?	Number of answers (N)	Per cent (%)
I know, but I've never been.	62	30,4
I know and I take my recyclable waste to this waste collection center.	12	5,9
I don't know.	130	63,7

It was observed that 63.7% of the participants answered "I do not know" to the question "Do you know about Mamak Municipality 1st Class Waste Collection Center?" (Table 28). This result shows that the residents participating in the research are unaware of the waste collection center in their districts. It is important to organize events, meetings and seminars for the residents of the region to be aware of the waste collection center and waste types in their districts, and to organize events, meetings and seminars in order to have their wastes collected or brought.

Table 29. Distribution of participants expectations about contributing to recycling

What will make society want to collect household waste separately and contribute to the recycling process?	Number of answers (N)	Per cent (%)
Showing concretely where, how and what waste is transformed into and what it is used for.	26	12,7
Increasing collection containers for separately collected waste.	35	17,2
To inform the society more about the importance of the issue, to create environmental awareness.	47	23
Rewarding citizens.	32	15,7
Citizens are included in the process and get their share of the recycling economy.	64	31,4

It is seen that the residents of the region who participated in the research want to have a share in the "recycling economy" and want to say that financial rewards will encourage them (Table 29). In a study conducted by Aygül and Yıldız (2018) in Antalya-Muratpaşa district, it was observed that 64 percent of those who sorted waste at source when individuals received money in return consisted of people who had not sorted waste at source before. This result is an indication of how effective it can be for citizens to contribute to the process by separating at source and taking their share of the recycling economy.

Table 30. Distribution the most important problems that respondents see in solid waste management services.

Which is the most important problem related to the provision of solid waste management services?	Number of answers (N)	Per cent (%)
Lack of awareness of responsibility among waste generators.	28	13,7
Problems with inspections.	22	10,8
Public institutions and organizations do not pay enough attention to the issue.	35	17,2
Lack of information and education about the importance of the issue.	75	36,8
Insufficient equipment (personnel, vehicles, containers, etc.) in institutions.	16	7,8
Inadequate legal regulations.	28	13,7

According to the results, "lack of education and information" is seen as the most important problem in solid waste management services by 36.8% (Table 30). In a study conducted by Argun (2021), 59.5% of the participants responded to the question "What do you think are the obstacles to waste minimization and recycling?" in which more than one option was marked, 59.5% of the participants answered lack of responsibility awareness, 52.7% answered lack of education and information. This issue is encountered in many tables and is seen as one of the processes that should be prioritized.

Table 31. Distribution of the participants opinions on raising social awareness in Mamak district

What should be done to make the society more aware of solid waste and environmental pollution in the district where you live?	Number of answers (N)	Per cent (%)
Environmental awareness and waste should be taught in schools, especially in kindergartens and nurseries.	42	20,6
Meetings and seminars should be organized in which everyone can participate.	20	9,8
Citizens should be made more aware through advertisements, posters and announcements.	34	16,7
Those who break the rules should be fined.	45	22,1
There should be more awareness-raising programs and posts on TV, radio and social media.	63	30,9

According to these results, 30.9% of the participants think that more awareness-raising programs and posts should be made on TV, radio and social media tools in order to raise public awareness in Mamak district (Table 31). The results show that these tools will help to access and share information faster, reach more people, exchange ideas and increase communication awareness.

Table 32. Participation in Education in Mamak District

Would you participate if there were activities or studies on waste, solid waste management, zero waste and environmental awareness in the district where you live?	Number of answers (N)	Per cent (%)
Yes	167	81,9
No	37	18,1

To the question "Would you participate if there were activities or studies on waste, solid waste management, zero waste and environmental awareness in the district where you live?" 81.9% of the participants answered "Yes" (Table 32). In the study conducted by Gündüz (2021) among 307 students, academicians, administrative staff and private sector employees at Necmettin Erbakan University, 31% of the participants answered, "strongly agree" and 23.4% answered "agree" to the question "I would participate if an event on Zero Waste management is organized at the university". These results show that as the level of education increases, the level of awareness, problem awareness and the rate of being disturbed by this problem increases. As the level of education increases, the willingness to participate in the activity also increases.

Table 33. Normality analysis

			Statistic	Std. Error
Gender:	Mean		1,55	0,035
	95% Confidence Interval for Mean	Lower Bound	1,48	
		Upper Bound	1,62	
	5% Trimmed Mean		1,55	
	Median		2	
	Variance		0,249	
	Std. Deviation		0,499	
	Minimum		1	
	Maximum		2	
	Range		1	
	Interquartile Range		1	
	Skewness		**-0,198**	0,17
	Kurtosis		**-1,98**	0,339
Have you received any training on environmental issues, zero waste and solid waste?	Mean		1,73	0,031
	95% Confidence Interval for Mean	Lower Bound	1,66	
		Upper Bound	1,79	
	5% Trimmed Mean		1,75	
	Median		2	
	Variance		0,2	
	Std. Deviation		0,447	
	Minimum		1	
	Maximum		2	
	Range		1	
	Interquartile Range		1	
	Skewness		**-1,018**	0,17
	Kurtosis		**-0,973**	0,339

	Kolmogorov-Smirnova			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
Gender:	0,366	204	<,001	0,633	204	<,001
Have you received any training on environmental issues, zero waste and solid waste?	0,456	204	<,001	0,558	204	<,001

Normality analysis was tested on two questions of the research (Table 33). It is possible to say that the data are normally distributed. Accordingly, ANOVA, Pearson correlation and regression analyses will be applied.

Table 33 shows the Skewness and Kurtosis values, which we examined as kurtosis and skewness through normality analysis. Here, we say that it does not show a normal distribution because the reference ranges are not provided (normal distribution not provided in studies conducted with Likert scale)

- Source citing Shapiro Wilks and Kolmogorov Smirnov tests: Büyüköztürk, Ş. (2011). *Data Analysis Handbook for Social Sciences*. Ankara: Pegem Akademi, p: 42.
- Values between+- 1,00 are considered sufficient source: Büyüköztürk, Ş., Çokluk, Ö., Köklü, N. (2011). *Statistics fot the Social Sciences* (7th Ed.). Ankara: Pegem Akademi, p:48-63.

Table 34. ANOVA Test According to Gender, Age, Education Level, Income Level, Residence in Mamak District

		Sum of Squares	df	Mean Square	F	Sig.
Gender:	Between Groups	1,882	1	1,882	7,82	0,006
	Within Groups	48,627	202	0,241		
	Total	50,51	203			
Age:	Between Groups	0,726	1	0,726	0,964	0,327
	Within Groups	152,195	202	0,753		
	Total	152,922	203			
Education Level:	Between Groups	0,264	1	0,264	0,541	0,463
	Within Groups	98,481	202	0,488		
	Total	98,745	203			
Your income level:	Between Groups	0,264	1	0,264	0,541	0,463
	Within Groups	98,481	202	0,488		
	Total	98,745	203			
Duration of residence in Mamak district:	Between Groups	0,264	1	0,264	0,541	0,463
	Within Groups	98,481	202	0,488		
	Total	98,745	203			
Approximately how many kilograms of solid waste (garbage) are generated daily in your household?	Between Groups	8,922	1	8,922	9,163	0,003
	Within Groups	196,705	202	0,974		
	Total	205,627	203			
Do you know the Mamak Municipality 1st Class Waste Collection Center on Samsun Road, which was opened within the scope of the "Zero Waste" project to prevent environmental pollution and to recycle recyclable waste into the economy?	Between Groups	3,35	1	3,35	4,077	0,045
	Within Groups	165,983	202	0,822		
	Total	169,333	203			

		Point Estimate	95% Confidence Interval	
			Lower	Upper
Gender:	Eta-squared	0,037	0,003	0,1
	Epsilon-squared	0,033	-0,002	0,096
	Omega-squared Fixed-effect	0,032	-0,002	0,096
	Omega-squared Random-effect	0,032	-0,002	0,096
Age:	Eta-squared	0,005	0	0,041
	Epsilon-squared	0	-0,005	0,036
	Omega-squared Fixed-effect	0	-0,005	0,036
	Omega-squared Random-effect	0	-0,005	0,036
Education level:	Eta-squared	0,003	0	0,034
	Epsilon-squared	-0,002	-0,005	0,029
	Omega-squared Fixed-effect	-0,002	-0,005	0,029
	Omega-squared Random-effect	-0,002	-0,005	0,029
Your income level:	Eta-squared	0,003	0	0,034
	Epsilon-squared	-0,002	-0,005	0,029
	Omega-squared Fixed-effect	-0,002	-0,005	0,029
	Omega-squared Random-effect	-0,002	-0,005	0,029
Duration of residence in Mamak district:	Eta-squared	0,003	0	0,034
	Epsilon-squared	-0,002	-0,005	0,029
	Omega-squared Fixed-effect	-0,002	-0,005	0,029
	Omega-squared Random-effect	-0,002	-0,005	0,029
Approximately how many kilograms of solid waste (garbage) are generated daily in your household?	Eta-squared	0,043	0,005	0,109
	Epsilon-squared	0,039	0	0,105
	Omega-squared Fixed-effect	0,038	0	0,105
	Omega-squared Random-effect	0,038	0	0,105
Do you know the Mamak Municipality 1st Class Waste Collection Center on Samsun Road, which was opened within the scope of the "Zero Waste" project to prevent environmental pollution and to recycle recyclable waste into the economy?	Eta-squared	0,02	0	0,072
	Epsilon-squared	0,015	-0,005	0,068
	Omega-squared Fixed-effect	0,015	-0,005	0,067
	Omega-squared Random-effect	0,015	-0,005	0,067

According to Table 34, it is checked whether there is a homogeneous distribution between the independent variables and the dependent variable (scale mean), and it is expected that the sig (p) value is greater than 0.05.

Table 35. Pearson Correlation Test by Gender, Age, Education Level, Income Level, Residence in Mamak District

		Gender:	Age:	Education level:	Your income level:	Duration of residence in Mamak district:	Have you received any training on environmental issues, zero waste and solid waste?	Approximately how many kilograms of solid waste (garbage) are generated daily in your household?	Do you know the Mamak Municipality 1st Class Waste Collection Center on Samsun Road, which was opened within the scope of the "Zero Waste" project to prevent environmental pollution and to recycle recyclable waste into the economy?
Gender:	Pearson Correlation	1	0,047	-0,035	-0,035	-0,035	,193**	0,078	0,007
	Sig. (2-tailed)		0,504	0,622	0,622	0,622	0,006	0,269	0,918
	N	204	204	204	204	204	204	204	204
Age:	Pearson Correlation	0,047	1	-0,1	-0,1	-0,1	0,069	,225**	-0,035
	Sig. (2-tailed)	0,504		0,154	0,154	0,154	0,327	0,001	0,617
	N	204	204	204	204	204	204	204	204
Education level:	Pearson Correlation	-0,035	-0,1	1	1,000**	1,000**	-0,052	0,053	-0,028
	Sig. (2-tailed)	0,622	0,154		<,001	<,001	0,463	0,448	0,687
	N	204	204	204	204	204	204	204	204
Your income level:	Pearson Correlation	-0,035	-0,1	1,000**	1	1,000**	-0,052	0,053	-0,028
	Sig. (2-tailed)	0,622	0,154	<,001		<,001	0,463	0,448	0,687
	N	204	204	204	204	204	204	204	204
Duration of residence in Mamak district:	Pearson Correlation	-0,035	-0,1	1,000**	1,000**	1	-0,052	0,053	-0,028
	Sig. (2-tailed)	0,622	0,154	<,001	<,001		0,463	0,448	0,687
	N	204	204	204	204	204	204	204	204
Have you received any training on environmental issues, zero waste and solid waste?	Pearson Correlation	,193**	0,069	-0,052	-0,052	-0,052	1	,208**	,141*
	Sig. (2-tailed)	0,006	0,327	0,463	0,463	0,463		0,003	0,045
	N	204	204	204	204	204	204	204	204
Approximately how many kilograms of solid waste (garbage) are generated daily in your household?	Pearson Correlation	0,078	,225**	0,053	0,053	0,053	,208**	1	0,036
	Sig. (2-tailed)	0,269	0,001	0,448	0,448	0,448	0,003		0,612
	N	204	204	204	204	204	204	204	204
Do you know the Mamak Municipality 1st Class Waste Collection Center on Samsun Road, which was opened within the scope of the "Zero Waste" project to prevent environmental pollution and to recycle recyclable waste into the economy?	Pearson Correlation	0,007	-0,035	-0,028	-0,028	-0,028	,141*	0,036	1
	Sig. (2-tailed)	0,918	0,617	0,687	0,687	0,687	0,045	0,612	
	N	204	204	204	204	204	204	204	204

*There is a significant relationship between the criteria indicated as ** at 0.01 level (Table 35).*
*There is a significant relationship between the criteria indicated as * at 0.05 level (Table 35).*

Table 35 shows the relationship between the independent variables (demography questions) and the dependent variable. Especially in Pearson Correlation values, it is necessary to look at the criteria that the expressions indicated as * or ** are in a significant relationship at the level of 0.05 and 0.01, and that the sig (p) value is greater than 0.05. We see that the expressions that appear as 1,000** are

one-to-one correlated. In Table 36, the relationship between more than one independent variable and the scale is analysed and the sig (p) value less than 0,05 is accepted.

Table 36. Regression Test by Gender, Age, Education Level, Income Level, Residence in Mamak District

R	R Square	Adjusted R Square	Std. Error of the Estimate	Durbin-Watson	
,048a	0,002	-0,013	0,919	2,097	
	Sum of Squares	df	Mean Square	F	Sig.
Regression	0,394	3	0,131	0,156	,926b
Residual	168,939	200	0,845		
Total	169,333	203			
	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
(Constant)	2,515	0,38		6,611	<,001
Gender:	0,015	0,13	0,008	0,112	0,911
Age:	-0,041	0,075	-0,039	-0,546	0,586
Duration of residence in Mamak district:	-0,042	0,093	-0,032	-0,45	0,653

	Minimum	Maximum	Mean	Std. Deviation	N
Predicted Value	2,21	2,46	2,33	0,044	204
Std. Predicted Value	-2,723	2,904	0	1	204
Standard Error of Predicted Value	0,092	0,239	0,125	0,032	204
Adjusted Predicted Value	2,17	2,48	2,33	0,05	204
Residual	-1,421	0,787	0	0,912	204
Std. Residual	-1,546	0,856	0	0,993	204
Stud. Residual	-1,578	0,878	0	1,003	204
Deleted Residual	-1,48	0,828	0	0,931	204
Stud. Deleted Residual	-1,584	0,878	-0,002	1,004	204
Mahal. Distance	1,023	12,701	2,985	2,234	204
Cook's Distance	0	0,027	0,005	0,005	204
Centered Leverage Value	0,005	0,063	0,015	0,011	204

Conclusion

- As the most important environmental problem within the borders of Mamak district, 32.8% of the participants answered insufficient green areas and 27.9% answered solid waste (garbage).
- The majority of the participants, 72.5%, state that they have not participated in any training on environmental problems, zero waste and solid waste.
- In the question where the daily amount of waste was evaluated, 42.2% of the participants answered 1-2 kg.
- 80.4% of the participants stated that kitchen waste was the most common waste generated from their homes.
- 85.3% of the participants think that separating waste at source will contribute to recycling.
- The majority of the participants, 44.6%, do not collect their wastes separately.
- 65.2% of the participants use special garbage bags when taking their garbage out of the house.
- 47.5% of the participants take out their rubbish between 16.30-18.00.
- 58.8% of the participants stated that they use plastic grocery bags to store the products they buy from the market.
- 82.4% of the participants think that batteries are more dangerous for the environment than other wastes.
- 31% of the participants think that getting a share from the recycling economy will contribute to the process of recycling and separate waste collection.
- 36.8% of the participants state that the most important problem encountered in solid waste management services is the lack of information and training.
- 81.9% of the participants stated that they would like to participate in activities and studies related to waste.
- When the answers given to the questions are evaluated according to demographic characteristics, the awareness of male individuals about solid wastes is higher than female individuals.

