Article

Determining Rainwater Harvesting Storage Capacity with Particle Swarm Optimization

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Abstract: Water is essential for living organisms. The increase in world population, global climate change and rapid growth in industrialization and urbanization have brought with them water issues around the world in recent years. Not only should existing water resources be used reasonably and efficiently but alternative water resources should also be explored and secured. Rainwater harvesting, which is one of the alternative water resources, can provide economic and environmental solutions. For rainwater harvesting, the size of reservoirs in which rainwater captured from roof catchments is stored should be determined. Determining the optimum tank capacity depending on precipitation and consumption rates allows us to make maximum use of rainwater tanks.

The aim of this study is to determine the optimum tank capacity for the storage of rainwater captured from roof catchments in order to meet the water demand for agricultural production. Precipitation data were collected from the city of Isparta and its districts. Rainwater tank capacity was determined using the Rippl, residual mass curve, minimum flow and particle swarm optimization methods. Storage capacities varying according to roof areas and consumption rates are shown in a graph. Results show that particle swarm optimization is the best method.

Keywords: rainwater harvesting; optimization; Rippl method; rainwater storage capacity

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1. Introduction

Water is essential for living organisms. The demand for water has increased significantly due to the rapid growth in industrialization and urbanization in recent years. Moreover, water resources are on the verge of running out due to overconsumption. Since water will always be a basic necessity, existing water resources must be used wisely, and alternative energy resources must be explored. There are a number of studies addressing different points regarding the use of rainwater as an alternative water resource [1]. Matos and others [2] stated that detailed research should be conducted before the establishment of rainwater harvesting systems in Portugal. Silva and others [3] examined system efficiency in geographical regions with different precipitation regimes. Imteaz and others [4] highlighted the importance of parameters affecting storage capacity in Australia. Gurung and Sharma [5] investigated the economic dimension of rainwater harvesting systems for different settlement types. Campisano and Modica [6] studied rainwater storage systems for different storage capacities in Italy. Montoya and others [7] focused on sustainability in rainwater harvesting systems in Mexico. Venkentesan and others [8] investigated the relationship between the surface areas of storage tanks and their capacities in India. Ghisi and others [9] determined the optimum tank capacity in Brazil, while Vialle and others [10] compared rainwater harvesting systems to other existing

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systems in France. Some studies aimed at keeping rainwater harvesting system installation costs to a minimum for optimum tank capacity [3,5,7]. The great majority of the studies focused on determining the optimum tank capacity to harvest rainwater by implementing various methods. Some of these methods are the Rippl method [2,11], daily water balance simulations [11,6,12,13], statistical methods [14], optimization methods [4]. This study used precipitation data from the cities of Isparta, Antalya and Burdur in the Mediterranean region of Turkey in order to determine the optimum tank capacity for rooftop rainwater harvesting. The Rippl, residual mass curve, minimum flows and particle swarm methods were used.

2. Materials and Methods

Precipitation data (1975-2006) from three stations (Burdur no 17238, Isparta no 17240 and Antalya no 17300) were used in the study. The coordinates of Burdur no 17238 are 37.721 north and 30.319 east of Greenwich. This station is 1074 meters above sea level. The total annual precipitation and average daily precipitation measured in this station are 426.97 mm and 1.17 mm, respectively. The coordinates of Isparta no 17240 are 37.764 north and 30.582 east of Greenwich. This station is 1006 meters above sea level. The total annual precipitation and average daily precipitation measured in this station are 512.02 mm and 1.40 mm, respectively. The coordinates of Antalya no 17300 are 36.909 north and 30.79 east of Greenwich. This station is 51 meters above sea level. The total annual precipitation and average daily precipitation measured in this station are 1122.31 mm and 3.07 mm, respectively (

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Table **1**).

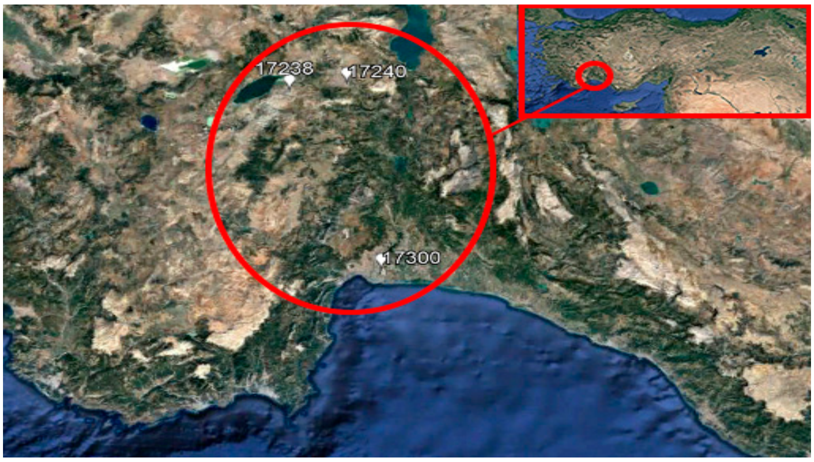

Figure 1. Location map of Burdur, Isparta and Antalya precipitation station

Table 1. Statistical Analysis of Precipitation Data

Station	Burdur	Isparta	Antalya
Average	426.97	512.02	1122.31
Standard Error	14.60	21.37	56.86
Standard Deviation	82.60	120.91	321.66
Kurtosis	-0.39	-0.34	-0.09
Skewness	-0.11	0.21	0.39
Interval	314.1	492.7	1289.6
Lowest	281.7	312	602.2
Highest	595.8	804.7	1891.8
Number of data (year)	32	32	32

One of the earliest studies on the storage capacity of reservoirs was conducted by W. Rippl who developed mass curve analysis, also known as Rippl's method, which is still the most commonly used method.

