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Determination of Heavy Metal Remediation to Soil from Community Buildings' Rooftop

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ABSTRACT

Considering the importance of water in the world, the amount of usable water is not sufficient throughout the world, the existing available fresh water resources are not enough, therefore, water shortages may be encountered in the following years. Keeping the quality of water as it is demanded gains more importance than before. Particularly, heavy metals begin to interfere with groundwater resources, and the quantity of pollution growing due to industrialization, and urbanization. In the present study, the quantitative analysis of heavy metals in harvested rainwater from the rooftop of public buildings in Bornova, Izmir is investigated. The results show that a minimum of 5 µg of copper, 4 µg of zinc, 2.69 µg of lead, 0.095 µg of cadmium, 0.55 µg of chromium, 89,7 µg of iron, 0.96 µg of arsenic, 0.0119 µg of mercury and 3.88 µg of nickel should be tossed away for obtaining a liter of potable water. In conclusion, first flush diverters are recommended to convert these non-point pollutants to point source. Thus, municipalities can take necessary measures to protect the environment such as using phytoremediation and hyperaccumulator plants in sewages.

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Introduction

Water, which emerged with the formation of the Earth, is a renewable resource. In the research, it was understood that the Isua Rocks in Greenland, which are known to be the oldest in the world, were encountered for the first time and the water in these rocks was 3.8 billion years old. Almost 65% of the world is covered with water. 97.5% of the water in the world is salt water, the remaining 2.5% is usable water. 2% of this water is in the form of glaciers in the polar region, and the remaining 0.5% is usable (Ulusoy, 2007; Kurnaz et al., 2016; Türkmen et al., 2018; Mutlu and Güzel, 2019). The scarcity of potable water is one of the most important problems encountered today.

Some of the water needed in the world is met by rainwater and snowfall. The runoff from rain and melting snow around the world accounts for a large part of the mass movements of water. However, due to reasons such as unconscious use, climate change, environmental pollution, rapid population growth, wars, and unplanned migrations, the amount of usable water is rapidly depleted. Obtaining drinking and utility water, and the need for water in the agricultural and industrial fields have become increasingly difficult for countries (Şahin, 2010). In addition, water shortage is experienced due to the unequal water resources between regions according to population densities. The Middle East and North Africa Regions, including Türkiye, are the places where waterfalls the least per capita in the world. Especially the water problems in the Middle East cause the strategic importance of water to increase and this situation causes international conflicts (Maden, 2011).

Rainwater harvesting is commonly utilized for providing water in areas, where access to water resources is tough or costly. For example, an average of 25,000 homes in the United States use rainwater harvesting systems. In Japan, rainwater is collected and used in emergencies. In the Fiji Islands, rainwater is collected from public institutions such as schools, airports, football fields, and public parks, and used by collecting them (TÜSİAD, 2008). In a study on rainwater harvesting in Brazil, it was determined that approximately 12-79% savings were achieved in the amount of usable water, depending on the dimensions of the roof and storage tanks (Ghisi et al., 2007). The use of rainwater for different purposes and its collection and storage will provide both the protection of water resources and economic gain in water bills (Marinoski et al., 2014). The use of rainwater collected from roofs for laundry, cleaning activities, and toilet cleaning in situations that do not require water at usable standards is one of the current alternative studies aiming to save water (Ghisi et al., 2009). The fact that the rainwater harvesting system is separate from the water network makes the system more useful for individual water consumption and irregular settlements. The design of rainwater harvesting systems applied in buildings during the construction phase rather than the subsequent installation will ensure that this practice becomes widespread (Thomas, 1998).

Rainwater obtained from roofs is used as drinking water, especially in rural areas where even tap water is difficult. Only 80-85% of the precipitation falling on the earth is collected and stored. Rainwater collected and stored with a well-planned roof system meets the annual water needs of a family living in areas with less than 200 mm of precipitation per year. The working principle of roof systems is quite simple. In the current situation, rainwater can be collected and stored in tanks by making use of the slope on the roofs. If the collected and stored rainwater is to be used in the house and garden at the same time, storage tanks must be installed separately. Roof systems are also used to increase the potential of groundwater. In the system used to increase groundwater, a well is built and the collected rainwater is transmitted to underground sources by infiltrating (Morgan, 2014).