Discussion and Recommendations

Individuals who participated in the research think that the most important environmental problems in Mamak are the lack of green areas (32.8%) and solid waste (garbage) (27.9%). 72.5% said that they had not participated in trainings to solve these problems before.

Looking at the educational level in the results, the number of university graduates is quite high and as the educational level increases, there is a tendency for people to want to receive training on environment and waste management and to increase their awareness on these issues. As the education level of individuals increases, the rate of realizing the problems and feeling discomfort increases. In addition, as the level of education increases, there is an expectation for training, conferences and seminars related to this process.

Most of the individuals participating in the research think that they produce less waste at home. It is important for producers to be aware of the wastes they produce in order to prevent and reduce waste. When the answers given to the questions are analyzed according to demographic characteristics, it is concluded that male individuals are more aware of solid waste than female individuals.

85.3% of the respondents think that separation of waste at source increases recycling efficiency. However, 44.60% of them state that they do not separate their wastes at source. These results show that individuals do not have knowledge about how to separate waste at source and cannot actively apply the idea of separating waste in their daily lives.

According to the responses of the participants, requests and complaints regarding solid waste management are mostly communicated to Mamak Municipality through phone calls and social media. In this context, it is considered that the widespread use of Mamak Municipality's official website and mobile application may be beneficial.

Increasing the number of recycling bins where Mamak residents can leave their glass, paper, battery and plastic waste near their homes or within easy reach is expected to make a significant contribution to recycling.

According to the results, it was concluded that individuals have not yet adopted a zero-waste lifestyle. It is considered that the implementation and continuation of activities that encourage individuals about zero waste will contribute positively to the adoption of zero waste lifestyle.

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Research Paper

Kahramanmaras Earthquakes: How Critical is the Uninterrupted Fuel Supply

Aysun Korucan[1,2], Sinem Okumuş[1,*]

[1]*Energy Market Regulatory Authority of Türkiye, 06510, Ankara, Türkiye;* [2]*Department of Economics, Middle East Technical University, 06531 Ankara, Türkiye.* akorucan@epdk.gov.tr

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Abstract: Historically, many cataclysmic earthquakes shook Türkiye, but the most devastating ones were on Feb. 6, 2023. Unprecedentedly, a pair of earthquakes caused a massive death toll, thousands of casualties, displacement of millions of people and damage to infrastructure. Logistically, fuel was indispensable for conveying urgent need goods to the disaster zones, so meticulous monitoring of fuel supply was critical. Under these chaotic and unexpected conditions, accessing real-time market data is invaluable for governmental authorities to make instant decisions. During the operations of disaster management, a fuel monitoring system, unique in the world in terms of providing real-time fuel data, was utilized in Türkiye. The data obtained from this system guided Turkish decision-makers to analyze and assess the impacts of the quakes on the market. This paper aims to reveal how the fuel supply and demand have been affected by the recent devastating Kahramanmaras earthquakes based on the monitoring system data. For this purpose, gasoil and gasoline sales between Jan. 30 and Feb. 13, 2023 were used as inputs for indexing/escalating, and daily sales data were adjusted by taking sales made on Jan. 30 as 100. The outputs of this study indicate that people ran to the stations in panic on the first day of the earthquakes. Hence, fuel sales increased remarkably in the less-affected zones, and some regions faced the risk of running out of gasoline due to the destruction of infrastructure and stations. Along with these striking outcomes, some recommendations for mitigating the negative impacts of upcoming earthquakes are also provided in this paper.

Keywords: *Fuel Monitoring; Kahramanmaras Earthquakes; Impacts on Fuel Market; Indexation*

Introduction

The sudden release of energy in the Earth's lithosphere that creates seismic waves results in numerous earthquakes every year. These unpredictable natural events can cause significant casualties (deaths and injuries) and damage infrastructures (residential areas, cultural heritages, industrial facilities, highways, etc.). Some countries have a higher propensity for earthquakes than others due to their location close to tectonic plates. Türkiye, among the world's most seismically active countries, has experienced several devastating earthquakes in its history, lost more than hundreds of thousands of people, and faced widespread destruction. In 2022, there were 20,288 earthquakes registered in Türkiye, or an average of 56 earthquakes per day (BDTIM, 2023).

On Feb. 6, 2023, two severe earthquakes with a magnitude of 7.8 and 7.5 (Kahramanmaras earthquakes) struck ten provinces in the southeastern part of Türkiye. These quakes are among the most powerful in the country's history, killing over 50,000 people and wounding thousands. Because of a pair of cataclysmic earthquakes, a three-month state of emergency was declared in 10 provinces of Türkiye: Adana, Adiyaman, Diyarbakir, Gaziantep, Hatay, Kahramanmaras, Kilis, Malatya, Osmaniye and Sanliurfa.

Kahramanmaras earthquakes occurred on Feb.6, 2023, at 4:17 a.m. and 1:24 p.m. local time (GMT+3), respectively. People in earthquake zones experienced the destructive impacts of the first earthquake while sleeping. After these two earthquakes, more than 200,000 buildings in ten provinces collapsed, and many people were stuck under the rubble. Search and Rescue (SAR) teams were deployed to initiate their operations as soon as possible to minimize the death toll and save people from demolished buildings. In the aftermath of the quakes, providing some crucial needs such as containers, tents, food and water, became the priorities of the governmental bodies and charities to save lives,

**Corresponding: E-Mai: okumus@epdk.gov.tr; Tel: +90(312)2014475*

evacuate victims and make the lives of survivors easier. Therefore, continuous fuel supply was crucial for the organizations racing against time in earthquake-stricken areas.

Under these unexpected and chaotic circumstances, real-time market data on fuel sales and stocks became invaluable for immediate decision-making. The Turkish fuel monitoring system comprised of the automation systems at the petrol stations and the storage facilities were utilized to provide hourly and daily data on fuel stocks and sales to the governmental agencies. Although this system was implemented to monitor the entire fuel market activities and prevent fuel tax evasion and smuggling, it was particularly useful for Türkiye to obtain real-time market data after devastating earthquakes.

This paper aims to provide information about how the Kahramanmaras earthquakes affected the Turkish fuel market and how governmental agencies used real-time fuel data to make instant decisions. The rest of the study is organized as follows. Earthquakes in Türkiye are introduced in Section 2. Turkish fuel monitoring system and the impacts of the Kahramanmaras Earthquakes on the Turkish fuel market are discussed in Section 3. Section 4 offers further implications on the earthquakes, and Section 5 concludes the paper.

Post-earthquake decision-making is quite challenging for governmental bodies, non-governmental organizations and municipalities. Explaining the priorities and making critical decisions under severe stress conditions are of great importance for search and rescue and delivery of urgent needs (Basbug et al., 2015). After Feb. 6, 2023, Turkish authority as a decision-maker faced a number of dilemmas, such as balancing short- and long-term needs (e.g. fuel supply to the quake-affected region) (Platt, 2016).The 10 provinces were not impacted by the two earthquakes to the same extent and also the pillars of the market in each province (such as daily fuel consumption, differentiated supply sources etc.) are different from each other.

So, indexation is one of the most effective methods for adjusting fuel sales in different geographic areas so as to predict the impact of the quakes on the market. Both gasoil and gasoline indices for each province were calculated by setting sales on Jan.30, 2023 as 100.

Earthquakes in Türkiye

Seismologically, Türkiye is one of the most active countries in the world. The Anatolian plate, on which Türkiye is mainly located, is adjacent to three main tectonic plates: Arabian, African, and Eurasian. While the Anatolian plate is compressed towards the north by the Arabian and African plates, it interacts with the Eurasian plate (Kalafat et al., 2021).

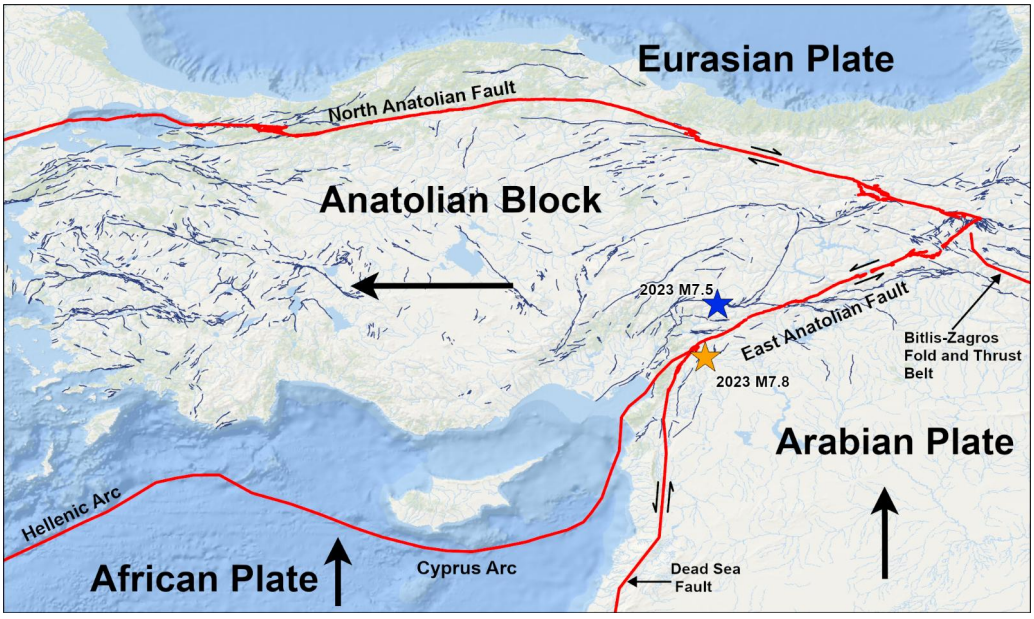

Figure 1: Tectonic map of Türkiye (**Source:** USGS, 2023b)

As seen in Figure 1 illustrating tectonic plates and their movement and interactions in Türkiye, this interaction between the plates makes the country more vulnerable to earthquakes and results in

tectonic activities in the region (Jacobo, 2023). Indeed, the complexity of the Turkish tectonic structure has been responsible for the deadly quakes in the last century.

Table 1. Major earthquakes (Magnitude > 7.0) in Türkiye (1900-2023) (ranked by death toll) (**Source:** Kandilli Observatory and Earthquake Research Institute at Bogazici University (NEMC, 2017) and Anadolu Agency (Oz, 2023)

Date	Location	Magnitude	Death Toll
February 6, 2023	Kahramanmaras	7.8 7.5	50,783
December 27, 1939	Erzincan	7.9	32,968
August 17, 1999	Kocaeli	7.8	17,480
November 27, 1943	Samsun	7.2	4,000
February 1, 1944	Bolu	7.2	3,959
November 24, 1976	Van	7.5	3,840
November 18, 1919	Balikesir	7.0	3,000
December 20, 1942	Tokat	7.0	3,000
May 7, 1930	Türkiye-Iran Border	7.2	2,514
March 28, 1970	Manisa	7.2	1,086
November 12, 1999	Duzce	7.5	763
October 23, 2011	Van	7.2	644
March 18, 1953	Canakkale	7.2	265
August 9, 1912	Tekirdag	7.3	216
April 25, 1957	Mugla	7.1	67
May 26, 1957	Bolu	7.1	52
October 30, 2020	Izmir	7.0	115
July 22, 1967	Adapazari	7.2	89
October 6, 1964	Balikesir	7.0	23

Twenty quakes greater than seven, detailed in Table 1, struck Türkiye between 1900 and 2023, killing more than 124 thousand people (NEMC, 2017 and Oz, 2023). Nonetheless, the Kahramanmaras earthquakes on Feb. 6, 2023, were the deadliest. The earthquakes occurred nine hours apart on different fault lines in the southern part of Türkiye and caused severe destruction in these regions.

Earthquakes on Feb.6, 2023

On February 6, 2023, two devastating earthquakes with magnitudes of 7.8 and 7.5 (USGS, 2023a) badly affected ten provinces of Türkiye, covering 13% of the total area with 16% of the country's population. More than 50,000 died, 200,000 buildings collapsed and 1,000,000 were severely damaged due to the earthquakes and aftershocks in Türkiye (MSF, 2023). After the earthquakes, with Presidential Decree No. 2023/6785 published in the Official Gazette dated Feb. 8, 2023, a three-month state of emergency was declared in ten provinces of Türkiye hit by a pair of cataclysmic earthquakes, which reveals the extent of the destruction. Table 2 gives the population, land area and density of these provinces stated as disaster zones in the Decree.

Although Kahramanmaras earthquakes were felt by most parts of Türkiye, ten provinces illustrated in Figure 2 were heavily impacted and destructed by the earthquakes greater than 7. In disaster zones, 84% of the total death toll (50,783) was recorded in Hatay, Kahramanmaras and Adiyaman (Turkish Ministry of Health, 2023). Besides many deaths in these regions, the unprecedented earthquakes also caused many religious places and cultural heritages to be demolished. Also, natural gas transmission pipelines and public buildings such as hospitals and schools heavily deteriorated (Gunasekera et al., 2023). According to the Türkiye Earthquakes Recovery and Reconstruction Assessment (TERRA) prepared by the Strategy and Budget Office (SBO) of the Turkish Presidency, economic losses of Türkiye are estimated as 9 percent of Türkiye's forecasted GDP for 2023, or equivalent to $103.6 billion (SBO, 2023).