Rippl's method is the most commonly used tank capacity determination method. According to this method based on the correlation between water entering the tank, water discharged from the tank and storage requirements, flows entering the tank are collected at consecutive time points represented by a dotted curve on a graph. Referred to as the total flow curve, this curve always shows an increase in value. The slope of the total curve at any time corresponds to flow at that time. As in the case of the total flow curve, flows discharged from the tank are also collected at consecutive time points and displayed on the graph. Unlike the total flow curve, the demand function forms a line instead of a curve as the demand flows are assumed constant. As with the total flow curve, this function always increases in value at time points. The total flow curve and demand line are plotted on the graph as a line parallel to the demand function drawn by pulling up it and down to form a tangent to the total flow curve. If the total flow curve is above the demand function, it means that the tank is filling up. If the demand function line is above the total flow curve, that is, if the volume of water drawn from the tank is more than that of water collected, then it means that the tank is draining.

All water was used to plot the graph in Figure 2. In reality, the amount of water used is not always 100%. According to the graph in Figure 2, the optimum tank capacity is equal to the vertical distance between points A and B [15,16,17].

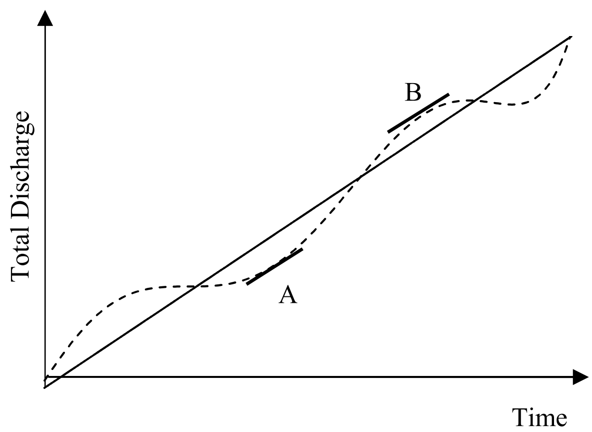

Figure 2. Determination of tank capacity using Rippl method

The residual mass curve method is similar to and a bit more complicated than Rippl's method but more suitable in terms of graph accuracy. In the residual mass curve method, first, average

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precipitation is determined. Residual mass value is calculated by subtracting average precipitation from precipitation of n th year and demand flow. Residual mass values are plotted on a graph. The largest difference between residual mass values and flows is used to determine the tank capacity (Figure 3) [18,17,19].

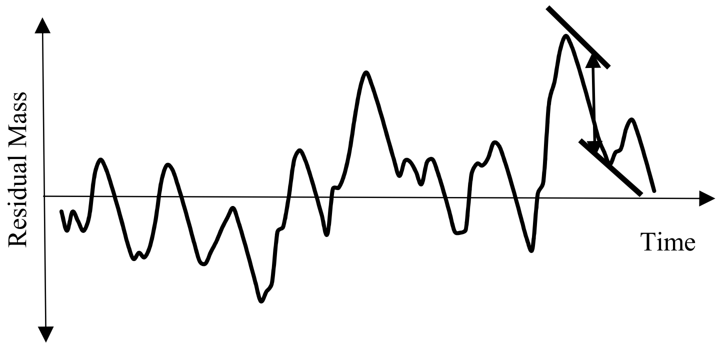

Figure 3. Determination of tank capacity using residual mass curve method

In the minimum flow method, minimum 12-, 24- and 36-month total flows are found using precipitation data in order to determine the tank capacity. Afterwards, those flows corresponding to the 12th, 24th and 36th months, respectively, are plotted on a time axis to obtain a line. Another line, the slope of which is equal to the demand flow, is drawn from the starting point of the graph. The maximum vertical distance (A-B) between the two lines gives the tank capacity required for storage (Figure 4) [15].

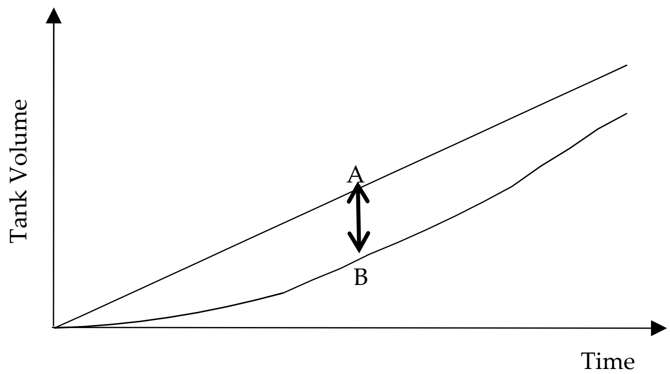

Figure 4. Determination of tank capacity using minimum flows method

Optimization is the process of finding the optimum solution for achieving specific objectives under constrained conditions [20]. Particle swarm optimization was developed in 1995 by James Kennedy and Russell Eberthart, who were inspired by birds, fish, and insects in flocks [21]. Particle swarm algorithm is based on information exchange within a swarm or community. Humans sharing information with one another, birds helping each other while migrating and fish in flocks is proof that living things have social intelligence. It has been noticed that animals in flocks are more likely to interact with each other during prey capture or escape from danger, and that this interaction allows them to reach their goals more easily. Thus, each candidate solution is referred to as a particle while

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a collection of particles is referred to as a swarm in particle swarm optimization (PSO) algorithm. Particles are elements that bring about different solutions to a problem. At the beginning, each particle in a swarm takes a random value for the solution of a problem [22,23]. Each particle adjusts its position based on its own experience and that of the particle with the best position. Each particle finds a better position than its previous position with every move and this process continues iteratively until the terminating condition [24]. The particle with the best position is referred to as the global best particle while the best position a particle has achieved so far is referred to as the local best [25].

In particle swarm optimization algorithm, the initial velocity and position of each particle are randomly determined. At each iteration, the initial velocity and position, and the local and global best positions are updated. The velocity and position, and previous best position of each particle, and the position of the best particle in the swarm are stored in the memory of the algorithm. These values are used to calculate the new velocity and position values. The best value in the swarm is the the solution value to the problem.

