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THE HARVESTED RAINWATER AS A SOURCE OF NON-DRINKING WATER SUPPLY IN TYPICAL RESIDENTIAL MICRODISTRICTS OF UKRAINIAN CITIES

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Ukraine, facing water resource scarcity, finds it increasingly challenging to provide high-quality drinking water for both its population and industries, particularly in times of war. Harvested rainwater, among these sources, aligns well with water resource protection and management measures to counteract drinking water shortages. A literature review indicates that domestic needs in cities (flushing toilets, cleaning, and laundry) account for over 50% of drinking water demand, which could be supplemented by harvested rainwater. The estimated volume of harvested rainwater for a residential building in Odesa and Uzhgorod showed a drinking water saving to 15% and 36.5%, respectively. Similar calculations were carried out for residential microdistricts with high-rise buildings in these cities, showing a saving of drinking water due to the use of rainwater to 9% and 19%, respectively.

Key words: harvested rainwater, runoff volume, depth of precipitation, runoff coefficient, surface runoff area, degree of urbanization.

Introduction

Ensuring the population of Ukraine with quality drinking water, including through new construction, reconstruction, major repairs, is enshrined in legislation. Moreover, one of the key expectations is the improvement of the sanitary, epidemiological, and environmental situation due to Law of Ukraine. The demands for water supply increase every year, while the quantity of natural water suitable for this purpose decreases, primarily due to climate change. Ukraine's access to clean water in 2020 stood at 89.02% (washdata.org). At the same time, constantly water supply is provided for approximately 93% of the urban population and only 3% of the rural population (Law of Ukraine, 2021; Vyshnevskyi, 2019). Today, in times of war, these figures are significantly lower, especially after the destruction of the Kakhovka Hydroelectric Power Plant. Therefore, the task of uninterrupted water supply set by the Government of Ukraine is becoming increasingly challenging. However, requests for not only quality drinking water but also technological or agricultural water needs are only growing.Ukraine belongs to the countries with insufficient water resources, being one of the least water-rich countries in Europe. Water bodies in Ukraine cover an area of 24.2 thousand km^2, which constitutes 4% of its total territory. The river network is not very dense, with an average density of 0.34 km/ km^2. Ukraine lacks large natural reservoirs, and the reserves of underground water are limited (Matselyuk, 2017; Vyshnevskyi, 2019). The extraction of water from natural sources and its treatment to meet drinking standards is quite costly (Matsenko, 2008). The use of drinking water for only drinking purposes remains unresolved in Ukraine, as it accounts for 12% of the total water consumption (Matselyuk, 2017). Nowadays, there is an increasing global search for ways to economize and rationally utilize water resources (Hatt, 2006; National Academies, 2016).

Efficiently addressing the issue of water scarcity to meet current and future needs necessitates the development and implementation of appropriate measures for the protection and management of water resources. These measures include:

– implementing systems for water recycling and creating conditions for non-discharge water use (with a complete cycle of wastewater treatment).
– improving irrigation systems.
– substituting water cooling for air-based methods in equipment.
– reducing the proportion of water-intensive production in the economy.
– safeguarding surface and groundwater from pollution, particularly from wastewater.
– preserving the quality of natural water sources, and so forth.

The most crucial condition for improving integrated water management is responsible consumption, conducting research, implementing innovations, as well as economically incentivizing the rational use, protection, and replenishment of water resources (Katkov, 2020; Mitchell, 2007). One of the most promising approaches in this direction is the utilization of rainwater runoff in all sectors of the economy for non-drinking purposes (Philp, 2008; Schuetze, 2013; Tkachenko, 2016; Zhang, 2020).

The objective of this study is to analyze Ukrainian and international practices regarding the use of rainwater for economic purposes, and to assess the annual volumes of rainwater runoff in various regions of Ukraine for non-drinking water supply in modern residential neighborhoods.

Materials and methods

Advantages of using harvested rainwater for water supply.