Table 2. Population, land area and density in the provinces affected by the earthquakes (sorted by population) (**Source:** TUIK, 2023a)

Provinces	Region	Land Area (sq. km)	Population (2022)	Density (person /km^2)
Adana	Mediterranean	13,844	2,274,106	164
Sanliurfa	Southeastern Anatolia	19,242	2,170,110	113
Gaziantep	Southeastern Anatolia	6,803	2,154,051	317
Diyarbakir	Southeastern Anatolia	15,101	1,804,880	120
Hatay	Mediterranean	5,524	1,686,043	305
Kahramanmaras	Mediterranean	14,520	1,117,436	77
Malatya	Eastern Anatolia	12,259	812,580	66
Adiyaman	Southeastern Anatolia	7,337	635,169	87
Osmaniye	Mediterranean	3,320	559,405	168
Kilis	Southeastern Anatolia	1,412	147,919	105
Total		**99,362**	**13,361,699**	**134**
Grand Total		**780,043**	**85,279,553**	**109**
%		**12.74%**	**15.67%**	**-**

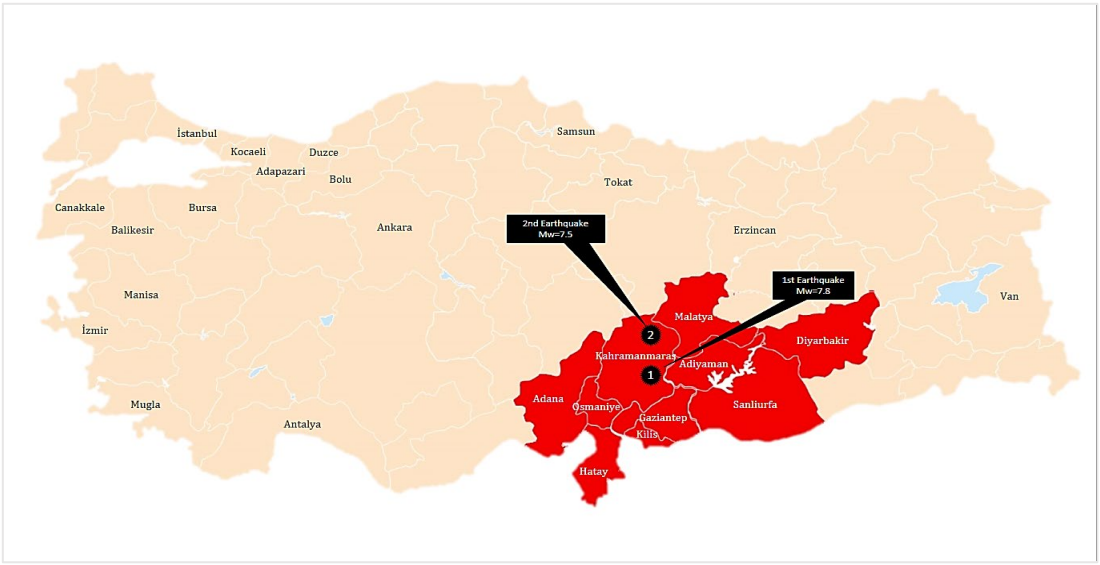

Figure 2. Provinces affected by the Kahramanmaras earthquakes (**Source:** Authors' own illustration)

Impacts of the Kahramanmaras Earthquakes on the Turkish Fuel Market

Alongside the high amount of death toll and causalities, the life stood at a standstill after the earthquakes in these provinces. Similar to other infrastructures in disaster zones, some petrol stations, roads, railways, and a few storage facilities were severely damaged. These provinces, with more than 1,800 petrol stations, accounted for 11% of the country's fuel consumption. Following the devastating earthquakes, many people ran to the stations along with rising fear, panic, and chaos; some of them left without shelter in frigid temperatures wanted to get fuel to heat themselves in their cars on the cold winter day, or rescue crews needed more fuel for the operations of ambulances or cranes, which brought supply problems in the first days of the earthquakes. Uninterrupted fuel supply is also critical for delivering sufficient emergency supplies promptly to affected individuals to alleviate their suffering. Indeed, the scarcity of fuel could potentially cause more harm than the shortage of emergency supplies. (Suzuki, 2012). Thus, forecasting future gasoline shortages can assist agencies in directing supplies to the appropriate regions and alleviating the shortage (Khare et al., 2020).

At this point, the importance of monitoring systems at storage facilities and petrol stations became prominent in the case of a force majeure, and these systems served a different purpose in Türkiye that had never been foreseen before, as in the earthquakes. In order to carry out the damage estimation and assessment and to maintain fuel activities in the areas hit by earthquakes, receiving real-time fuel data

from the whole country and processing them quickly were crucial for rescue teams and many government agencies.

Turkish Fuel Monitoring System

Türkiye's proximity to oil-rich regions, inconsistent fuel market tax rates, lubricant oil used as a substitute for fuel, and inadequate inspection and monitoring mechanisms were the main factors accounting for raising smuggling activities in the country in the past (Yalta & Yalta, 2016). To deal with these problems, the authorities devised a solution, such as monitoring the petrol stations through electronic systems, namely automation systems. In 2007, necessary amendments were made in Turkish Petroleum Market Law No. 5015 (from now on referred to as PML) and in 2011, the obligation of establishing the automation systems was imposed in the Turkish fuel market apart from Liquefied Petroleum Gas (LPG) that is used as a complementary fuel.

The automation system at the petrol stations allows monitoring of underground tanks and sends some information about the volume, temperature of the fuel, the amount of fuel filled into the tank and exited from the tank to the system users instantly. The fuel distributors have to submit these data over the Internet to the Energy Market Regulatory Authority (EMRA). In this way, EMRA can control the obligations of license holders and analyze fuel market by utilizing automation data (the amount of fuel sold and stored at the stations).

In addition to the automation systems in the petrol stations, some terms and conditions were added to the PML in 2017, and a storage tank monitoring system was envisaged in the country. Since 2018, all fuel activities at refineries and storage facilities can also be monitored in detail by EMRA. In the tank monitoring system, fuel and LPG distributors, refineries and storage facilities eligible to store petroleum products regarding the PML have to send comprehensive fuel data such as fuel type, customs tariff number (HS codes) of fuel, measured fuel density, volume/level of fuel and fuel temperature over the Internet to EMRA for further analysis and compilation. Table 3 provides the details on the data compilation process through both station and tank storage automation systems in Türkiye. In addition to hourly and daily fuel data sent to EMRA, the administrative authority can monitor real-time fuel stocks and sales at the petrol stations and storage facilities remotely.

Table 3: Fuel monitoring system and data compilation process in Türkiye (**Source:** Authors' own compilation)

System	Data Provider	Data Sent to EMRA	Submission Period to EMRA	Correction Time (if needed)
Petrol Stations Monitoring System	Fuel Distributors	- The volume of fuel in the underground tank -Temperature of the fuel -The amount of fuel filled into the tank and exited from the tank -Fuel sales -Fuel price	Daily	24 hours after submission to EMRA
Storage Tank Monitoring System	Refineries Fuel Distributors Storage Facilities	-Fuel type -Customs tariff number (HS Codes) of fuel -Measured fuel density -Volume/level of fuel -Fuel temperature	Hourly and Daily	24 hours after submission to EMRA

As given in Table 3, a considerable amount of fuel data is gathered from the market players mainly to control obligations. In the aftermath of the Kahramanmaras earthquakes, governmental agencies conducted analyses by using real-time fuel data:

- to make damage assessment of the petrol stations and storage facilities,
- to detect fuel shortages,
- to guide and advise market players on how to refuel stations,

- to follow supply-demand balance in disaster areas.

With the implementation of these systems, EMRA can perform real-time monitoring at 100 storage facilities, 38 fuel distributors and more than 13,000 petrol stations. In other words, most fuel activities carried out in the Turkish oil infrastructure, given in Figure 3, can be tracked with this fuel monitoring system. In Figure 3, the complex Turkish oil infrastructure is illustrated and the capacities of refineries, storage facilities and railways and the pipelines used to transmit crude oil and oil products are shown thoroughly.

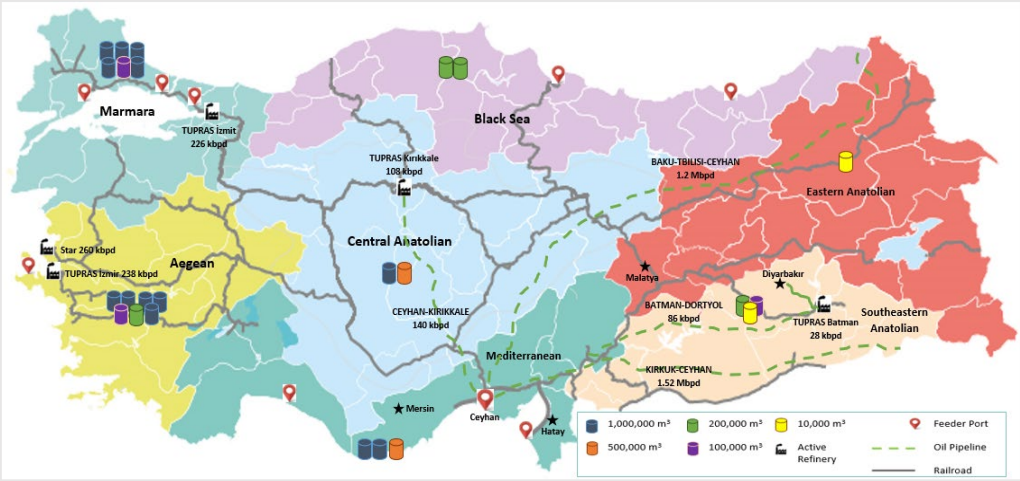

Figure 3. Turkish oil infrastructure (**Source:** Authors' own illustration)

Five refineries with a distillation capacity of 43 million tons/year (860 kb/d) (EPDK, 2023b) are scattered over Turkish territory. Three refineries on the Aegean and Marmara coasts are designed to refine imported crude oil by sea tankers. Although refineries on the coastline are fed by seaborne imports, the inland refineries in Central and Southeastern Anatolian regions are supplied via pipeline and road tankers. While crude oil is mainly transmitted to the Kirikkale refinery via the pipeline extending from Türkiye's Mediterranean oil hub, Ceyhan, to Kirikkale, with a length of 448 km and an annual capacity of 7.2 million tons (IEA, 2021), the Batman refinery, which refines dominantly indigenously produced oil, obtains oil through road tankers and a pipeline with a length of 518 km and an annual capacity of 4.5 million tons extending from Ceyhan (Dortyol) to Batman (Botas, 2023).

Over the past decades, the production of refineries has increased substantially with the activation of the Star Refinery at Izmir and the implementation of the Residuum Upgrading Project (RUP) at TUPRAS Izmit Refinery. However, refinery throughput has been far from meeting ever-growing Turkish oil demand. For this reason, Türkiye imports massive amounts of petroleum products (gasoil/diesel, LPG, aviation fuel, etc.) through the seaports on the Marmara, Aegean, Black Sea and Mediterranean coasts (Figure 3). All domestically produced and imported oil fuels are delivered to the end users in the coastal regions dominantly by sea transportation. Consumers in the inland of Türkiye are fed by pipeline, road and rail transport.

Table 4: Modes of fuel transportation to the earthquake-affected regions (**Source:** Authors' own compilation)

Type of Transport	**Provinces**			
	Diyarbakir	**Hatay**	**Mersin** *	**Malatya**
Railway	X	x	x	
Sea		x	x	
Road		x	x	x

*This province on the Mediterranean coast is very active in oil trade.

Fuel in earthquake-stricken zones is normally supplied by pipeline, road, sea and rail transport. In Table 4, the primary transport sources of fuel are exhibited. Although storage facilities are scattered in Diyarbakir, Hatay, Mersin and Malatya, high volumes of fuels are stored in Hatay and Mersin. The fuels

stored in these two provinces are transported to the southern part of the Central Anatolian Region, the Southeastern Anatolian Region and some parts of the Eastern Anatolian Region.

Impacts of the Earthquakes on the Turkish Fuel Market

In the scope of this paper, the impacts of the Kahramanmaras earthquakes on the Turkish fuel market were investigated by using data gathered from the fuel monitoring system and the market players, mainly refineries and fuel distributors. In this study, only gasoil and gasoline data are taken into account, and the data of Liquefied Petroleum Gas (LPG), used as a complementary fuel in the market, was not utilized because the fuel monitoring system was implemented to track fuel transactions other than LPG. Although the Turkish fuel monitoring system was not mainly designed to compile the latest fuel data to make decisions about the fuel market, after the quakes on Feb. 6, 2023, the use of real-time data collected remotely from data providers became vital for the authorities.

After two devastating earthquakes and aftershocks, Türkiye utilized station and storage facility systems data to monitor the balance of fuel supply and demand in ten provinces. Consequently, Türkiye was able to know how much fuel stock was in the storage facilities and petrol stations and whether there was an urgent need in disaster zones considering the remaining stock and daily consumption patterns.

The Turkish fuel market was affected in various ways after the quakes. In disaster zones, damage to infrastructure (railways, roads and transmission pipelines) and destruction of petrol stations and storage facilities negatively impacted fuel distribution and sales. Using data from the fuel monitoring system, in the following section, the effects of the quakes on the market were assessed under three sections: impacts on infrastructure, fuel supply and fuel sales.

Impacts on Infrastructure

The first damage control of all petrol stations and storage facilities in the earthquake-affected provinces was carried out by EMRA through the monitoring system. After the quakes, most of the data providers could send daily data despite power outages and internet connection losses, which made the Turkish authorities permanently control the fuel stocks and take action in the earthquake zones. It was confirmed that the data of more than 93% of the tanks in the stations could be submitted to EMRA, even in the provinces such as Hatay, Adiyaman, Kahramanmaras and Malatya, where the earthquake had hit the hardest.

According to TERRA, the earthquake-related damage is estimated at roughly 355 million Turkish Liras (18.8 million USD) (SBO, 2023). The total loss of oil infrastructure (mostly petrol stations) by provinces was also revealed by SBO and is given in Figure 4. According to the first damage assessment by EMRA, some petrol stations in the earthquake-affected region were completely or partially demolished. In addition, some underground storage tanks and the connection parts collapsed and had to be repaired. As illustrated in Figure 4, approximately 89% of the total damage occurred in Hatay, Kahramanmaras, Malatya and Adiyaman.

All fuel movements in the disaster zone faced logistical difficulties due to unexpected infrastructure damage. After two devastating earthquakes, cracks on highways and roads, and meters of displacement at the road and railways occurred. According to the statement made by the Turkish Ministry of Transport and Infrastructure, 1,275 km of railway lines, 446 bridges and 175 tunnels in the disaster zone were significantly impacted (Artymiuk, 2023). As stated in TERRA, 17.4 billion Turkish Liras (922 million USD) are required to repair and reconstruct damaged railways (SBO, 2023).

Essential ports for Turkish trade were damaged. Mersin, the third biggest port in Türkiye, and Hatay (Iskenderun), the seventh one, suspended their operations after the quakes (Rubenstone, 2023). Because of the earthquakes, nearly 38 million Turkish Liras (2 million USD) of damage occurred (SBO, 2023). Considerable demolition of logistics infrastructure in the disaster zones after the quakes caused the oil movement to be disrupted. Deliveries in and out of the damaged ports were diverted to nearby ports (Johnson, 2023).