Depending on the type of the problem, minimization can be achieved by selecting particles with the smallest value while maximization can be achieved by selecting those with the largest value. Due to its speed and requirement for fewer parameters in solving a problem, the particle swarm algorithm is superior to other methods [26].

Figure 5 shows deterministic finite automata (DFA) for particle swarm algorithm.

$$M = (Q, \{0,1\}, \delta, q1, \{q7\}) \quad (1)$$

where Q is the set of states, $\{0,1\}$ is the input alphabet, δ is the transition function, q1 is the initial state and $\{q7\}$ is the final state.

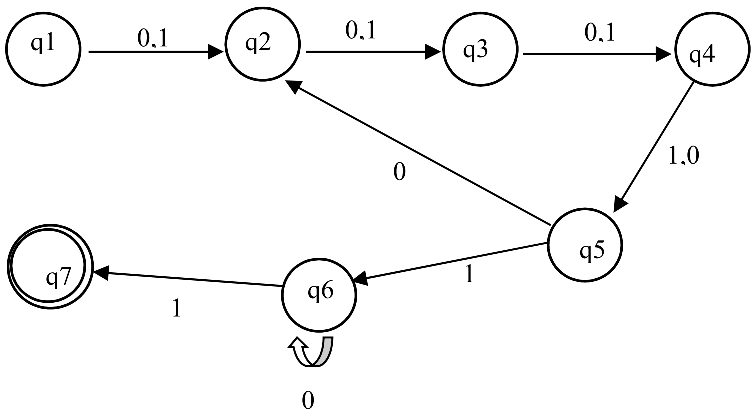

Figure 5. DFA for particle swarm optimization algorithm

q1. Randomly generated initial positions and velocities are used to generate the initial swarm.

q2. The fitness values of all particles in the swarm are calculated.

q3. The local best (pbest) is found using the current generation for each particle. The number of the best positions in the swarm is as many as the number of particles.

q4. The global best (gbest) position is selected from the local best positions in the current generation.

q5. Positions and velocities are updated according to equation 1.

q6. Stopping criterion

q7. Final state

$$V_{id} = W * V_{id} + c_1 * rand_1 * (P_{id} - X_{id}) + c_2 * rand_2 * (P_{gd} - X_{id}) \quad (2)$$

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$$X_{id}=X_{id}+V_{id} \quad (3)$$

where P_{gd} is the position vector with the best value (gbest) for the problem, X_{id} is the current position vector of particle i., P_{id} is the best position (pbest) of particle i., V_{id} is the current velocity vector of particle i., c_1 and c_2 are random numbers determined at the beginning of the solution of the problem, W is the momentum coefficient and $rand_1$ and $rand_2$ are random numbers in the range of [0 1].

On the left side of the equations, Vid is the velocity vector of particle i. and Xid is the position vector of particle i. at the end of iterations [27].

Demand values are assumed to be constant by the methods used to determine the tank capacity. However, the fact that the amount of water demanded changes with time reduces the accuracy of these methods. The demand for water is less in rainy seasons than in arid seasons, therefore, keeping the demand flow rate constant while determining the tank capacity conflicts with the principle of affordability and with the purpose of fully meeting needs. If the demand flow rate is as much as the amount of water consumed in arid seasons, then too large a tank capacity is calculated and the tank remains empty, which means an unnecessary increase in cost during the installation of the system. On the other hand, if the demand flow rate is as much as the amount of water consumed during rainy seasons, then the tank capacity calculated is less than the amount of water demanded. There would be no point in using such a system if it failed to meet the needs. Taking all these factors into consideration, we believe that determining the monthly demand will solve the problems. In this study, a computer software that can provide monthly and annual information using particle swarm optimization was developed. The DFA of the software is given in Figure 6. It can make calculations for the two different scenarios: (1) the demand flow rate is constant throughout the year (Figure 7) and (2) the demand flow rate changes on a monthly basis (Figure 8).

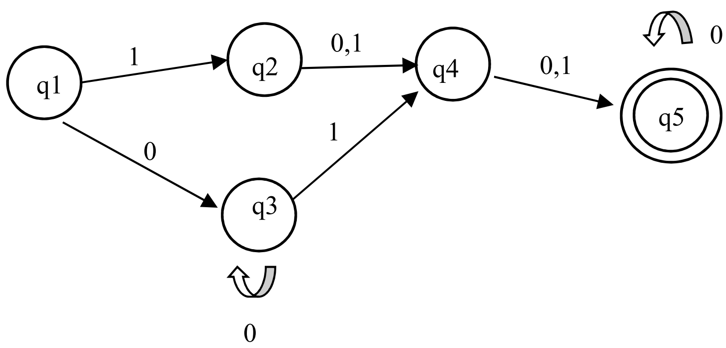

Figure 6. Software DFA

q1 is the onset, q2 is the Annual Model, q3 is the Monthly Model, q4 is the selection of roof area and q5 is the optimization algorithm given in Figure 4.