In addition to solar and wind energy, rainwater is a fundamental renewable resource for any territory (Vovk, 2023). The harvested rainwater is utilized as independent water supply in regions facing water quantity restrictions, and in developed countries, it is often used as a supplement to the water supply (Mitchell, 2007; Philp, 2008; Schuetze, 2013; Tkachenko, 2016; Zhang, 2020). The harvested rainwater provides water for agriculture during droughts, reduces the likelihood of low-lying areas flooding, and reduces the need for constructing shaft or other types of wells, allowing for the maintenance of a steady groundwater level. The harvested rainwater are available for various purposes, reducing dependence on surface or underground water sources, improving soil quality by diluting salinity, causing no environmental pollution, and being environmentally friendly. The use of harvesting rainwater (Hatt, 2006; National Academies, 2016; Schuetze, 2013) and the implementation of management methods (Orel, 2020) reduce the amount of rainwater runoff in sewage systems and contamination of freshwater reservoirs (Mitchell, 2007; National Academies, 20016; Zhang, 2020). Current technological advancements allow for expanding the use of harvested rainwater not only for agricultural irrigation but also for urban residents' domestic needs: flushing toilets, cleaning, and laundry. This constitutes more than 50% of water needs per inhabitant (Table 1) (Delhiraja, 2020; Gurung, 2014; Novytska, 2014; Schuetze, 2013; Wilo, 2016).

While rainwater itself is a clean water source, often superior to groundwater or water from rivers or lakes, the process of collection and storage can leave it contaminated and unsuitable for drinking. Rainwater collected from roofs may contain animal and bird feces, mosses and lichens, wind-borne dust, solid pollution particles from cities, pesticides, and inorganic ions from the atmosphere (Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, Cl^{-}, SO_4^{2-}) as well as dissolved gases (CO_2, NO_x, SO_x) (Erickson, 2007; Rahman, 2014).

Table 1

Percentage of Water Consumption per Capita for Various Household Needs that can be Substituted with Rainwater

Needs	Countries				
	Ukraine	Australia	India	USA	Canada
toilet	32,7	16.5	26	32,1–28	30
laundry	15,7	21	12	24,2–22	20
cleaning	6,1	2	2	2	5

Rainwater Collection System

For the targeted drainage of water from roofs, it is recommended to install an organized drainage system. Organized rainwater drainage from building roofs starts directly from the roof. Depending on the height of the building's eaves from the site elevation, an internal or external drain is arranged (DBN V.2.6-220:2017). Almost all roof surfaces are suitable for collecting rainwater. From here, the water enters the gutter, where the initial contaminants are captured with the help of protective screens. Before entering the reservoir, rainwater is purified through a filter installed on the downpipe. A crucial detail is the first flush diverter, which prevents the entry of contaminated first flush rainwater into the reservoir. Screens are installed at the entry point of the reservoir for additional purification of rainwater. To prevent mosquitoes and pests from entering the reservoir, a filter is installed. In the reservoir, an automated water level control system and a pump can be installed (Fig. 1).

Determining the volume of harvested rainwater and the size of the reservoir is the most crucial task for the designer.

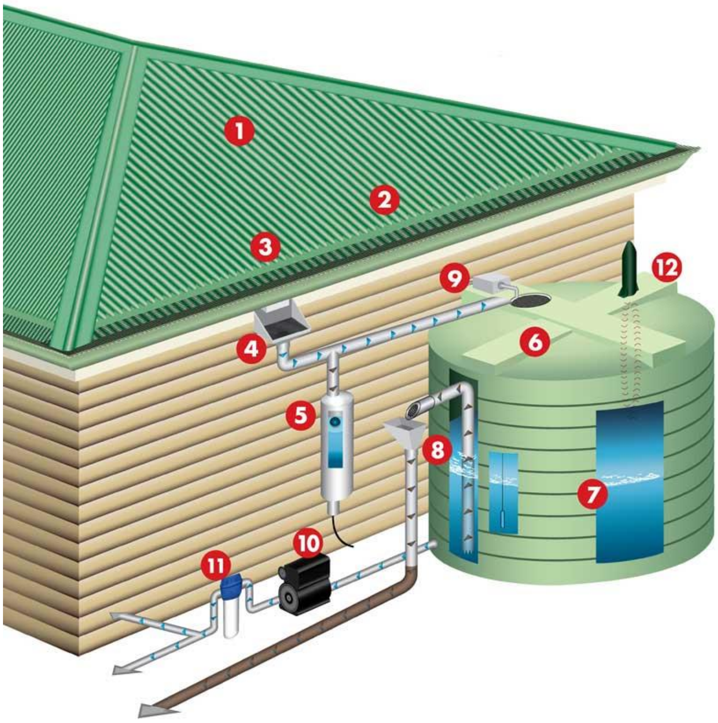

Fig. 1. Rainwater Collection System (Beqaj, 2022): 1. roof; 2. protective screen; 3. gutters; 4. filter on the downpipe; 5. first flush diverter; 6. reservoir screens; 7. reservoir; 8. insect protection valve; 9. automatic filling system; 10. pump; 11. irrigation filter; 12. water level indicator.