Heavy metals are considered the most dangerous and harmful because of their threat to living organisms (Aricak et al., 2019; Cesur et al. 2021). Heavy metals bioaccumulate within organisms (Karacocuk et al., 2022) and can be toxic, carcinogenic, and lethal even at low concentrations (Aricak et al., 2020; Cetin et al., 2022a,b) but some of them both are structural components for living organisms (Cesur et al., 2022) and can even be harmful when at high concentrations (Savas et al., 2021; Turkyilmaz et al., 2020) . Besides that, since the half-life of heavy metals is very long, they cannot be easily degraded in nature (Cetin and Jawed, 2022). Thus, it is very important to monitor the change in heavy metal concentrations in the water (Ucun et al., 2019; Ucun et al., 2020). There are also studies to determine the physicochemical properties of liquid for human health (Mutlu and Kurnaz, 2018; Demir et al., 2021; Tokatli et al., 2021). It is important to be given to rainwater harvesting in government policies, the amount of water to be disposed of before the first rain, underground water tanks, and rainwater storage tanks, maintenance, cleaning and importance of storage tanks, determining the purpose of use according to the quality of rainwater, microbiological and physicochemical effects of stored water on human health, the effect of fuel oil and fossil fuels on rainwater as a result of air pollution, the variation of rainwater quality between regions reasons, the effect of the material used in the rainwater collection area on the water quality will be the subject of the paper.

Materials and Methods

Methodology

In order to determine public buildings rooftops areas such as schools, hospitals, and sports centers, the Turkish General Directorate of Land Registry and Cadastre application implemented in the Yandex map is used. Thus, rainwater harvesting potential can be calculated by the Gould and Nissen formula (Gould and Nissen-Petersen, 1999):

$$R = S \times A \times Cr \quad (1)$$

Where R is the rainwater harvesting potential, S stands for rainfall, A stands for catchment area, and Cr is the runoff coefficient. The amount and characteristics of collected rainwater are affected by the size of the roof, the material from which it is produced, and its location. Since a roof made of bamboo material provides low-efficiency water, high-quality materials such as iron, aluminum, and galvanized should be preferred instead of this material. In order to obtain high efficiency from rainwater, leaves, dust, dirt, and bird droppings on the roof collecting surface should be cleaned frequently (Pradhan and Sahoo, 2019). Mild steel or tiled roofs are preferred in roof systems to obtain clean water and be easy to use (Alpaslan et al., 1992). Clay tile roofs made of porous and textured materials trap more rainwater than roofs made of smooth metal-like materials. Rainwater harvest field material, although in small amounts, also affects the potential and leaching of toxic substances into the water. Rainwater collected on asphalt, tar shingles, and wooden roofs is only suitable for irrigation (Ling and Benham, 2014). When the precipitation starts, a certain amount of rainwater is separated by first flush diverters, which prevent the penetration of deposited heavy metals on rooftops to rainwater storage tanks.

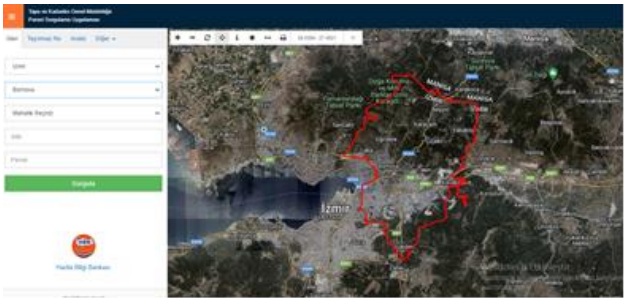

Figure 1. Bornova District from the Parcel Inquiry Screen of the TKGM Site

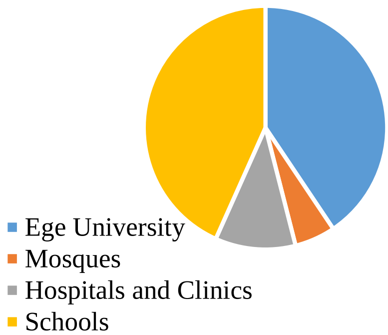

Figure 2. Distribution of rooftop area of public buildings in Bornova, İzmir

Table 1. The Average Monthly Precipitation in İzmir (mm)

Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Rainfall (mm)	135.0	101.9	75.4	46.1	31.8	12.0	4.1	5.6	15.5	44.8	92.6	145.7

Table 2. Drinking Water Quality Parameter Values in µg/l

Maximum Acceptable Values			
Standards	TSE 266	EC	WHO
Nickel	0.02	0.02	0.02
Arsenic	0.01	0.01	0.01
Cadmium	0.005	0.005	0.005
Mercury	0.001	0.001	0.001
Chromium	0.05	0.05	0.05
Lead	0.01	0.01	0.01
Copper	2.0	2.0	2.0
Iron	0.2	0.2	0.3
Zinc	5.0		

Table 3. Heavy Metal Amount from Various Rooftops in µg/l

Metals	Gravel Roof (1)	Zn and slate roof (2)	Tile and polyster roof (3)	Metal roof (5)	GI Roof (6)	Metal roof (7)	Min – Max
Cu	18-842		225	7.0-91.0	11-75.0	>7.5	7 - 842
Zn	9-115	29998	42	120-1200	680-3500	>100	9 – 29998
Pb	2.70-41.0	392	16	28-310	21-93		2.7 – 392
Cd	0.1-0.4		0.17	0.32-3.4	1.1-5.7		0.1 5.7
Cr	0.6-1.7			6.9-69.0	8.1-44.0		0.6 - 69
Fe	90-415						90 - 415
As				0.97-8.0	1.3-5.7		0.97 – 8
Hg				0.012-0.24	0.04-0.062		0.012 – 0.24
Ni				3.9-30.0	5.1-27.0		3.9 - 30

Table 4. Harvestable Rainwater Potential of Bornova, Izmir

Months	Catchment Area (m^2)	Rainfall (mm)	Runoff Coefficient	Total Harvested Rainwater (m^3)
January	206583	112	0.7	16196.11
February	206583	105	0.7	15183.85
March	206583	84	0.7	12147.08
April	206583	67	0.7	9688.74
May	206583	42	0.7	6073.54
June	206583	17	0.7	2458.34
July	206583	3	0.7	433.82
August	206583	4	0.7	578.43
September	206583	27	0.7	3904.42
October	206583	65	0.7	9399.53
November	206583	100	0.7	14460.81
December	206583	116	0.7	16774.54
Total	206583	742	0.7	107299.21

The amount of water to be disposed of in the first wash varies according to the air pollution of the region. In addition, the shape and size of the roof and the period between precipitation are among the parameters that are effective in the first siphon. In the parameters of some research made accordingly; After <1 mm of precipitation for three consecutive days, the 1 mm deep runoff should be diverted with the first flush (Ammas, 2015). According to Martinson, 5.0 NTU out of 2000 NTU is targeted turbidity and min. for 1mm max. An 8.5 mm first flush is recommended (Shafi, 2010). The Australian Water Service Association (2005) recommended that the first flush be 100 liters/ 100 m^2 (Sharma, 2015). The first wash-deflection time should be at least 5 minutes (Lee et al., 2011), and maximum of 20 minutes (Lay et al., 2011). Samples of roof flow in a few mm of rain collected on an urban residential roof in the Sydney Metropolitan area were analyzed. The results show that the first 2 mm of precipitation yields water with water quality parameters per the Australian Drinking Water Directives Standards. The parameters that do not comply with these standards are lead (Pb) and turbidity in rainwater.

Field of Study

In this study, it was aimed to determine the potential rainwater harvest of the Bornova district. Roof area information obtained from the TKGM website was used (Figure 1).

According to 29 the General Directorate of Meteorology, the average rainfall in İzmir between 1960 and 2022 is 742 millimeters. Due to the sufficient amount of precipitation that occurs in Bornova, the rainwater harvesting systems are soon to be constructed. The heavy metal deposited on the rooftops can be remediated or transported to a point source of pollution. Therefore, the necessary measures can be taken more easily.