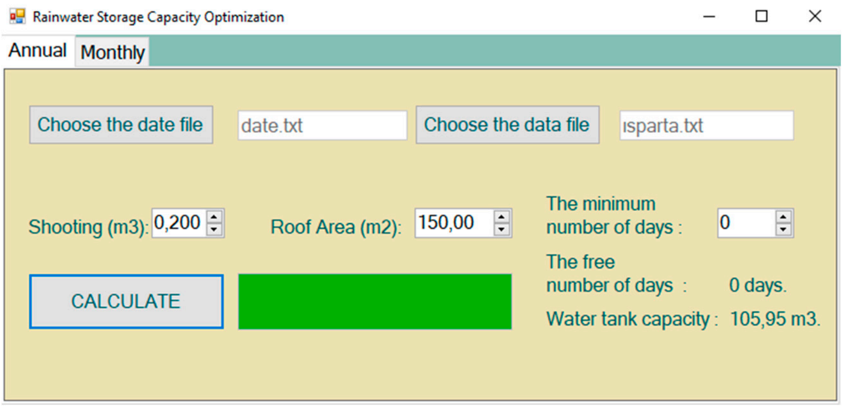

Figure 7. Analysis of constant demand flow in PSO

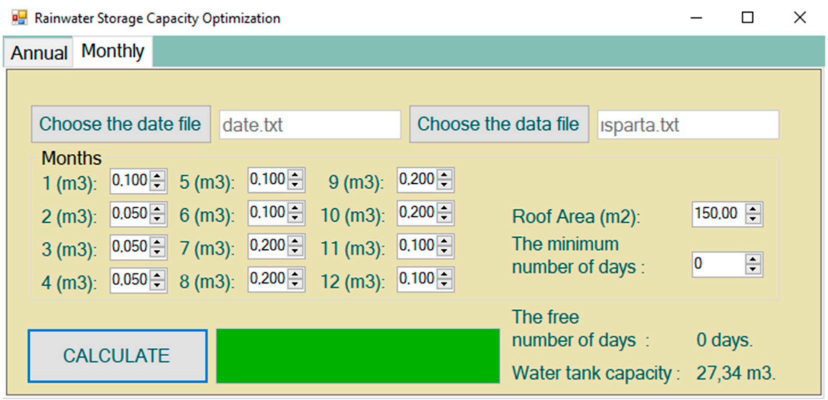

Figure 8. Analysis of variable demand flow in PSO

3. Results and Discussion

This section summarizes the calculations of optimum tank capacities obtained from Burdur, Isparta and Antalya stations. The software tested the tank capacities obtained using other methods with 32 years of operation. The study determined both the optimum tank capacity and the optimum consumption.

In all stations, the calculations made by the Ripple method and particle swarm optimization are very close to each other. The results of the minimum flows method meet the demand far better but are not cost-effective. In the residual mass curve method, the tank capacity is cost-effective but fails to provide the desired benefit.

Table 2 shows that very high capacities are achieved at Burdur station because the average annual precipitation does not meet the demand. Therefore, the end points of the curves (Figure 9) represent the tank capacities that cannot be satisfied by precipitation in the given roof areas. The consumption flow rates corresponding to these tank capacities are 0.13 m^3 per 100 m^2 roof area, 0.16 m^3 per 125 m^2 roof area, 0.19 m^3 per 150 m^2 roof area, 0.22 m^3 per 175 m^2 roof area, 0.25 m^3 per 200 m^2 roof area, 0.29 m^3 per 225 m^2 roof area and 0.32 m^3 per 250 m^2 roof area. The break points on the curve indicate sudden increases in tank capacities. Optimum consumption rates can be

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determined using these points. When optimum consumption rates are exceeded, the tank capacity increases suddenly, resulting in an increase in the cost. These rates are 0.10 m³ per 100 m² roof area, 0.13 m³ per 125 m² roof area, 0.15 m³ per 150 m² roof area, 0.17 m³ per 175 m² roof area, 0.20 m³ per 200 m² roof area, 0.22 m³ per 225 m² roof area and 0.25 m³ per 250 m² roof area.

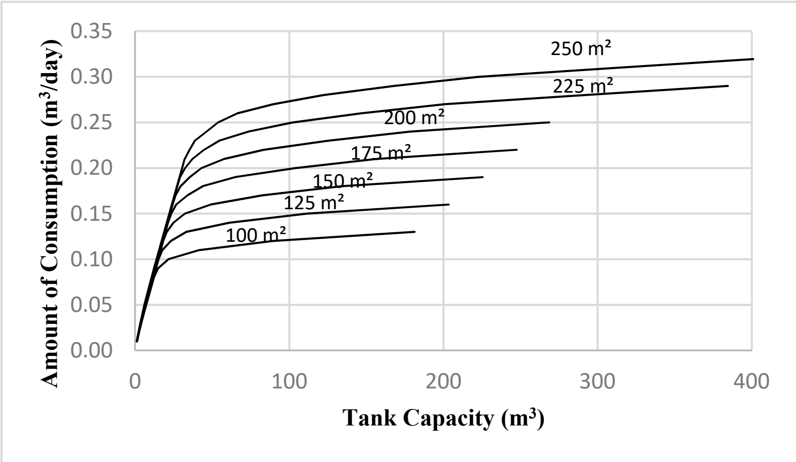

Figure 9. Tank capacity results of particle swarm optimization for Burdur station

Table 2. Comparison of methods used in the determination of tank capacity at Burdur station