Runoff volume definition

The total runoff volume of rain and meltwater draining into the stormwater system from the territories of drainage basins for the warm and cold periods of the year can be determined according to the normative documents (Vovk, 2018). The runoff volume, m³, that is created on a specific area in a year is recommended to be calculated using the formula.

$$W_r = 10\, h_r\, \Psi_r\, F, \tag{1}$$

h_r – the average annual precipitation depth (mm); Ψ_r – the total runoff coefficient, which takes into account losses due to initial retention, infiltration, and evaporation, and depends on the type of surface cover; F – the surface area of runoff (ha).

The average annual precipitation depth in Ukraine is determined based on data from the nearest hydrometeorological station or according to the regulatory document (DBN V.2.5-74:2013). Calculations of runoff volume for the same area, according to the regulatory documents currently in effect in Ukraine, may have an error of up to 24.9% due to variations in the total runoff coefficient (Vovk, 2018). Moreover, the reliability of the results depends significantly on the level of detail in classifying surface types and their respective runoff coefficients (Vovk, 2018; Zhuk, 2020).

Rainwater for reuse is most commonly collected from roofs, as this requires less treatment. According to (DSTU-N B V.2.5-61:2012), for an improved roof covering, the runoff coefficient $\Psi_r = 0.7$. In global design practice, different types of coverings have different values for the coefficient Ψ_r (Wilo, 2016) ranging from 0.2 for flat roof with with plantings to 0.8 for sloped concrete roof (Fig. 2).

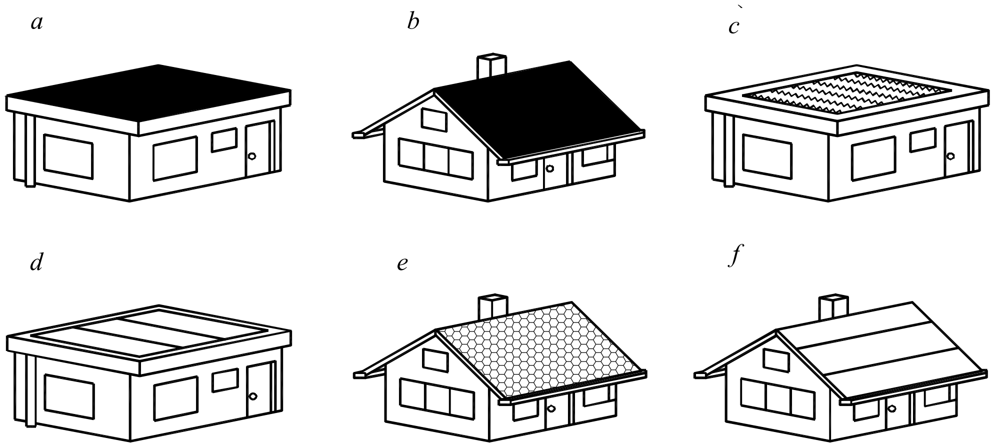

Fig 2. Types of roof with different flow coefficient Ψ_r: flat roof with plantings, $\Psi_r = 0.2$ (a); sloped roof with plantings, $\Psi_r = 0.25$ (b); flat roof with grit, $\Psi_r = 0.6$ (c); flat concrete roof, $\Psi_r = 0.7$ (d); sloped tiling roof, $\Psi_r = 0.75$ (e); sloped concrete roof, $\Psi_r = 0.8$ (f)

During the construction of new residential quarters, it is essential to consider the potential use of harvested rainwater for non-drinking purposes right from the initial design stage. Taking into account successful practices in international construction (National Academies, 2016; Hatt, 2006; Schuetze, 2013; Mitchell, 2007), it is possible to forecast the volume of rainwater for further hydraulic calculations of the water supply network, based solely on the known built-up area. In Ukraine, there are clear regulations regarding the maximum allowable land use when placing residential buildings, which range from 30% to 50% and depend on the building density (DBN B.2.2-1-01).