Precipitation in Izmir

The region is under the influence of different air masses in two periods of the year, Maritimtropical, which is hot and humid in the summer period, and the Maritim Polar, which is affected by Northwest Europe in the winter period, is under the influence of the Maritim tropical air masses from the south. The amount of precipitation reaches 1000 mm due to factors such as urbanization, and changes in the topographic structure. However, it decreases to 300 mm in some years. Climate change affects the variability of the precipitation year by year, it is a wise idea to check out monthly average precipitation rather than annual. Table 1 shows the monthly precipitation of Izmir in millimeter.

Results and Discussion

After rainwater is collected, it must be safely free of contamination so that it can be made usable. For this, properly made water filters should be used. Carbon filter, sand gravel filter, sponge filter, and PVC-Pipe filter systems are used in filtration systems. As a result of the analysis of the research, heavy metals such as aluminium, arsenic, chromium, copper, cadmium, iron, manganese, lead, mercury, selenium, zinc, silver, and nickel were found in the collected rainwater. In addition, minerals such as calcium, magnesium, chloride, potassium, sodium, and sulfate appear to be present in collected rainwater. Heavy metals combine with components such as enzymes and proteins in the living body and disrupt their structures. With the introduction of cadmium, zinc, lead, copper, and aluminium heavy metals into the body, the risk of diseases such as stomach ailments and diarrhea increases. In addition, the incidence of diseases such as kidney failure, cirrhosis, hair loss, and anemia increase due to heavy metals and microbiological factors in unfiltered rainwater (Duruibe et al., 2007; Tam et al., 2010).

In literature, there is a limited number of studies that publish heavy metals quantity in the first flush rainwater system. Table 2 shows the amount of heavy metals variability with respect to authors.

In the present study, the whole public buildings in Bornova, Izmir Province are investigated. A total of 133 public buildings with 206,583-meter square area is determined. Figure 2 shows the divergence of the public buildings among themselves. Ege University and schools consist majority area of the public buildings. From an efficient perspective, Ege University is the more compact and better location to start heavy metal removal from the environment.

Using the Gould and Nissen formula, it can be calculated the potential rainwater harvesting amount. As it is stated before, the total area of the public buildings in Bornova is 206,583 m^2. Due to the tiled and concrete surface of the public buildings' rooftop surface, the runoff coefficient is taken as 0.7 in this study. The monthly harvestable rainwater of the public buildings of Bornova can be observed in Table 4. Approximately, a hundred thousand tons of water can be harvested from these buildings during an average year.

Considering the minimum amount of heavy metals we obtained in the literature, all this harvested water is converted to potable water. Each liter of rainwater, 5 μg of copper, 4 μg of zinc, 2.69 μg of lead, 0.095 μg of cadmium, 0.55 μg of chromium, 89.7 μg of iron, 0.96 μg of arsenic, 0.0119 μg of mercury, and 3.88 μg of nickel should be tossed away. If it is considered harvestable water in public buildings, each quantity turns to gram scale and accumulates year by year. Moreover, the previous study (Ülker, 2022) shows that harvested rainwater from public buildings is not sufficient for the community and the public buildings don't even contribute 0.5% of the water demand in the location. As a matter of fact, the quantity of heavy metal pollution can be avoided on kilogram scale if the first flush diverter is connected to the rainwater pipe system of all buildings in any community.

Conclusion

Water is one of the vital components of the Earth and should be kept clean as much as possible. Due to industrialization, urbanization, and technological enhancement, pollutant quantities are growing and interfering with the environment. Particularly, heavy metals are some of the main problems nowadays. In this study, heavy metals tracking by rooftop rainwater harvesting is investigated. Results show the number of heavy metals in the harvested rainwater from the rooftop is significant. Each liter of rainwater, 5 μg of copper, 4 μg of zinc, 2.69 μg of lead, 0.095 μg of cadmium, 0.55 μg of chromium, 89,7 μg of iron, 0.96 μg of arsenic, 0.0119 μg of mercury, and 3.88 μg of nickel should be tossed away. Accumulation of that many heavy metals on the soil is going to interfere with the strata and sooner or later in groundwater, which is the major part of available fresh water on the Earth. The first flush diverter prevents and allows to store of the first coming rainfall with swept roof materials. More than 85% of the pollutant can be captured with this tool. In the light of this study, it is strongly recommended to authorities to pass a code that the whole buildings set first flush diverters and after each storm, that water has to be collected or store to be collected by the municipalities to remediate heavy metals in the environment.

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