BURDUR		RIPPLE METHOD			MINIMUM FLOWS METHOD			RESIDUAL MASS CURVE METHOD			OPTIMIZATION METHOD		
Roof Area	Amount of Consumption	Tank Capacity (m3)	Number of Days Empty	Days Empty (%)	Tank Capacity (m3)	Number of Days Empty	Days Empty (%)	Tank Capacity (m3)	Number of Days Empty	Days Empty (%)	Tank Capacity (m3)	Number of Days Empty	Days Empty (%)
$100m^2$	0.01	1.09	0	0	8.79	0	0	1.00	23	0.20	1.09	0	0
	0.05	7.19	0	0	102.45	0	0	5.94	42	0.36	7.19	0	0
	0.10	21.48	0	0	344.38	0	0	13.88	742	6.35	21.48	0	0
	0.15	389.10	0	0	694.11	0	0	54.33	9992	85.49	389.10	0	0
	0.20	967.95	0	0	1126.52	0	0	172.02	9434	80.72	967.95	0	0
	0.25	1549.70	1	0.01	1616.96	0	0	297.40	9326	79.79	1549.74	0	0
	0.30	2133.90	0	0	2150.52	0	0	424.90	9292	79.50	2133.90	0	0
	0.35	2718.10	1	0.01	3698.57	0	0	552.90	9268	79.30	2718.12	0	0
	0.40	3302.40	0	0	3264.32	0	0	680.30	9252	79.16	3302.40	0	0
$150m^2$	0.01	1.08	0	0	7.71	0	0	0.94	26	0.22	1.08	0	0
	0.05	6.66	0	0	79.15	0	0	5.68	36	0.31	6.66	0	0
	0.10	14.94	0	0	252.06	0	0	12.29	73	0.62	14.94	0	0
	0.15	32.22	0	0	516.57	0	0	20.82	744	6.37	32.22	0	0
	0.20	318.26	0	0	853.76	0	0	54.87	9342	79.93	318.26	0	0
	0.25	872.18	0	0	1244.65	0	0	139.07	9631	82.40	872.18	0	0
	0.30	1451.90	1	0.01	1689.78	0	0	258.03	9434	80.72	1451.93	0	0
	0.35	2032.60	1	0.01	2171.25	0	0	381.90	9346	79.96	2032.65	0	0
	0.40	2616.60	0	0	2688.34	0	0	509.20	9313	79.68	2616.60	0	0
$200m^2$	0.01	1.07	0	0	6.63	0	0	0.87	39	0.33	1.07	0	0
	0.05	6.29	0	0	66.30	0	0	5.54	29	0.25	6.29	0	0
	0.10	14.38	0	0	204.90	0	0	11.88	42	0.36	14.38	0	0
	0.15	22.68	0	0	413.67	0	0	18.64	97	0.83	22.68	0	0
	0.20	42.96	0	0	688.76	0	0	27.76	742	6.35	42.96	0	0
	0.25	269.59	0	0	1016.68	0	0	58.47	8334	71.30	269.59	0	0
	0.30	778.20	0	0	1388.22	0	0	108.66	9992	85.49	778.20	0	0
	0.35	1356.10	1	0.01	1800.72	0	0	224.16	9605	82.18	1356.15	0	0
	0.40	1935.90	1	0.01	2253.04	0	0	344.04	9434	80.72	1935.91	0	0
$250m^2$	0.01	1.06	0	0	6.40	0	0	0.81	55	0.47	1.06	0	0
	0.05	6.00	0	0	58.55	0	0	5.38	22	0.19	6.00	0	0
	0.10	13.83	0	0	177.40	0	0	11.53	43	0.37	13.83	0	0
	0.15	22.13	0	0	349.05	0	0	18.23	46	0.39	22.13	0	0
	0.20	30.43	0	0	580.40	0	0	25.05	118	1.01	30.43	0	0
	0.25	53.70	0	0	860.95	0	0	34.70	744	6.37	53.70	0	0
	0.30	223.10	0	0	1184.10	0	0	61.98	7393	63.25	223.10	0	0
	0.35	688.15	0	0	1544.60	0	0	105.93	9614	82.26	688.15	0	0
	0.40	1260.70	0	0	1934.60	0	0	193.40	9665	82.69	1260.70	0	0

Table 3 shows that very high capacities are achieved at Isparta station because the average annual precipitation does not meet the demand. Therefore, the end points of the curves (Figure 10) represent the tank capacities that cannot be satisfied by precipitation in the given roof areas. The consumption flow rates corresponding to these tank capacities are 0.14 m^3 per 100 m^2 roof area, 0.18 m^3 per 125 m^2 roof area, 0.22 m^3 per 150 m^2 roof area, 0.26 m^3 per 175 m^2 roof area, 0.30 m^3 per 200 m^2 roof area, 0.34 m^3 per 225 m^2 roof area and 0.38 m^3 per 250 m^2 roof area. The break points on the curve indicate sudden increases in tank capacities. Optimum consumption rates can be determined using these points. When optimum consumption rates are exceeded, the tank capacity increases suddenly, resulting in an increase in the cost. These rates are 0.12 m^3 per 100 m^2 roof area, 0.15 m^3 per 125 m^2 roof area, 0.19 m^3 per 150 m^2 roof area, 0.23 m^3 per 175 m^2 roof area, 0.25 m^3 per

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200 m² roof area, 0.28 m³ per 225 m² roof area and 0.31 m³ per 250 m² roof area.

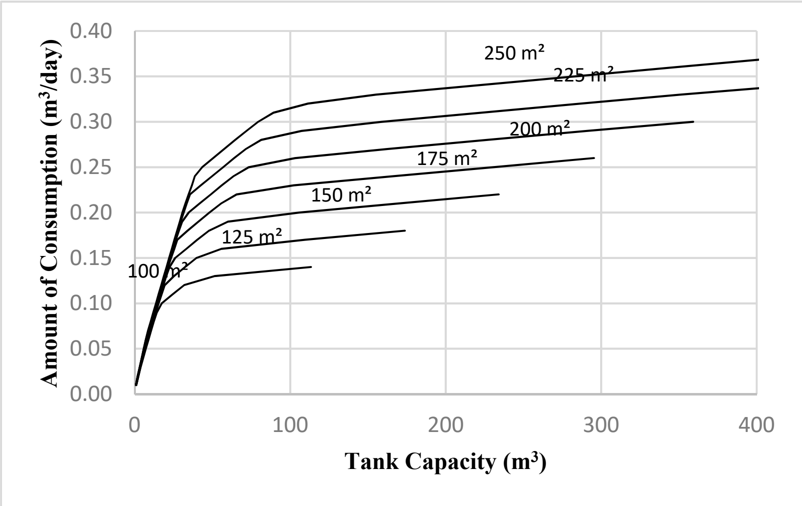

Figure 10. Tank capacity results of particle swarm optimization for Isparta station

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Table 3. Comparison of methods used in the determination of tank capacity of Isparta station