Results and discussion

Based on meteorological maps for regional centers in Ukraine, the calculation of the annual volume runoff formed by different types of roofs (table 2) was performed for a roof area of 100 m². This is nearly the minimum area for newly designed buildings, which are most commonly chosen by small families of 2-3 persons. The minimum precipitation depth is observed in the southern regions of Ukraine, specifically in Odesa with $\boldsymbol{h_r} = 350$ mm, while the maximum is in the western city of Uzhhorod with $\boldsymbol{h_r} = 750$ mm.

Water consumption for a resident in a modern building with plumbing, sewage, and water-heated baths using solid fuel according to Ukraine's regulatory document (DBN V.2.5-64:2012), depends on the architectural-climatic zoning of Ukraine's territory. In Zone I, the consumption is 150 l/day per person, while in Zones II, III, IV, it is 170 l/day. Consequently, the total consumption of drinking water amounts to 164.25 m³ in Zone I, and 186.15 m³ in Zones II, III, IV for a family of three persons. On the other hand, rainwater harvested from roof of such a family's building (Table 2) can substitute drinking water more than 35%. For example, in Odesa City, 4% of water consumption occurs when a building has a roof with a runoff coefficient of 0.2, while 15% is with a roof having a runoff coefficient of 0.8. In Uzhhorod City, under the same conditions, the range varies from 9% to 36.5% respectively. Thus, by harvesting rainwater even from small areas under favorable climatic conditions, significant savings in drinking water for household needs can be achieved. According to Table 1, families in Odesa City can use the harvested water for cleaning or laundry, while in Uzhhorod City for cleaning and/or toilet flushing, depending on the type of building roof.

Table 2

Volume of harvested rainwater (dm³) that can be collected from 100 m² of roof per year

City	Precipitation height (mm)	Flow coefficient for different types of roof					
		Flat roof with plantings	Sloped roof with plantings	Flat roof with grit	Flat concrete roof	Sloped tiling roof	Sloped concrete roof
		0.2	0.25	0.6	0.7	0.75	0.8
Vinnytsia (I)	500	10000	12500	30000	35000	37500	40000
Dnipro (II)	500	10000	12500	30000	35000	37500	40000
Donetsk (II)	550	11000	13750	33000	38500	41250	44000
Zhytomyr (I)	600	12000	15000	36000	42000	45000	48000
Zaporizhzhia (II)	450	9000	11250	27000	31500	33750	36000
Ivano-Frankivsk (IIIA)	700	14000	17500	42000	49000	52500	56000
Kyiv (I)	600	12000	15000	36000	42000	45000	48000
Kropyvnytckyi (II)	500	10000	12500	30000	35000	37500	40000
Lygansk (II)	500	10000	12500	30000	35000	37500	40000
Lytsk (I)	600	12000	15000	36000	42000	45000	48000
Lviv (I)	700	14000	17500	42000	49000	52500	56000
Mykolaiv (II)	400	8000	10000	24000	28000	30000	32000
Odesa (II)	350	7000	8750	21000	24500	26250	28000
Poltava (I)	500	10000	12500	30000	35000	37500	40000
Rivne (I)	650	13000	16250	39000	45500	48750	52000
Sumy (I)	600	12000	15000	36000	42000	45000	48000
Ternopil (I)	600	12000	15000	36000	42000	45000	48000
Yzhhorod (IIIB)	750	15000	18750	45000	52500	56250	60000
Harkiv (I)	550	11000	13750	33000	38500	41250	44000
Herson (II)	400	8000	10000	24000	28000	30000	32000
Hmelnytskyi (I)	650	13000	16250	39000	45500	48750	52000
Cherkasy (I)	500	10000	12500	30000	35000	37500	40000
Chernivtsi (IIIA)	700	14000	17500	42000	49000	52500	56000
Chernihiv (I)	550	11000	13750	33000	38500	41250	44000
Simferopol (II)	550	11000	13750	33000	38500	41250	44000

Note: architectural and construction climatic zoning of the territory of Ukraine is indicated in parentheses.