Road freight transport has always been indispensable for earthquake-affected provinces due to the geographical and infrastructure constraints (e.g., limited number of storage facilities). Fuel stored in Mersin and Hatay provinces is transported to the inner parts of the Eastern and Southeastern Anatolia regions by road tankers. In these regions, Nurdagi, one of the most critical connection points in the region, is located on the shortest route between Mersin-Gaziantep and Hatay-Gaziantep. During the

earthquakes, the highway near Nurdagi became unusable and was blocked. For this reason, fuel transmission into disaster zones, except for Hatay and Adana, was stopped entirely.

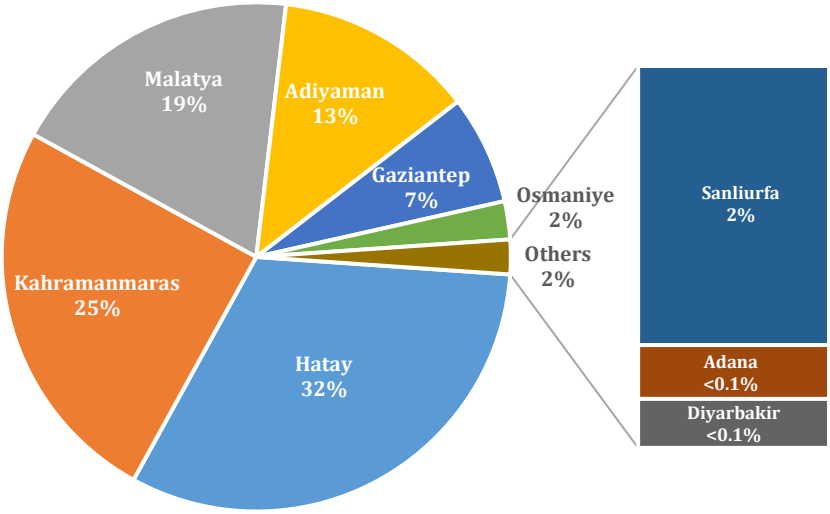

Figure 4: Total loss of Turkish oil infrastructure (mostly petrol stations) (**Source:** SBO, 2023)

Destruction of essential highways, railroads and ports in the earthquake-stricken provinces made it difficult for market players (refineries and fuel distributors) to deliver fuel to the disaster zones. Therefore, alternative itineraries were used to transport fuel to these provinces. To illustrate, fuel was delivered from the Black Sea and Central Anatolia Regions to the inner parts of the Eastern and Southeastern Anatolia regions by road freight transport.

Impacts on Fuel Supply

The massive earthquakes caused a cataclysm in 10 provinces of Türkiye, where 11.46% of total Türkiye's fuel sales in 2022 were realized. Based on Table 5, presenting the number of petrol stations and storage facilities and the amount of sales in the earthquake-affected provinces, 15.14% of total petrol stations and only 9.6% of total storage facilities in Türkiye exist in these ten provinces. Most of these facilities with very limited storage capacities are located in Hatay on the Mediterranean coast, indicating the importance of supplying fuel to these regions with different alternatives.

Table 5: Number of petrol stations and fuel sales in the provinces affected by the Earthquakes (sorted by region) (**Source:** Petroleum Market Reports (EMRA, 2023a), Licenses at Turkish Oil Market (EMRA, 2023b) and Turkey 2021 Energy Policy Review (IEA, 2021))

Province	Region	# of Stations as of Feb.6, 2023	# of Storage Facilities as of Feb. 6, 2023	Storage Capacities as of Feb.6, 2023 (m^3)	Gasoline and Gasoil Sales in 2022 (ton)
Adana	Mediterranean	295	1*	2,568	644,557
Hatay	Mediterranean	238	5	249,177	489,229
Kahramanmaras	Mediterranean	197	-	-	290,895
Osmaniye	Mediterranean	95	-	-	128,038
Adiyaman	Southeastern Anatolia	144	-	-	142,180
Diyarbakir	Southeastern Anatolia	216	1	9,256	282,625
Gaziantep	Southeastern Anatolia	252	1*	677	552,823
Kilis	Southeastern Anatolia	22	-	-	26,511
Sanliurfa	Southeastern Anatolia	288	-	-	329,166
Malatya	Eastern Anatolia	132	1	4,980	183,149
Total		**1,879**	**9**	**266,658**	**3,069,172**
Grand Total		**12,413**	**94**	**14,791,209****	**26,787,937**
%		**15.14%**	**9.6%**	**1.8%**	**11.46%**

*It represents the storage facility where aviation fuels are stored at Adana and Gaziantep airports.

** It is calculated by the authors considering the storage capacities of EMRA licensed tanks.

Figures 5 and 6 reveal the quakes' immediate impacts on the amounts of the fuel stored and purchased. Considering the gasoil and gasoline stocks and sales after the earthquakes, the beginning fuel stocks of February 7 provide some clues about refueling to stations and the status of fuel stocks.

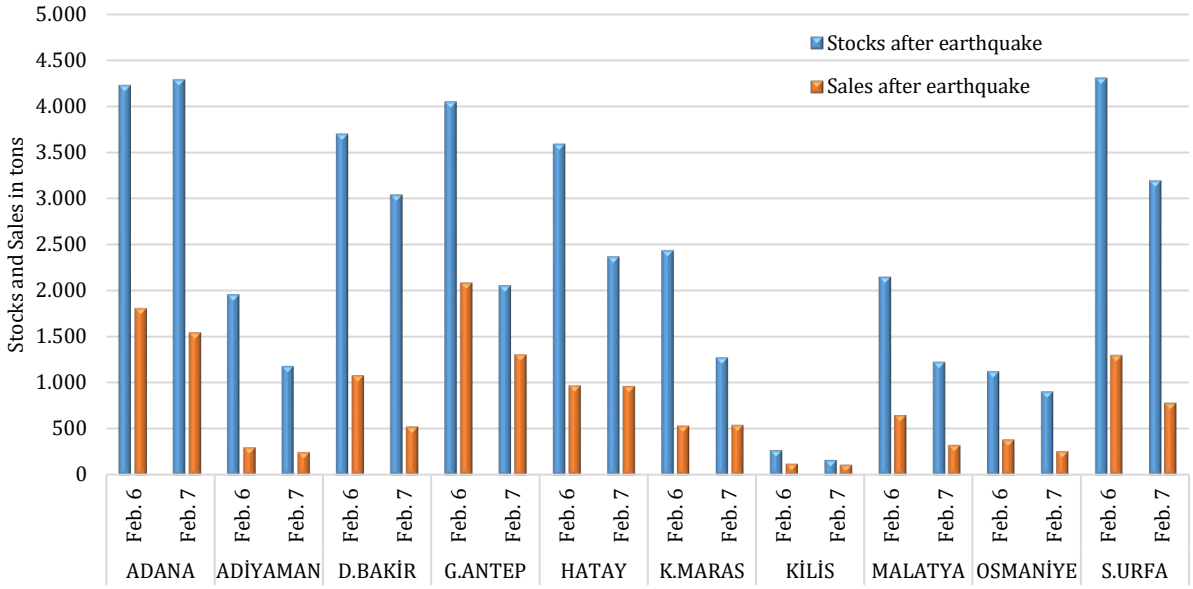

Figure 5: Gasoil stocks at the beginning of the day and sales at petrol stations before and after the quakes (**Source:** Authors' own elaboration based on the Turkish fuel monitoring system data)

Figure 5 shows that almost all provinces had enough supply to meet gasoil demand in the first two days of the earthquakes. Nonetheless, in Figure 6, the gasoline stocks on February 7 in some provinces, such as Gaziantep, Hatay, Kahramanmaras, and Kilis were alarming, which could lead to the authorities taking additional measures to prevent a supply crisis there. Indeed, the Turkish authority, EMRA, directed many distributors to supply fuel to these areas.

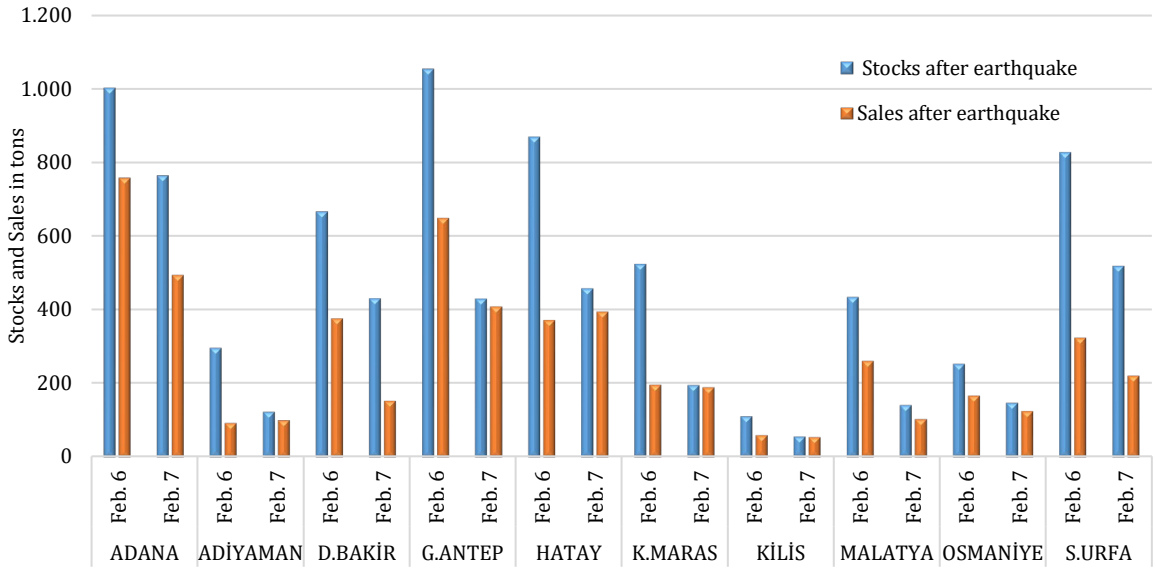

Figure 6: Gasoline stocks at the beginning of the day and sales at petrol stations before and after the quakes **(Source:** Authors' own elaboration based on the Turkish fuel monitoring system data)

Figures 5 and 6 also show the impacts of railroad and highway damage on the fuel market in the provinces apart from Adana and Hatay. In most earthquake-affected provinces, gasoline stocks at the

beginning of Feb. 7 were equal to fuel sales on Feb. 7. This situation indicating supply problems warns the authorities to take necessary measures before the stocks run out at the stations.

Impacts on Fuel Sales

To measure the impact of the earthquakes on fuel sales, whole fuel sales in Türkiye were scrutinized thoroughly, and it was found that the effects of Kahramanmaras earthquakes on the fuel market varied from region to region. Although the impact of the quakes on the market was insignificant in some regions, such as the Marmara and Aegean Regions, the main effects can be observable in the earthquake-affected provinces and their neighboring ones. Therefore, only fuel transactions in the earthquake-affected provinces and their neighbors were taken into account in this study so as not to make a misleading assessment.

In order to measure the effects of the quakes on the fuel market, seven days before and after the day of the Kahramanmaras earthquakes, periods namely Jan.30 and Feb.13, 2023, were chosen as the time interval. As a starting point, fuel sales between Jan.30 (Monday) and Feb. 13 (Monday) are rescaled by taking the sales on Jan.30, 2023, as 100. Based on the data submitted by the automation system to EMRA, rescaled gasoil and gasoline sales are illustrated in Figures 7 and 8. In this way, it was aimed to exhibit the daily fuel sales in the quake-affected provinces and how the sales fluctuate in response to the earthquakes. In Figure 7, gasoil sales in the earthquake zone on the day of the earthquakes (Feb. 6) jumped suddenly and increased by 250% compared to the sales on Feb.5. After the quakes, gasoil sales skyrocketed on Feb. 6 and then fell sharply on Feb. 7. The impact of quakes on the local fuel market in Kilis, Malatya and Diyarbakır is more remarkable than in other provinces. Unlike these three provinces, gasoil sales remained relatively stable in severely damaged provinces, such as Hatay, Kahramanmaras, and Adiyaman. As seen from Figure 7, the gasoil sales generally decreased on the second day of the earthquake, Feb. 7, which may raise some critical questions, such as whether there were enough stocks in these cities, whether the panic environment on the first day of the earthquakes led people to rush to the stations was annihilated later. Considering gasoil used by construction machinery, ambulances, SAR teams and lightening equipment (e.g., generators) during SAR operations, it is expected that the amount of gasoil is higher than usual in all disaster-stricken provinces. However, according to the data in Figure 7, this was not the case in some provinces such as Adiyaman, Hatay and Kahramanmaras.

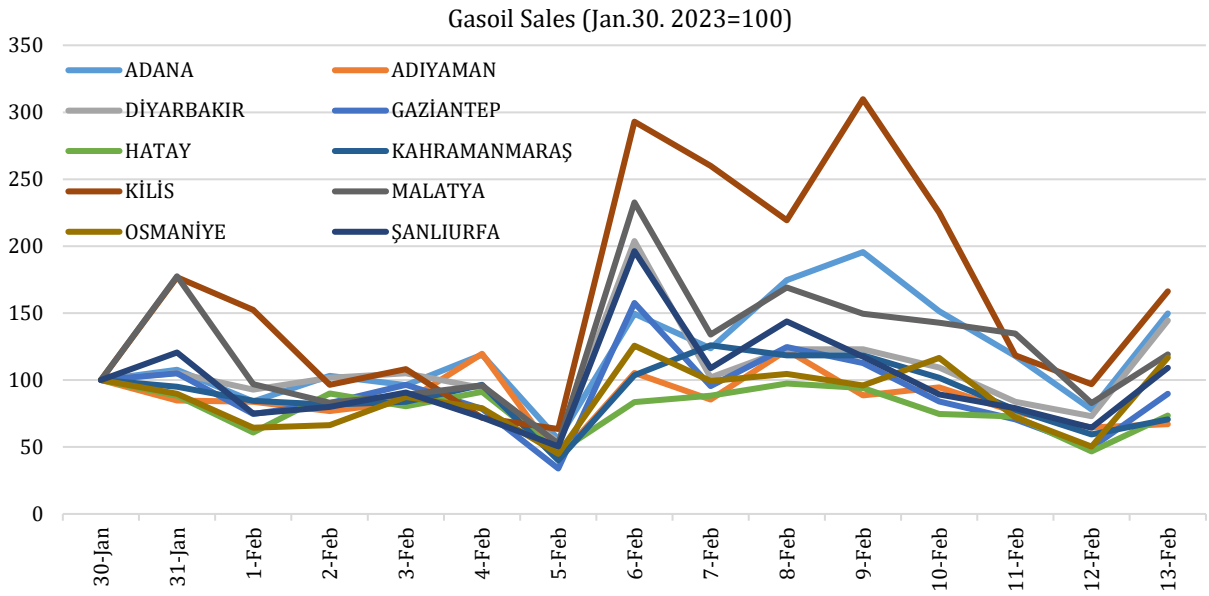

Figure 7: Gasoil sold at the stations in disaster zones before and after the quakes (**Source:** Authors' own elaboration based on the Turkish fuel monitoring system data)

Similar to Figure 7, Figure 8 exhibits gasoline sales in the disaster zones for the period starting from Jan.30 to Feb.13, 2023, to analyze the effects of the quakes. Unlike gasoil sales in the region, an increase in gasoline sales on the day of the quakes is higher than the rise in gasoil sales. Similar changes

in gasoline sales were observed before and after the quakes. As shown in Figure 8, gasoline sales increased significantly in all provinces on Feb. 6, 2023, by 560% compared to Feb. 5, 2023.