ISPARTA		RIPPLE METHOD			MINIMUM FLOWS METHOD			RESIDUAL MASS CURVE METHOD			OPTIMIZATION METHOD		
Roof Area	Amount of	Tank Capacity (m^3)	Number of Days Empty	Days Empty (%)	Tank Capacity (m^3)	Number of Days Empty	Days Empty (%)	Tank Capacity (m^3)	Number of Days Empty	Days Empty (%)	Tank Capacity (m^3)	Number of Days Empty	Days Empty (%)
100m²	0.01	1.04	0	0	7.59	0	0	0.62	125	1.07	1.04	0	0
	0.05	7.19	0	0	96.93	0	0	6.17	56	0.48	7.19	0	0
	0.10	17.35	0	0	309.90	0	0	14.80	109	0.93	17.35	0	0
	0.15	179.55	0	0	617.64	0	0	36.78	7666	65.59	179.55	0	0
	0.20	707.43	0	0	1015.68	0	0	139.00	8546	73.12	707.43	0	0
	0.25	1284.20	0	0	1466.62	0	0	261.60	8866	75.86	1284.20	0	0
	0.30	1863.30	1	0.01	1959.12	0	0	385.50	8920	76.32	1863.32	0	0
	0.35	2447.20	0	0	2481.59	0	0	513.20	8954	76.61	2447.20	0	0
	0.40	3031.40	1	0.01	3028.68	0	0	640.90	8998	76.98	3031.42	0	0
150m²	0.01	0.91	0	0	6.22	0	0	0.54	139	1.19	0.91	0	0
	0.05	6.54	0	0	72.78	0	0	4.98	106	0.91	6.54	0	0
	0.10	15.04	0	0	234.64	0	0	13.59	45	0.39	15.04	0	0
	0.15	26.03	0	0	464.85	0	0	22.20	109	0.93	26.03	0	0
	0.20	105.95	0	0	758.96	0	0	40.51	5656	48.39	105.95	0	0
	0.25	489.55	0	0	1113.09	0	0	88.02	7870	67.33	489.55	0	0
	0.30	1061.10	1	0.01	1523.52	0	0	208.10	8550	73.15	1061.15	0	0
	0.35	1637.40	1	0.01	1966.33	0	0	331.00	8825	75.50	1637.44	0	0
	0.40	2215.10	1	0.01	2439.00	0	0	453.90	8886	76.03	2215.14	0	0
200m²	0.01	0.79	0	0	5.86	0	0	0.54	131	1.12	0.79	0	0
	0.05	6.01	0	0	61.49	0	0	4.30	172	1.47	6.01	0	0
	0.10	14.38	0	0	193.86	0	0	12.34	73	0.62	14.38	0	0
	0.15	22.88	0	0	381.72	0	0	20.89	64	0.55	22.88	0	0
	0.20	34.70	0	0	619.80	0	0	29.60	863	7.38	34.70	0	0
	0.25	73.34	0	0	908.53	0	0	45.39	7835	67.03	73.34	0	0
	0.30	359.10	1	0.01	1235.28	0	0	73.56	9299	79.56	359.11	0	0
	0.35	843.00	1	0.01	1616.50	0	0	155.50	9474	81.06	843.10	0	0
	0.40	1414.90	0	0	2031.36	0	0	277.90	9305	79.61	1414.90	0	0
250m²	0.01	0.79	0	0	5.50	0	0	0.54	98	0.84	0.79	0	0
	0.05	5.88	0	0	54.05	0	0	3.95	129	1.10	5.88	0	0
	0.10	13.73	0	0	164.50	0	0	11.15	73	0.62	13.73	0	0
	0.15	22.23	0	0	329.40	0	0	19.70	49	0.42	22.23	0	0
	0.20	30.73	0	0	531.90	0	0	28.25	42	0.36	30.73	0	0
	0.25	43.38	0	0	774.75	0	0	37.00	110	0.94	43.38	0	0
	0.30	79.40	0	0	1058.10	0	0	50.28	946	8.09	79.40	0	0
	0.35	283.33	0	0	1373.70	0	0	76.13	7360	62.97	283.33	0	0
	0.40	644.10	0	0	1727.40	0	0	115.63	7819	66.90	644.10	0	0

Table 4 shows that very high capacities are achieved for Antalya station because the average annual precipitation does not meet the demand. Therefore, the end points of the curves (Figure 11) represent the tank capacities that cannot be satisfied by precipitation in the given roof areas. The consumption flow rates corresponding to these tank capacities are 0.25 m^3 per 100 m^2 roof area, 0.31 m^3 per 125 m^2 roof area, 0.38 m^3 per 150 m^2 roof area, 0.40 m^3 per 175 m^2 roof area, 0.40 m^3 per 200 m^2 roof area, 0.40 m^3 per 225 m^2 roof area and 0.40 m^3 per 250 m^2 roof area. The break points on the curve indicate sudden increases in tank capacities. Optimum consumption rates can be determined using these points. When optimum consumption rates are exceeded, the tank capacity increases suddenly, resulting in an increase in the cost. These rates are 0.17 m^3 per 100 m^2 roof area, 0.21 m^3 per 125 m^2 roof area, 0.27 m^3 per 150 m^2 roof area, 0.30 m^3 per 175 m^2 roof area, 0.34 m^3 per 200 m^2.

There is no such use for 200m² and 250m² roof area.