The relationship between the annual volume of rainwater runoff and the total area for micro-districts of different building densities, taking into account the percentage of maximum allowable land plot coverage when locating residential buildings for varying depths of precipitation, allows for consideration of the amount of rainwater for non-drinking use in the planning and design of a modern city block. Formula 1 with refinements regarding the runoff area was used for constructing the graphs (Figure 3). In this case, only the roof area is considered, which was determined based on the percentage of maximum allowable land plot coverage according to DBN B.2.2-1-01. This is because rainwater is most often collected from roofs for household purposes as the cleanest type of rainwater that can be collected from an urbanized area. This will enable the prediction of savings in drinking water from the municipal water supply system and facilitate hydraulic calculations for the water supply system supplied by rainwater. Also crucial at this stage is the design of a rainwater tank.

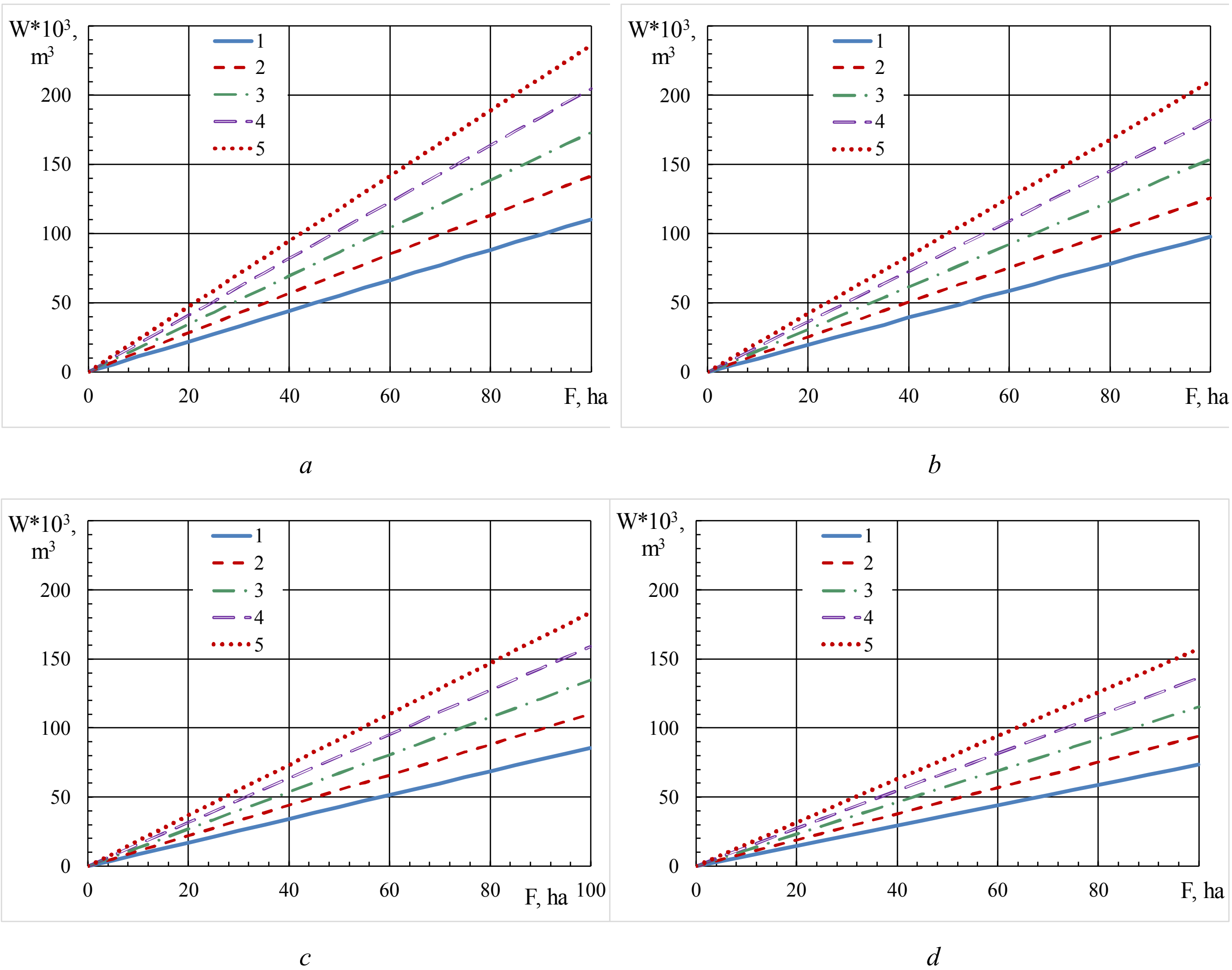

Fig 3. Dependence of the volume runoff of harvested rainwater collected from a roof with a runoff coefficient of 0.7, depending on the area of residential quarters with different degrees of development: a) 0.45, b) 0.40, c) 0.35, d) 0.30 for different precipitation depth h_r: 1 – 350 mm, 2 – 450 mm, 3 – 550 mm, 4 – 650 mm, 5 – 750 mm.