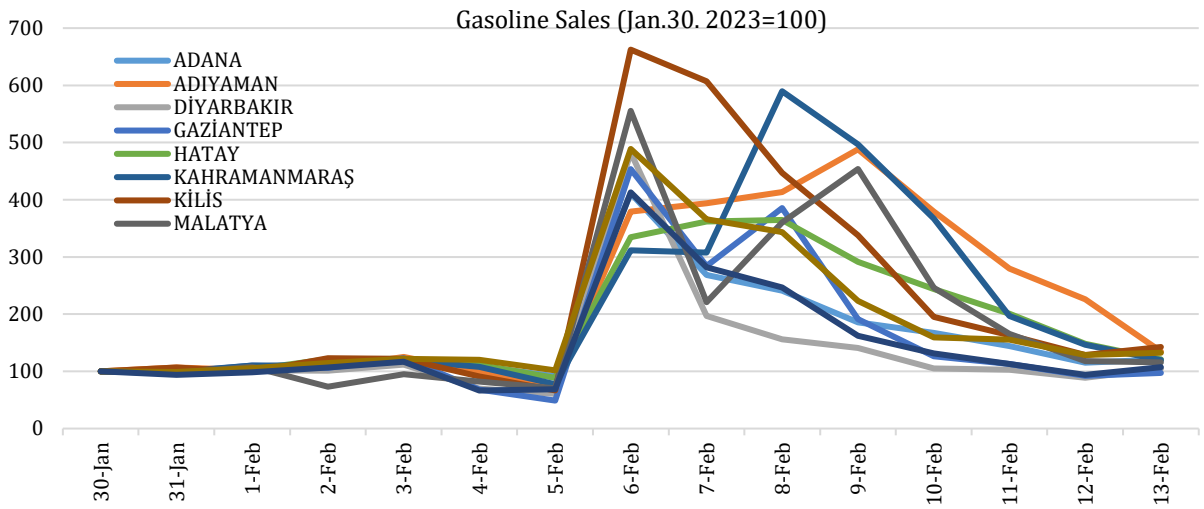

Figure 8: Gasoline sold at the stations in disaster zones before and after the quakes (**Source:** Authors' own elaboration based on the Turkish fuel monitoring system data)

Regarding the Turkish Statistical Institute's statistics, 3.14 million motor vehicles, corresponding to 11.9% of the total vehicles in Türkiye, are registered in disaster zones as of January 2023. 46.4% of these vehicles are automobiles and the fuel types consumed by these vehicles are gasoil (36.9%), LPG (35.1%) and gasoline (26.8%) (TUIK, 2023b). In light of these data, Figures 7 and 8, the gasoil and gasoline were primarily used for travel to other provinces.

When gasoil and gasoline sales submitted by the automation system to EMRA are examined to determine the effects of the earthquakes on the whole market, it was seen that quakes had ripple effects on the market and fuel sales not only in ten provinces but also in their neighbors were impacted drastically.

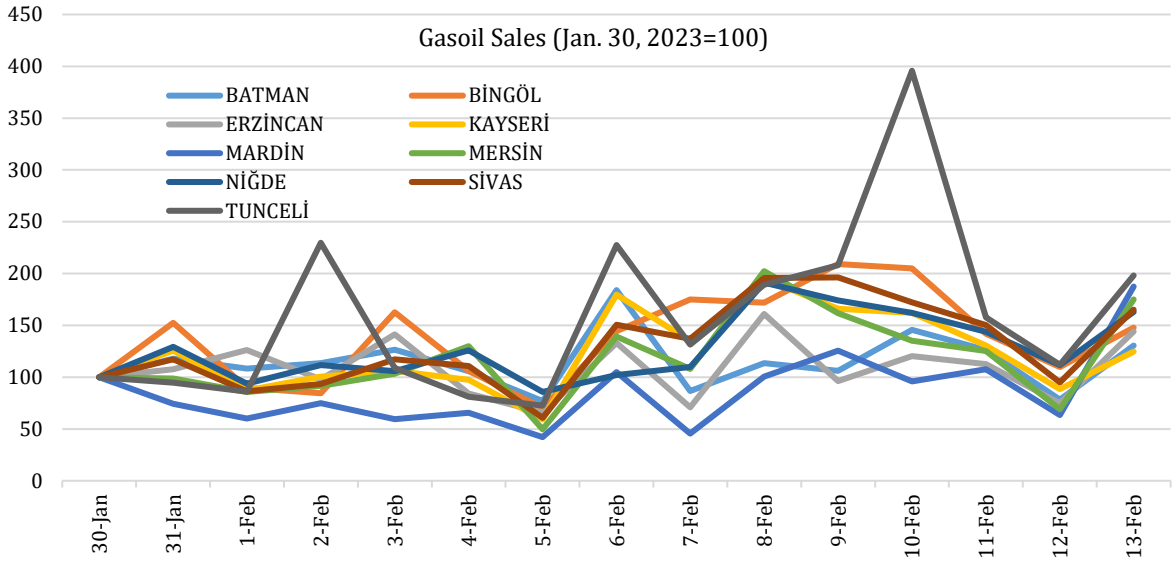

Fig. 9: Gasoil sold at the stations in the neighboring provinces of the disaster zones before and after the quakes (**Source:** Authors' own elaboration based on the Turkish fuel monitoring system data)

Figures 9 and 10 illustrate gasoil and gasoline sales in neighboring provinces of the earthquake-impacted zones before and after the quakes. As in the ten provinces affected by the earthquakes, gasoil

sales in the surrounding provinces (e.g. Tunceli, Kayseri, Batman, Sivas etc.) increased on the day of the earthquakes and their impacts lasted the following week.

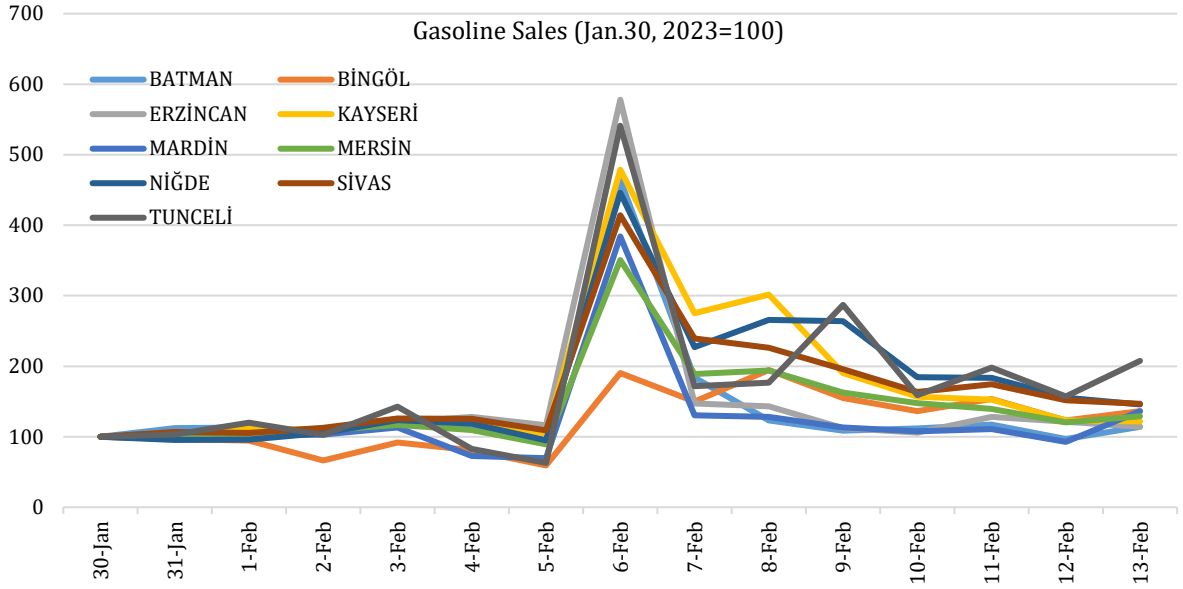

Fig. 10: Gasoline sold at the stations in the neighboring provinces of the disaster zones before and after the quakes **(Source:** Authors' own elaboration based on the Turkish fuel monitoring system data)

The trend of gasoline sales in the neighboring provinces presented in Figure 10 is similar to the trend given in Figure 8. On Feb. 6, 2023, the earthquakes catapulted gasoline sales, and all sales decreased significantly.

Future Implications of Earthquakes

After the destructive earthquakes on Feb. 6, 2023, the fuel market, one of the essential markets to support search and research activities, has gained importance. In Türkiye, one of the most active earthquake hotspots, many emergency plans have been implemented to save more lives and make the lives of the victims easier after quakes.

Türkiye is located between two major fault systems, the North Anatolian and East Anatolian Faults, which make the country vulnerable to an earthquake of magnitude 7 or stronger. Tracing back the history of the country, it has faced destructive earthquakes many times, and according to the analysis carried out by the National Disaster Mitigation Agency (BNPB), earthquakes in Türkiye have a repeated history (ANTARA, 2023).

There has been an ever-continuous rise in the number of earthquakes since 1990, as seen in Figure 11, focussing on the earthquake statistics between 1990 and Oct. 5, 2023. Although only 344 earthquakes were recorded in 1990, this number has increased to 65,011 as of Oct. 5, 2023. Considering the recurrence and exponential rise of earthquakes in Türkiye, these numbers are expected to continue.

In order to be prepared for future quakes, the Turkish government should develop an emergency response plan outlining also fuel supply and demand restraint measures by using the Turkish fuel monitoring system as a guide. These measures should be considered complementary to the search and research operations. These measures should be categorized as light- and heavy-handed measures in the fuel sector to guarantee ongoing fuel supply.

While light-handed fuel supply measures can include modeling current fuel supply by provinces and districts, diversification of alternative fuel supply routes by provinces and assessing/auditing resilience of existing oil infrastructure, heavy-handed fuel supply measures can consist of utilization of storage facilities that are not regulated by the PML after the earthquakes.

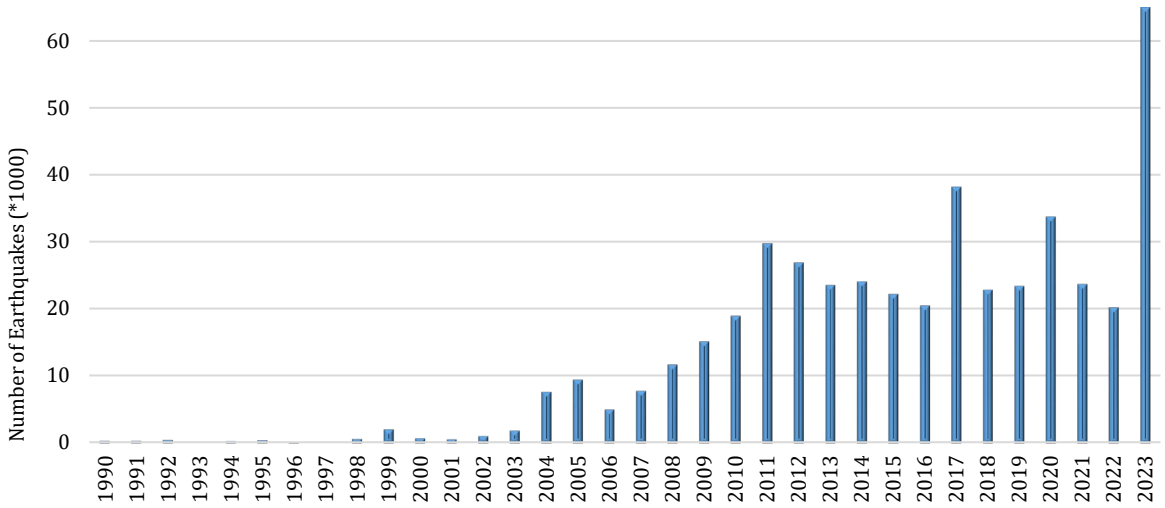

Fig. 11: Earthquake statistics in Türkiye between 1990 and Oct. 5, 2023. (**Source:** Disaster and Emergency Management Authority (AFAD, 2023))

For the demand side, light-handed measures can ensure sustainable data transmission and plan mobile fuel delivery systems by regions and provinces. Classification and limitation of individual and SAR equipment use should be implemented as a heavy-handed measure.

In light of the points mentioned earlier, Türkiye's objective must be to utilize the Turkish fuel monitoring system more efficiently and concoct an earthquake contingency plan

Conclusion

Türkiye, which has experienced many earthquakes throughout its history, woke up on the morning of Feb. 6, 2023, with the biggest of these disasters. The Kahramanmaras earthquakes, with magnitudes of 7.8 and 7.5, struck ten provinces in the southeastern part of Türkiye and led to significant destruction in these regions. The earthquakes caused more than 50,000 people to die and wound thousands. In addition to massive casualties, many infrastructures, cultural heritages, natural gas transmission pipelines, and public buildings such as hospitals and schools were severely destroyed. In the disaster zone, where life came to a standstill, besides humanitarian needs, administrative authorities had to focus on ensuring an uninterrupted fuel supply and take immediate action in case of a supply crisis. The fuel supply after the disaster was more critical to evacuate victims from the earthquake-affected zones and maintain SAR activities without disruption. At this point, Türkiye utilized its unique fuel monitoring system with the petrol stations and tank storage automation systems that had been implemented for many years mainly to monitor the activities in the fuel market to prevent fuel tax evasion and fuel smuggling.

These destructive earthquakes revealed how real-time fuel market data can be vital in a force majeure. Thanks to the data compiled from these systems, Turkish authorities could instantly determine the amount of fuel stocks in the facilities and stations and direct the fuel to the stations in the earthquake zones at need. They applied other alternatives for supplying fuel to the disaster zones while checking the stocks at neighborhood storage facilities, given that many railway lines, bridges, and tunnels were severely damaged.