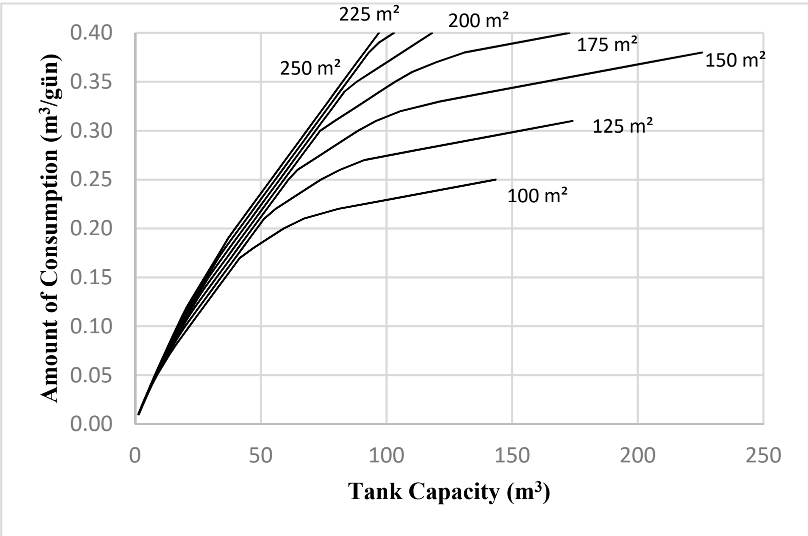

Figure 11. Tank capacity results of particle swarm optimization for Antalya station

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Table 4. Comparison of methods used in the determination of tank capacity of Antalya station

ANTALYA		RIPPLE METHOD			MINIMUM FLOWS METHOD			RESIDUAL MASS CURVE METHOD			OPTIMIZATION METHOD		
Roof Area	Amount of	Tank Capacity (m^3)	Number of Days Empty	Days Empty (%)	Tank Capacity (m^3)	Number of Days Empty	Days Empty (%)	Tank Capacity (m^3)	Number of Days Empty	Days Empty (%)	Tank Capacity (m^3)	Number of Days Empty	Days Empty (%)
$100m^2$	0.01	1.47	0	0	23.44	0	0	1.36	25	0.21	1.47	0	0
	0.05	8.71	0	0	165.59	0	0	7.88	96	0.82	8.71	0	0
	0.10	21.63	0	0	395.68	0	0	16.12	294	2.52	21.63	0	0
	0.15	35.91	0	0	670.80	0	0	24.30	618	5.29	35.91	0	0
	0.20	59.11	0	0	971.36	0	0	34.45	1214	10.39	59.11	0	0
	0.25	143.42	0	0	1309.07	0	0	47.01	3817	32.66	143.42	0	0
	0.30	287.07	0	0	1669.38	0	0	69.43	6249	53.47	287.07	0	0
	0.35	627.92	0	0	2054.98	0	0	112.16	9155	78.33	627.92	0	0
	0.40	1130.40	0	0	2466.04	0	0	157.74	10136	86.72	1130.40	0	0
$150m^2$	0.01	1.38	0	0	22.31	0	0	1.29	21	0.18	1.38	0	0
	0.05	8.23	0	0	149.20	0	0	7.70	55	0.47	8.23	0	0
	0.10	18.94	0	0	355.38	0	0	15.74	197	1.69	18.94	0	0
	0.15	32.45	0	0	593.52	0	0	24.18	294	2.52	32.45	0	0
	0.20	46.70	0	0	863.52	0	0	32.32	440	3.76	46.70	0	0
	0.25	61.07	0	0	1152.20	0	0	41.53	741	6.34	61.07	0	0
	0.30	88.67	0	0	1457.04	0	0	51.68	1214	10.39	88.67	0	0
	0.35	163.01	0	0	1790.23	0	0	63.66	2917	24.96	163.01	0	0
	0.40	273.11	0	0	2136.98	0	0	77.96	4662	39.89	273.11	0	0
$200m^2$	0.01	1.33	0	0	21.23	0	0	1.26	19	0.16	1.33	0	0
	0.05	8.00	0	0	139.53	0	0	7.57	28	0.24	8.00	0	0
	0.10	17.42	0	0	331.18	0	0	15.62	114	0.98	17.42	0	0
	0.15	29.17	0	0	549.75	0	0	23.81	228	1.95	29.17	0	0
	0.20	43.26	0	0	791.36	0	0	32.00	311	2.66	43.26	0	0
	0.25	57.51	0	0	1060.11	0	0	40.37	408	3.49	57.51	0	0
	0.30	71.82	0	0	1341.60	0	0	48.80	599	5.12	71.82	0	0
	0.35	88.18	0	0	1633.60	0	0	58.75	853	7.30	88.18	0	0
	0.40	118.22	0	0	1942.72	0	0	68.90	1214	10.39	118.22	0	0
$250m^2$	0.01	1.33	0	0	20.70	0	0	1.25	11	0.09	1.33	0	0
	0.05	7.83	0	0	133.35	0	0	7.45	17	0.15	7.83	0	0
	0.10	16.78	0	0	313.60	0	0	15.50	71	0.61	16.78	0	0
	0.15	27.65	0	0	519.30	0	0	23.60	161	1.38	27.65	0	0
	0.20	39.83	0	0	746.50	0	0	31.80	251	2.15	39.83	0	0
	0.25	54.08	0	0	989.20	0	0	39.95	311	2.66	54.08	0	0
	0.30	68.33	0	0	1256.70	0	0	48.40	381	3.26	68.33	0	0
	0.35	82.58	0	0	1531.00	0	0	56.70	475	4.06	82.58	0	0
	0.40	96.98	0	0	1823.00	0	0	65.83	693	5.93	96.98	0	0

Demand values are assumed to be constant in the methods used to determine the tank capacity. However, the fact that the amount of water demanded changes with time reduces the accuracy of these methods. Two problems arise from the fact that the demand for water is less in rainy seasons than in arid seasons. If the demand flow rate is as much as the amount of water consumed in arid seasons, then too large a tank capacity is calculated and the tank remains empty. On the other hand, if the demand flow rate is as much as the amount of water consumed during rainy seasons, then the tank capacity calculated is less than the amount of water demanded. There would be no point in using such a system if it failed to meet demands. Taking all these factors into consideration, we believe that determining the monthly demand will solve these problems.

Antalya station was the station of choice for model application.