A rough estimate of water consumption for a drinking water supply system for a modern residential quarter with an area of 60 hectares and a population density of 200 persons/hectare (DBN B.2.2-1-01) confirmed the provision of rainwater for private single-family homes. For building densities within the range of 0.3…0.45, Odesa achieves savings of up to 6…9% in drinking water, and Uzhhorod reaches 13…19%.

Conclusions

Harvested rainwater is a source of water supply, especially for non-drinking purposes. Its use aligns very well with measures for the protection and management of water resources to prevent the issue of drinking water scarcity. A literature review revealed that household needs account for over 50% of the demand for drinking water, for which harvested rainwater can be used (toilet flushing, cleaning, and laundry).

A calculation was performed for the volume of collected rainwater for the roof of a family house with an area of 100 m² and a runoff coefficient of 0.2...0.8, for the cities of Odesa and Uzhgorod with precipitation depths of 350 mm and 750 mm respectively. Water savings of drinking quality were found to be 4...15% and 9...36.5% respectively. The same calculation was carried out for residential neighborhoods in Odesa and Uzhgorod. The calculation of rainwater runoff volume for a residential quarter with an area of 60 hectares and a degree of urbanization of 0.3...0.45, for a population density of 200 people/hectare, showed water savings of drinking quality through the use of rainwater by 6...9% and 13...19% respectively.

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ДОЩОВА ВОДА ЯК ДЖЕРЕЛО НЕПИТНОГО ВОДОПОСТАЧАННЯ ТИПОВИХ МІКРОРАЙОНІВ ЖИТЛОВОЇ ЗАБУДОВИ МІСТ УКРАЇНИ

Позаяк Україна належить до держав з недостатнім забезпеченням водними ресурсами, то постачати якісну питну воду населенню та промисловості і сільському господарству, особливо сьогодні, у воєнний час, стає все складніше. Тому постає питання пошуку інших, не природних, джерел водопостачання, зокрема для непитних потреб. До них можна віднести дощові води, використання яких дуже добре узгоджується із заходами з охорони й управління водними ресурсами для запобігання проблемі дефіциту питної води. Це має також паралельні переваги, зменшуючи кількість дощового стоку в системах водовідведення та забруднення прісних водойм. Так, літературний огляд виявив, що господарські потреби мешканців у містах (змивання унітазу, прибирання та прання) становлять понад 50 % потреб питної води, для яких можна використовувати дощові води. Аналіз метеорологічних карт для обласних центрів України виявив, що мінімальна висота шару опадів припадає на південні області, а максимальна – на західні. Згідно з ДБН В.2.5-64:2012, витрата води на питне водопостачання залежить від архітектурно-кліматичного районування території України. Розрахунок для даху площею 100 м² з коефіцієнтом стоку 0,2…0,8, проведений для м. Одеса та м. Ужгород з висотою шару опадів 350 мм та 750 мм відповідно, виявив економію води питної якості за рахунок використання дощової 4…15% та 9…36,5%. З іншого боку, згідно з ДБН Б.2.2-1-01, витрата води на питне водопостачання залежить від ступеню забудови та щільності населення. Розрахунок для даху з коефіцієнтом стоку 0,7, згідно з ДСТУ-Н Б В.2.5-61:2012, для будинку, розташованому в житловому кварталі площею 60 га зі ступенем забудови 0,3…0,45 для щільності населення 200 осіб/га, проведений для м. Одеса та м. Ужгород, виявив економію води питної якості за рахунок використання дощової 6…9% та 13…19% відповідно.

Ключові слова: забудови зібрана дощова вода, об'єм стоку, глибина опадів, коефіцієнт стоку, площа поверхні стоку, ступінь забудови.