In this study, gasoline and gasoil sales in and around the disaster zones between Jan. 30 and Feb. 13, 2023 and the stocks of these fuels on Feb. 6 and 7 were selected to assess the impacts of the quakes on the Turkish fuel market. The disproportionate effect of the quakes on the provinces was eliminated by rescaling of fuel sales data by taking sales on Jan. 30 as 100. Also, pre- and post-earthquake fuel stocks compared.

According to the data compiled from the station monitoring system, some provinces faced the threat of being out of stock for a few days after the earthquake. In relatively less damaged provinces, fuel sales increased on the day of the earthquake compared to the previous week's sales, indicating people's behavior in a chaotic environment with panic. On the contrary, in severely destroyed provinces, fuel sales, mainly for the gasoil, were stable, revealing the extent of the disaster since most of the stations in

these regions became already unusable. Many provinces faced the risk of running out of gasoline, which was an alarming situation that the authorities had to ponder while considering gasoline supply schemes for these regions.

Using data from the fuel monitoring system, Türkiye managed the possible fuel supply crisis in a contingency, even though this system was initially designed for different purposes. Since the country is prone to further earthquakes, building roadmaps and contingency plans is critical before such disasters. Concentrating on emergency action plans by making use of the available data and all possibilities and conducting case studies for possible earthquake zones is crucial in minimizing the destructive effects of such disasters in the fuel market.In possible earthquakes, e.g., Istanbul, the impacts can spread over the whole country, and fuel crisis management can be much more challenging for the authorities. Therefore, the results of this study are beneficiary for the public authorities. The area affected from the quakes is wide and consists of dozen of provinces. By using outcomes of this study, contingency plans can be organized by authorities to mitigate the impacts of upcoming earthquakes.

Lastly, this study, which sheds light on the challenges of meeting an urgent need following unexpected disasters, emphasizes the importance of conducting more sophisticated analyses on demand management and optimal resource allocation post-disaster.

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Research Paper

Numerical Modelling of the Flow Passing through a Rectangular Linear Weir with Flat Crest Shape

Ali Yıldız *

Konya Technical University, Engineering and Nature Science Faculty, Civil Engineering, Konya, Turkey

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Abstract: The most common hydraulic structures used for discharge measurements in open channels are linear weirs due to their accuracy, simplicity, design, and ease of construction. Linear weirs are also used to increase flow depth, control floods, and regulate flow. Before the actual on-site manufacturing of weirs, their hydraulic properties must be determined with experimental and numerical studies. In this study, experiments were carried out on a rectangular linear weir with dimensions 60 cm width, 30 cm height, 1 cm thickness and a flat crest shape. 2-Dimensional numerical models of the flow passing over the linear weir were created by ANSYS-Fluent. The data obtained from the experimental and numerical model were evaluated in terms of, total head (H_T) and discharge coefficient (Cd) and water surface profile. According to the results, although there are differences between the models in the discharge (Q) – total head (H_T) comparison due to the working principle of the 2-dimensional numerical model, the models gave 92.5 % consistent results in the discharge coefficient (C_d) and dimensionless total head (H_T/P) comparison. In addition, the experimental and numerical models were compared visually, and it was seen that the numerical models of the experiments were created with a high degree of accuracy.
Keywords: *Experimental Modelling, Linear Weirs, Numerical Modelling, Sharp-Crested Weirs*

Introduction

Dams and hydraulic structures are used to supply and control water, which has great importance on human life. Dams are large-sized barrier structures made of different materials and types that block the flow of water and create reservoirs and lakes. Since water is an important resource for human life, studies on the use of water began with the existence of humans. Dams built for many purposes basically consist of structures such as body, reservoir, spillway, bottom outlets and water intake structure. Additionally, depending on the purpose of construction, there may be additional structures such as sedimentation pools, penstocks pipes, energy dissipation pools and energy production facilities.

Weirs are widely used in open channels for flow measurement, flow direction and control. Their main functions include controlling water levels on the upstream and downstream sides as well as maintaining channel stabilization (Kumar *et al*., 2011). They also have different engineering applications, such as the controlling excessive discharge coming from rivers and dams during flood times. Weirs are mainly divided into two types, broad-crested and sharp-crested, according to their geometry and design. The crest thickness (t) of broad-crested weirs increases along the channel direction, and in some cases, the crest thickness may even be greater than the net crest length (L_{net}) of the weir. In sharp-crested weirs, the crest thickness (t) is very small compared to the net crest length (L_{net}). In broad-crested weirs, the critical flow depth occurs on the top of weir, while in sharp-crested weirs, the critical flow depths occurs as it spills over the weir to downstream. The name sharp-crested weir comes from the crest shape of the weir. These types of weirs can also be called linear or rectangular weirs. Rectangular sharp-crested weirs are classified as fully narrowed, partially narrowed and full-width weirs according to the weir opening (Bos, 1978). In a full-width weir, since the channel width (W) and net crest length (L_{net}) are the same, there is no narrowing from the sides, and this can be called a linear weir. Linear weirs are sharp- crested weirs formed from a vertical plate. The thickness (t) of a linear weir placed in a rectangular channel and perpendicular to the flow is equal to the crest thickness along its height. Thanks to these features, there are no lateral contractions in the flow and the flow is two-dimensional. Linear sharp-crested weir in a rectangular open channel is used for flow measurement and controlling discharge in open channels.

*Corresponding: E-Mail: ayildiz@ktun.edu.tr, Tel: +05555642466. Fax: +903322410635

Weirs are useful and widely used devices in flow measurements. The most basic and important parameter in weirs is the discharge coefficient (C_d). Additionally, there are weirs where the flow over the weir is not continuous along the z axis, such as labyrinth weirs, which do not continue in the same plane throughout the channel width. If there is an irregularity in the weir along the channel width, the flow becomes 3-dimensional (Henderson, 1966) and labyrinth weirs are an example of this. Weirs can have rectangular, triangular, trapezoidal, and circular plain view or shapes can be changed for special applications.

The first studies on linear weirs were conducted by Boileau (1854), Horton (1907), Escande and Sabathé (1937), Istomina (1937). Rouse and Reid (1935) conducted mathematical and experimental studies on the design of spillway crest shapes based on the examination of the flow characteristics of a linear sharp-crested weir. Rouse and Kandaswamy (1957) experimentally investigated the weir discharge coefficient (C_d) as a function of H_T/P; where H_T is the total head and P is the weir height. Kindsvater and Carter 1957) presented a comprehensive solution for the flow-discharge capacity of the weir based on experimental results and dimensional analysis. Rajaratnam and Muralidhar (1971) experimentally examined in detail the velocity and pressure distributions in the weir crest region. Han and Chow (1981) developed a model using ideal flow theory to obtain the properties of the flow. Based on experimental results and simplified theoretical evaluations, a general relationship between the discharge coefficient (C_d) and the H_T/P parameter was determined by others. Khan and Steffler (1996) predicted water surface profiles for sharp- crested weirs with inclined upstream faces using a two-dimensional finite element model incorporating continuity and momentum equations. Aydin et al. (2011) conducted experiments on rectangular weirs with a height (P) of 10 cm and 16 different net crest length (L_{net}). Bagheri and Heidarpour (2010) conducted experiments on linear weirs at 3 different weir heights (P) and 6 different net crest length (L_{net}). With the data they obtained, they produced equations showing the profiles of the upper and lower nappe flows from 3 and 4 streams. Arvanaghi and Oskuei (2013) conducted experiments at 3 different weir heights (P) and created numerical models of these experiments. According to the data obtained, despite the increasing discharge (Q), the discharge coefficient (C_d) of sharp- crested weirs remained constant at $C_d = 0.7$. Qu et al. (2009), used Reynolds Averaged Navier Stokes (RANS) equations to solve flow over a sharp-crested weir numerically. Numerical and experimental results are compared in terms of pressure, velocity and water surface profile. Mahtabi and Arvanaghi (2018), conducted experiments on 3 different weir height (P=10, 15 and 20 cm) with a L_{net}=25 cm net crest length. Experiments show that after HT/P exceed the 0.6, discharge coefficient (C_d) reach maximum value of 0.7. Also, they found consistent results between experiments and numerical model calculated in Fluent.

Experiments conducted to determine the performance of hydraulic structures and water surface profiles can be laborious and time-consuming. In addition, experimental research of hydraulic variables, field tests and finding the necessary equipment also increase the cost. Therefore, numerical simulation of hydraulic problems such as flow over a linear weir using computational fluid dynamics (CFD) can be less costly and practical than laboratory experiments. It can simulate turbulent flow using advanced numerical methods and is used to determine the velocity distribution, water surface profile, flow velocity and some other coefficients. However, to ensure that the numerical modeling results are accurate enough, the numerical solution needs to be validated with experimental data.

In this study, the discharge (Q), and total head (H_T) values are obtained from the flow passing over a weir which has P=30 cm height and have flat crest shape placed in a channel rectangular open channel. Additionally, numerical models of these measurements with the same size as the experiments were created and the results were compared.

Material and Method

Sharp-Crested Weirs

Linear weirs are important hydraulic structures for controlling water in stream regulation. These structures are used to raise water levels and control flow from canals, rivers and other water sources. During heavy rainfall, the upstream water level can be adjusted depending on the weir height (P) of the sharp-crested weir, providing protection against floods (Bos, 1978). As the flow passes over the weir, the flow characteristics change from the subcritical to the supercritical (Henderson, 1966). The water surface profile formed by the flow passing freely over a linear weir is called nappe flow (Figure 1). In

the nappe flow, after the water passes over the weir, there is air between the wall and the water. Linear weirs are a type of overflow weirs (Escande & Sabathé, 1937).

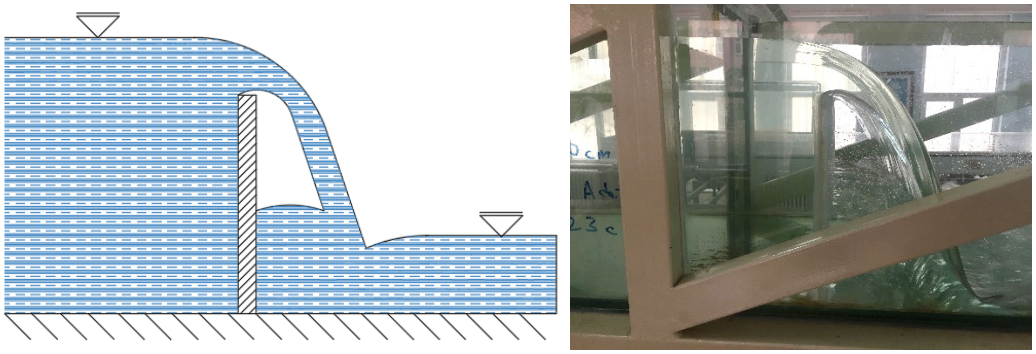


Figure 1. Nappe flow passing over sharp-crested weir.

Aeration of the flow passing over a linear weir can occur in four different ways (Falvey, 2002). These are unvented (viscid) flow (a), partially aerated flow (b), self-aerated or nappe flow (c) and submerged (choked) flow (d), as shown in Figure 2. The flow condition has a significant effect on the discharge coefficient (C_d).

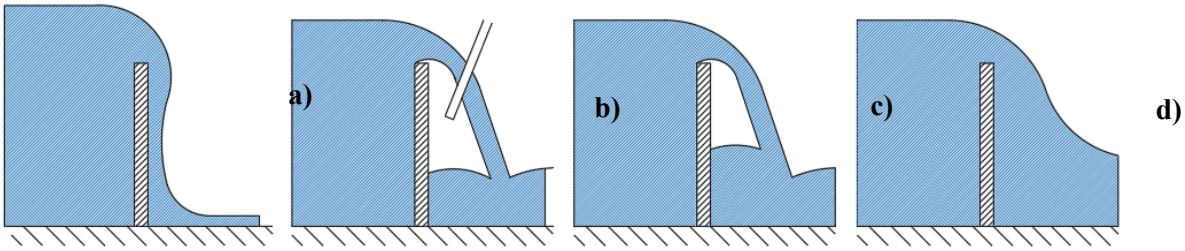


Figure 2. (a) Unvented (viscid) flow, (b) Partially aerated flow, (c) Self-aerated or nappe flow, (d) Submerged (choked) flow

The main parameters to be considered in the design of linear weirs are spillway (channel) width (W), weir height (P), approach velocity (V), total head (H_T) and crest thickness (t) are shown in Figure 3.

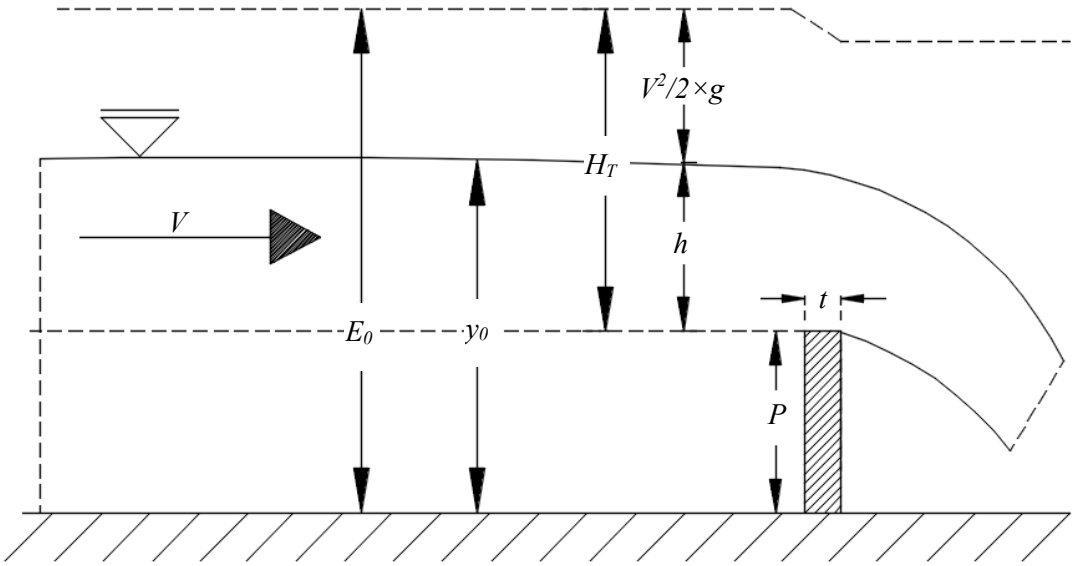


Figure 3. Parameters affecting the flow over a linear (sharp-crested) weir.

Discharge (Q) passing over a sharp- crested weir is calculated with Equation (1). In this equation, it is assumed that H_T is the total head and $H_T=h+V^2/2\times g$ (Tullis et al 1995).

$$Q = \frac{2}{3} * C_d * L_{net} * \sqrt{2 * g} * H_T^{1,5} \quad (1)$$

where;
Q : Discharge
C_d : Discharge Coefficient
L_{net} : Net Crest Length
g : Gravity
H_T : Total head over the weir.
Crest shape has a significant impact on the flow and discharge performance of linear weirs. Different types of crest shapes that can be used in linear weirs are shown in Figure 4. below. Circular crest shape has better hydraulic performance than sharp- crested crest shape. The profile of the flow as it passes over different crest shapes is different.