Let us assume that demand is 0.1 m^3, 0.05 m^3, 0.05 m^3, 0.05 m^3, 0.1 m^3, 0.1 m^3, 0.2 m^3, 0.2 m^3, 0.2 m^3, 0.2 m^3, 0.1 m^3 and 0.1 m^3 for January, February, March, April, May, June, July, August, September, October, November and December, respectively (scenario 1). Let us further assume, for comparison purposes, that demand is constant throughout the year. Let it be 0.15 m^3, which is average of the monthly varying values (scenario 2). The tank capacity at Antalya station was found to be 41,2 m^3 (

Figure 12) and 32,45 m^3 (

Figure 13) per 150 m^2 roof area for scenario 1 and scenario 2, respectively.

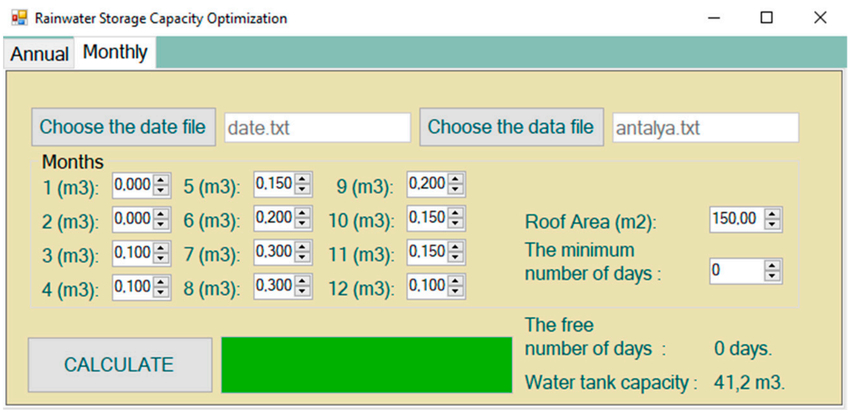

Figure 12. Tank capacity calculation for monthly varying demand (Antalya station)

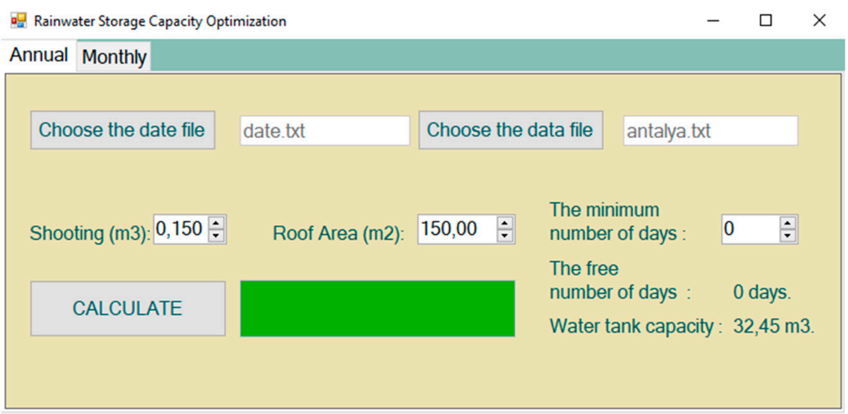

Figure 13. Tank capacity calculation for constant demand throughout the year (Antalya station)

4. Conclusions

Rapid population growth around the world has resulted in an increase in demand for food and therefore also for agricultural production. The increase in food production has, on the other hand, led to an increase in demand for soil and water resources. The increase in urbanization in parallel with population growth causes the degradation and pollution of agricultural land and water resources. The impacts of global warming will be significantly negative in the coming years. We should, therefore, use our water and soil resources wisely and increase our food production. One of the key steps in maximizing the benefits provided by our water resources is to assess the available resources and to determine our needs to be able to develop projects suitable for those resources.

Plants consume water through transpiration from leaves and evaporation from soil surface. The amount of water consumed by plants depends on many factors such as plant type, time of sunlight exposure, temperature, humidity, wind, concentration of soil water, duration of plant growth and also season. Lysimeters are used to measure water use by plants. However, Lysimeters are expensive and time-consuming. Therefore, water use by plants can also be estimated using various modeling techniques based on seasonal data.

This study investigated the use of rainwater as an alternative resource to meet the water needs of plants and calculated the optimum tank capacity for rainwater harvesting systems for different water demand scenarios. Precipitation data from the city of Isparta and its districts were used, and the optimum tank capacity was determined depending on different roof areas and consumption rates. The results of computer software developed using classical methods and particle swarm optimization were also included and compared.

The results show that there were no days when the tank was empty in the particle swarm algorithm and minimum flows method. However, the tank capacity obtained from the minimum flow method was quite large.

The tank capacities obtained from the residual mass curve method were quite small, indicating that although the results of the residual mass curve method were cost-effective, this method failed to meet the demand especially at high consumption rates. However, the results of the residual mass curve method and particle swarm optimization methods were similar at low consumption rates.

The tank capacity results of the particle swarm optimization and ripple methods were also similar. It is, however, difficult to use the ripple method when consumption varies monthly. The ripple and particle swarm optimization methods can be used interchangeably when consumption rate is constant throughout the year. However, the latter is the best method when consumption varies monthly.

Based on the same roof areas, the tank capacities are larger at stations with low precipitation than at those with high precipitation. Of all stations, Karapınar station has the largest tank capacity while Antalya station has the smallest. It can be clearly seen that these results are related to the amount of precipitation because Karapınar station with the largest tank capacity has the lowest amount of precipitation while Antalya station with the smallest tank capacity has the highest amount of precipitation. Similarly, Isparta and Güney stations with similar amounts of precipitation have similar tank capacities.

The results of the model application show that the difference in tank capacity for Antalya station between scenario 1 (constant demand flows) and scenario 2 (variable demand flows) is 9 m^3, indicating the importance of changing demand flows monthly.

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