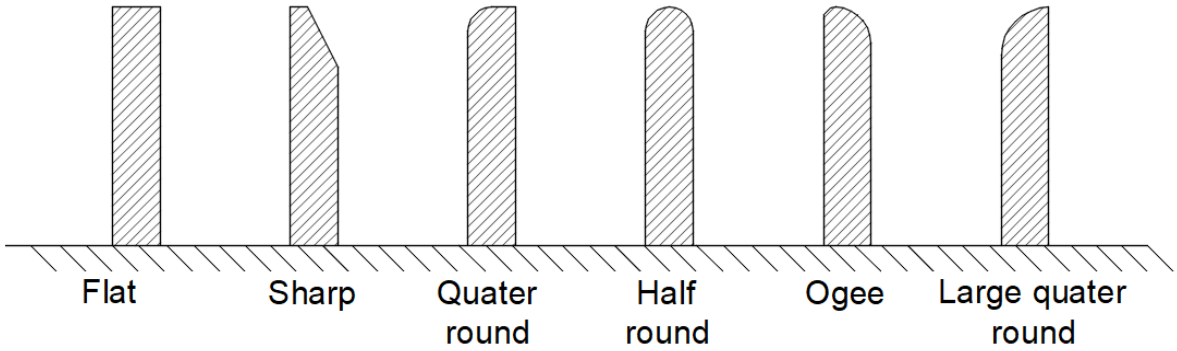


Figure 4. Different weir top crest shapes

Experimental Setup
The open channel system used in linear weir experiments is shown in Figure 5. The open channel system used in the experiments is 6.50 m long, 0.60 m wide and 0.50 m high. Linear weirs were placed 3 m away from the beginning of the channel. The purpose of choosing this location is to minimize the fluctuations in the water coming from the reservoir and prevent the fluctuations from affecting the water surface profile.

Figure 5. Open channel system

In the open channel system, the flow is provided by circulating water between two reservoirs. In the open channel system, discharge (Q) can be adjusted between 1 lt/s and 45 lt/s can be obtained with the help of the frequency converter connected to the pumps. The discharge (Q) circulated in the system

is measured with an ultrasonic flowmeter with a accuracy of 0.01 lt/s placed between the pipes after the pumps (Figure 5). Total heads (H_T) of the flow over the weirs placed in the channel were measured with a limnimeter. The upper part of the linear weirs used in the experiments has a flat crest shape. Since there is no rounding at the top of the weirs, the thickness of the crest is equal to the wall thickness (t) of the weir 1 cm. The linear weir used in the experiments was made of plexiglass (acrylic) sheets. The net crest length and height of the weir used in experiments is L_{net} = 60 cm and P = 30 cm respectively (Figure 6).

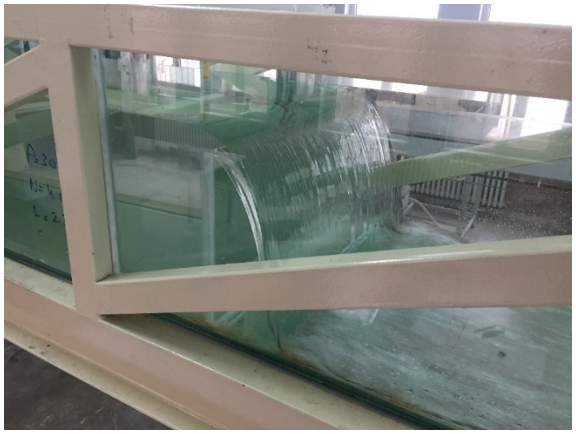


Figure 6. Sharp-Crested weir used in experiments.

10 mm thick plexiglass was used in the manufacture of sharp-crested weir. In the experiments carried out on linear weir, attention was paid to the formation of nappe flow and all experimental data were obtained in the case of nappe flow. Data were not obtained in case of the nappe flow condition did not occur, unventilated (viscid) flow or submerged (choked) flow condition. When the images obtained from the experiments are examined, it is seen that self-ventilated nappe flow occurs in all measurements.

Numerical Modelling

ANSYS-Fluent is a Computational Fluid Dynamics (CFD)-based program used to analyze and optimize the motion and interaction of fluids in hydraulic applications. CFD is a branch of fluid mechanics that uses mathematical and numerical methods to model, numerically analyze and simulate the behavior of fluids (liquids, gases or solid-liquid mixtures). Volume of Fluid (VOF) is used to model a free-surface flow in the numerical solution of fluids. In computational fluid dynamics, mathematical modeling of fluid motion is based on the Navier-Stokes equations (Fluent, 2023). These equations describe the momentum, mass, and energy of the fluid. The motion of the fluid is calculated by the numerical solution of these equations. A grid system is created to calculate the continuous fluid field. This grid is divided into sub-cells (meshes) to describe the movement of the fluid. Momentum and energy calculations of the fluid are made in these cells (mesh) and updated over time. Equations used in solving sets of differential equations obtained from the laws of conservation of momentum, energy and mass.
The conservation of mass equation or continuity equation can be written as Formula 2:

$$\frac{\partial \rho}{\partial t} + \nabla * (\rho \vec{v}) = S_m \quad (2)$$

The continuity equation for 2D axisymmetric geometries is given by Formula 3.

$$\frac{\partial \rho}{\partial t} + \frac{\partial}{\partial x}(\rho v_x) + \frac{\partial}{\partial r}(\rho v_r) + \frac{\rho v_r}{r} = S_m \quad (3)$$

Conservation of momentum in an inertial (non-accelerating) reference frame is explained by Formulas 4.

$$\frac{\partial}{\partial t}(\rho\, \vec{v}) + \nabla * (\rho \vec{v}\, \vec{v}) = -\nabla P + \nabla * (\vec{\tau}) + \rho\, \vec{g} + \overrightarrow{F} \quad (4)$$

where x axial coordinate, r radial coordinate, v_x axial velocity, v_r radial velocity, ρ density of fluid, P static pressure, g gravity, $\overrightarrow{F}$ force and $\vec{\tau}$ shear tensor.

A validated numerical model allows obtaining the hydraulic parameters of a sharp- crested weir without resorting to expensive and time-consuming experimental methods. Additionally, on the same numerical model, geometric parameters, inlet and outlet conditions can be changed and their effects on the flow over the weir can be examined in same numerical model. In order to obtain consistent results from numerical model with the experiments, boundary conditions of the physical model should be entered the program in a way that best suits the environmental conditions. Although the linear weir used in the physical model 3-dimensional, there is no irregularity along the channel width. For this reason, numerical models were created in 2 dimensions.

Geometry-Mesh

In the Fluent, program used in the analysis of the numerical model, the flow area is the total area of containing only water and air. All hydraulic events that occur must remain within this flow area. The 2D flow area used in the numerical models of linear weirs were created in AutoCAD and transferred to Fluent with sat (Standard ACIS Text) format. The dimensions of the flow area used in the numerical model are shown in Figure 7.

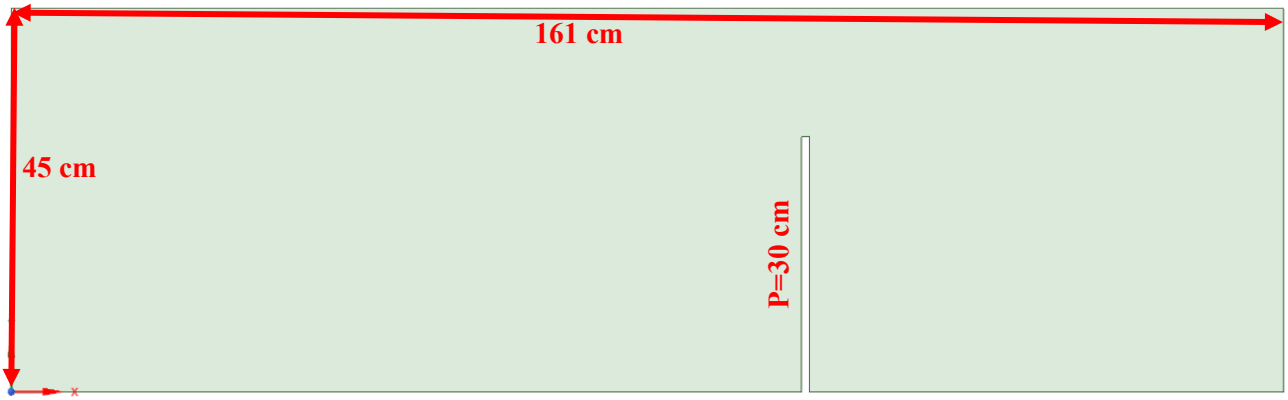


Figure 7. Geometry and dimensions of the flow area used in numerical modeling of linear weirs.

Fluent program divides the flow area into small sub-cells to analyze the movement of the fluid and performs calculations with the finite area method in these cells. Each mesh (cell) is modeled by solving the continuity and Navier-Stokes equations. Increasing the number of meshes in the flow area increases the accuracy of the solution. However, the most important factors that limit the mesh size and the total number of cells that will emerge due to this increase in accuracy are the technical specifications of the computer used and the time it takes to complete the analyses.

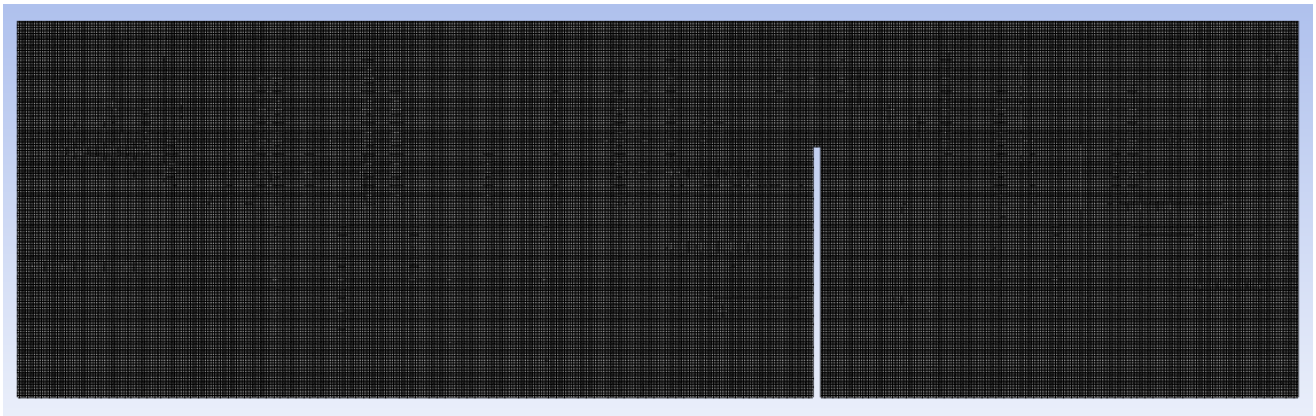


Figure 8. Separation of geometry into mesh (cells)

When dividing the flow area into cells, square-shaped meshes were preferred. The edge size of the square meshes used is 0.0025 m = 2.5 mm (Figure 8). In this study, before determining the optimum mesh size, mesh independence study was carried out using the Grid Resolution method. Before creating numerical models for all discharge (Q) values, 4 different mesh sizes were used for modeling og 5 and 10 lt/sec and the average errors were calculated by comparing the results with the experiments. Average

errors were calculated as 12% for 10 mm mesh size, 7% for 5 mm mesh size, 2% for 2.5 mm mesh size and 1% for 1.25 mm mesh size (Figure 9). What the percentage error between the numerical model and the experimental results should be is entirely related to the physics and importance of the hydraulic problem. In this study, it will be sufficient for the numerical model results of sharp-edged weirs to be 5% consistent with the experimental models. Because the sensitivity of the limnimeter used to measure the total weir load on sharp-edged weirs is 1 mm and this value goes up to 10% of cm. There is a possibility of a 10% margin of error during measurements made with a limnimeter. For a effective numerical model to be effective, its results must be below the desired error rates, be consistent with experimental data, and analysis times must not be too long depending on the severity of the problem. While the analysis with a 2.5 mm mesh size took 3 hours to finalize, the model with a 1.25 mm mesh size took 9 hours to finalize. Therefore, it is appropriate to use 2.5 mm mesh size.

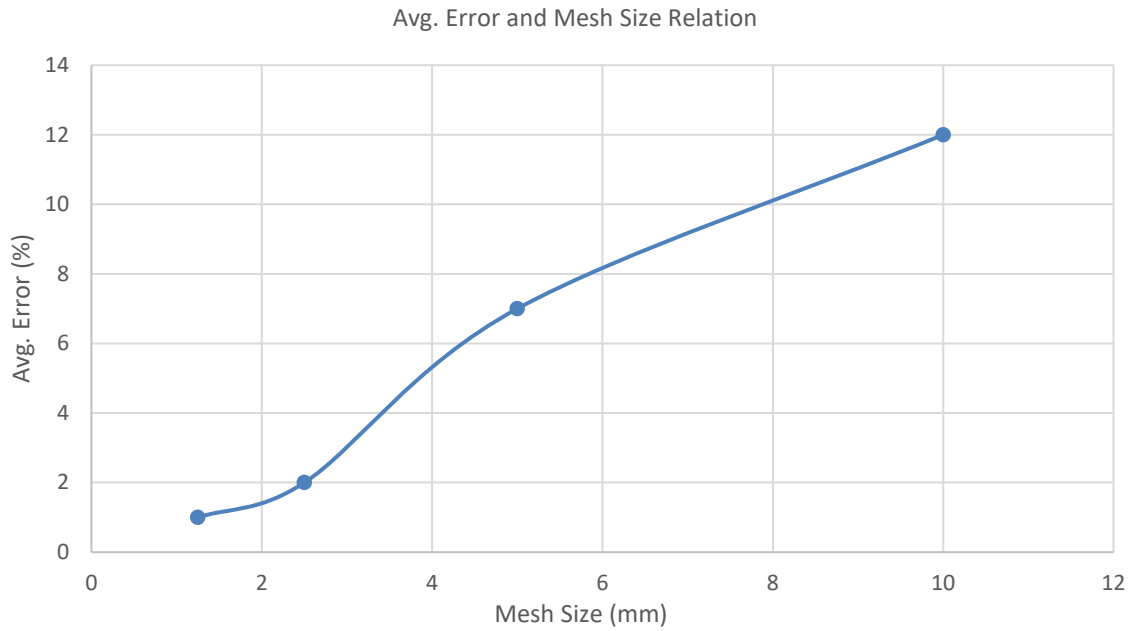
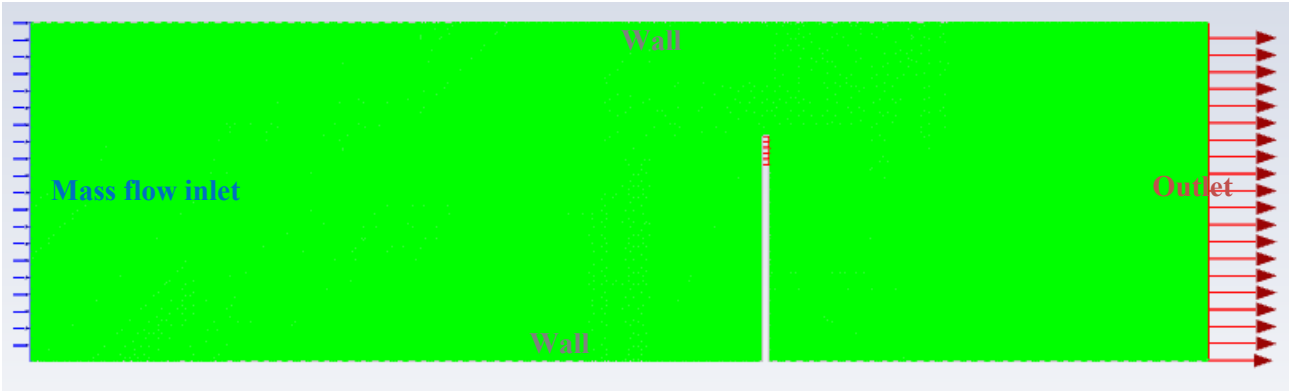


Figure 9. Average error calculation based on mesh size.

Analyzes were carried out with a total of 115440 meshes. While solving a 2D numerical model in the Fluent program, the width along the z-axis in 3D is accepted as 1 m by the program. The discharge (Q) values entered the program will be valid for 1 m width. The "inlet" part, which is the surface where water enters the flow volume, is defined as "mass flow inlet". Flow input is determined in kg/s, that is, lt/s. The "outlet" surface of the flow volume is defined as "pressure outlet". The remaining parts are defined as “wall” (Figure 10).



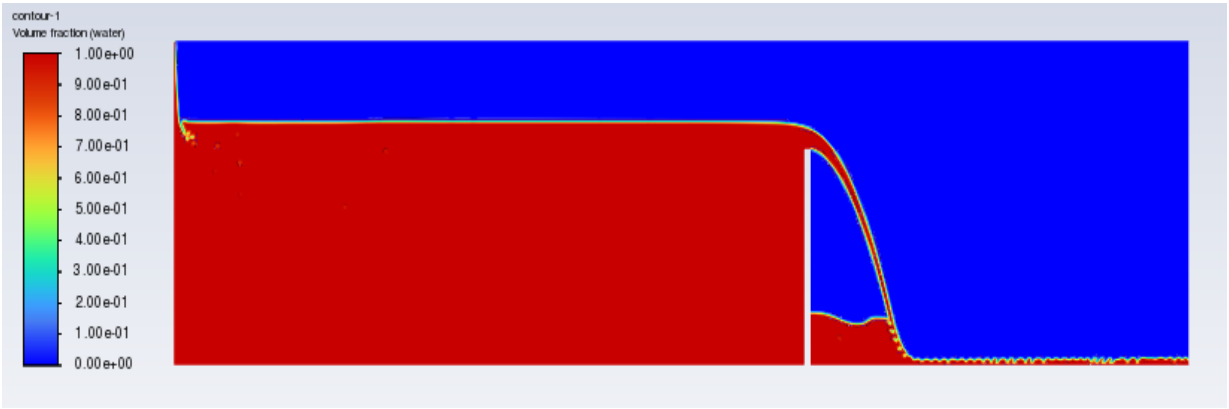


Figure 10. Boundary layer conditions created on the geometry and the image of the model as a result of the analysis.

Setup

Experiments in the laboratory, the free surface flow and the atmosphere above flow represent therefore in the numerical analysis a two-phase free surface flow is aimed. Therefore, by choosing the "Multiphase" model as the VOF (Volume of Fluid) method, it is aimed to consider the presence of both air and water in the flow area. At the same time, the "explicit" solution was preferred over the traditional "implicit" solution to increase the detail of the analysis. The effects of air on water, especially atmospheric pressure, are taken into account with this method. "Time step size" varies between 0.001 and 0.005 seconds depending on the total head (H_T), discharge (Q) and mesh size of the weirs. In the numerical model, the analyzes were continued until difference between the inlet and outlet discharge values become zero, and the total water volume in the flow area was expected to remain constant.

Results and Discussions

Numerical models of the tested linear (sharp-crested) weir were created by using the Fluent module of the ANSYS program. In the experiments, the discharge (Q) was gradually increased from 1 lt/s to 40 lt/s, depending on the Total head (H_T) capacity of the linear weir. Linear weir experiments were repeated for approximately 32 different discharge (Q) values. Since it would not be practical to use all discharge values (Q) in the numerical model, the analyzes were limited to certain discharge (Q) ranges. In this context, analyzes were carried out by selecting 7 8 different discharge (Q) values, Q=5-10-15-20-25-30-35-40 lt/sec, the total head (H_T) values corresponding to these discharge (Q) values were determined in linear weir numerical models. The results obtained from the numerical models were compared with the experimental data in two main aspects. In visual comparison, 2D images obtained from the numerical model were compared with laboratory experiments. Water surface profiles, the way the water spills depending on the features of the weir, and the turbulence that occurs in the downstream part of the weirs after it is spilled, were taken into consideration. In numerical comparison, the results obtained from numerical models and experiments were examined from two different perspectives: total head (H_T) - discharge (Q) and discharge coefficient (C_d) – dimensionless total head (H_T/P). The linear weir for which numerical models were created can be seen in Figure 10. At each discharge (Q) entered in the numerical model, the analyzes took between 3-4 hours, depending on the value of the discharge (Q). In linear weirs, discharge (Q) and total head (H_T) measurements were collected in the presence of a self-aerated nappe flow. No experimental data were collected in airless and adherent flow situations.

Graphical data showing the experimental and numerical model results of linear weirs are shown in Figure 11. The main goal of the graphical comparison is to visually highlight the differences between the discharge (Q) values determined in the numerical model and the differences that occur when the same discharge (Q) values are not found in the experiments. When the results obtained from models were examined, it was seen that the numerical models gave different results than the experiments. The main reason for this is that in the 2-dimensional numerical model, the model width in the 3rd dimension in z-axis is accepted as 1 m by the program default. While the net crest length (L_{net}) of linear weirs is equal to the channel width, L_{net} = 60 cm, the net crest length of the model used in the numerical model is L_{net} = 100 cm.

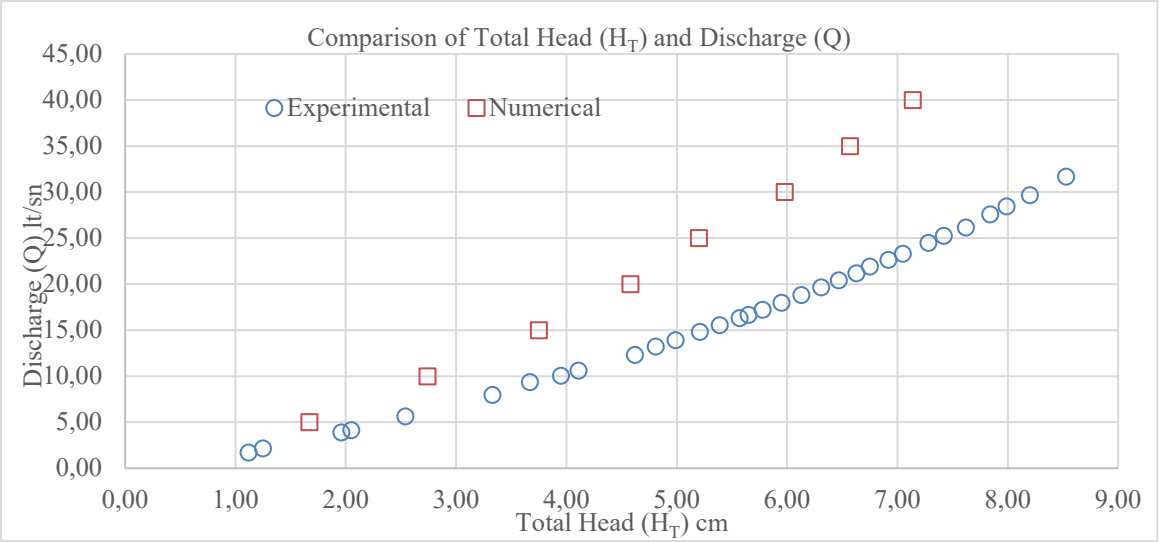


Figure 11. Comparison of experimental and numerical results in terms of total head (H_T) and discharge (Q)

The most important parameter of the discharge equation of linear weirs is the discharge coefficient (C_d). The effect of net crest length (L_{net}) disappears when compared with discharge coefficients (C_d). If a comparison is to be made to determine the hydraulic performance of weirs, the discharge coefficients (C_d) must be compared, and since the results obtained will be independent of the weir height (P), they can be used in comparisons with all weirs. Equation (5), obtained by rearranging Equation (1), was used to compare the discharge coefficients (C_d). Comparison of discharge coefficient (C_d) – dimensionless total (H_T/P) for linear weirs is given in Figure 12.

$$C_d = \frac{Q}{\frac{2}{3} * L_{net} * \sqrt{2 * g} * H_T^{1.5}} \tag{5}$$

Unlike the comparison of total head (H_T) - discharge (Q), numerical and experimental models of linear weir gave close results in the comparison of discharge coefficient (C_d) - dimensionless total head (H_T/P). Since the linear weirs in the numerical models have a longer net crest length (L_{net}) than the weirs in the experiments, they passed more flow at the same total head (H_T). However, this does not show that the weir in the numerical model is more hydraulically efficient. To compare weirs in terms of hydraulic efficiency, discharge coefficients (C_d) must be examined. The net crest length (L_{net}) of the weir is not important in the discharge coefficients (C_d).

ANSYS-Fluent program provides not only numerical results of the analyzes but also visual two and three-dimensional results. These visual results can be used to check whether the numerical model produces results consistent with physical experiments. By focusing on factors such as the path of the flow, the profile of the water as it spills over the weirs, and the conditions of the nappe flows, the performance of the numerical model can be visually examined thanks to the images obtained.

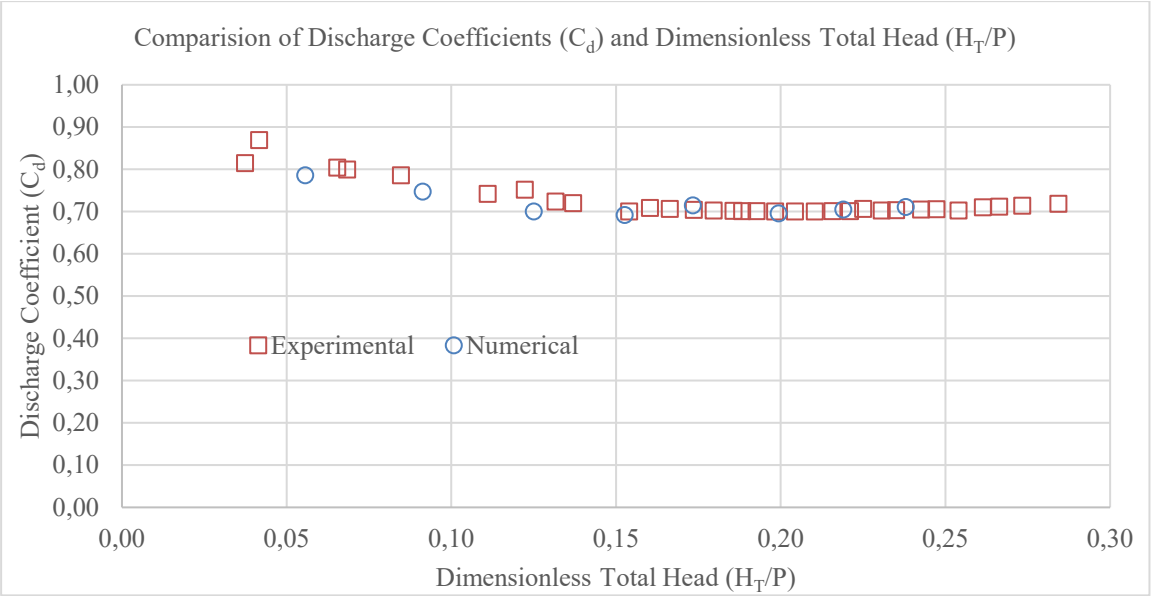


Figure 12. Comparison of experimental and numerical results in terms of discharge coefficients (Cd) and dimensionless total head (HT/P)

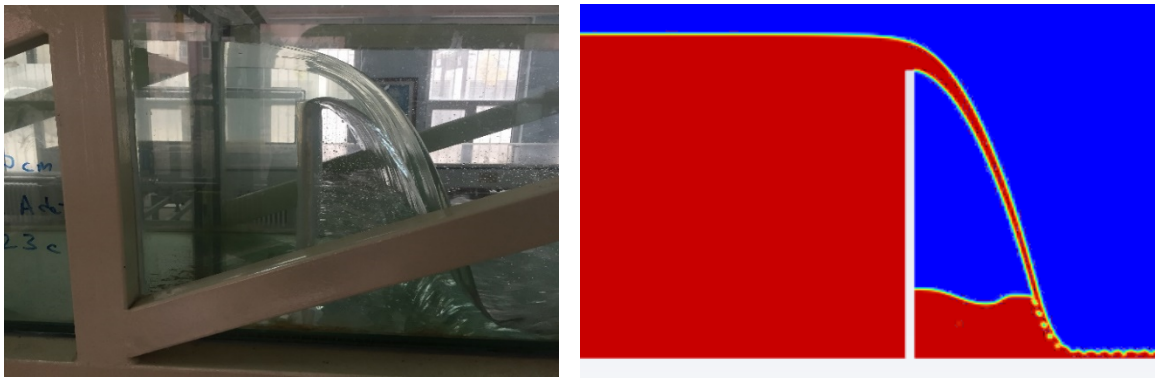


Figure 13. Visual comparison of Experimental and Numerical model

The 2-Dimensional images obtained from the numerical model show great similarities in terms of water surface profiles and flow properties when compared with the experimental results. In both models, water behaves as if it flows in a reservoir behind the weirs and exhibits a similar flow profile over the weirs. No fluctuation or turbulence is observed in the chamber, which indicates that the "boundary condition" has been successfully applied. While the water flows freely over the weirs, the flow is in a semi-aerated state on the downstream side and a distinct nappe flow is observed (Figure 13). The comparison between the 2-dimensional images obtained from the numerical model and the experimental images is presented below.

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