雨水資源化システムの地域的可能性に関する一考察(1)

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A Study on Regional Potential of Rainwater Cistern Systems (I)*

— Basic Analysis of Daily Precipitation Data and Simulation of Cistern Store —

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雨水資源化システムの地域的可能性に関する一考察（I）

—日降水量データの基礎解析と資源化水量のシミュレーション—

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This paper studied on the potential utilization quantity and some regional comparisons for designing the rainfall cistern systems by the basic analysis of the characteristics of daily rainfall data of remote islands in Japan.

At first, some references were made to show the relations between the annual rainwater depth and the scale, the structure and many problems for maintaining and improving the water quality.

Secondly, the basic analysis was made on the daily rainfall data in the remote islands islands in Seto Inland Sea where water supply condition has been so severe and the data in Maizuru was added for comparison, where annual precipitation depth is near the average value of all Japan.

Here the potential maximum utilization of cistern system with roof (100 m^2) catchment system in the districts were estimated from the average annual precipitations from long terms as over 10 years. And the characteristics of the frequency distributions of daily rainfall and the continuous no rain days have proved that those effect so much on the desing the system. And simulation of cistern store with daily rainfall showed the needed the storage volume of the cistern tank and supplementaly water volume to maintain the stable water supply in the cictern system.

I Introduction

About 50 years passed since last World War II, Japan must have completed so great economic development and abundant or satisfactory water supply everywhere, but even today, in so many districts, people live wth very severe condition on water supply for irrigation, industry and domestic use. Besides, it become almost impossible to find the suitable place to construct new big dams and channel systems. So some modern methods as construction of the under ground dams, the freshing reserviors etc. have been planed and made.

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The charactristics of the time serires of precipitation data in Japan show many regional differences. Shortly saying, usually, from June to October some regions have been hovered by the front extending east and west. And some regions have been swept over by the typhoons. And in winter, it is called as the "snow season" in north districts and many districts along the seashore of Sea of Japan.

Then it has been very severe especially for some remote islands as near the Setouchi Inland Sea District to get sufficient water supply,and where water supply plans have been considered as to make the desalinization plant projects, to sink wells, to construct the freshing reservior and water conveyance pipe line system under the sea. And even water transport boats have been used.

In these days the Japan Goverment had prepared the development law of remote islands called "Law of Remote Island Developments". And the global plannnig are now under consideration by central and local goverments.

Here, the rainwater cistern system as using roof of big buidings, village office, and school have gathered so much remarkable attention even in big cities and in remote islands as in Seto Inland District where water supply is severe.

In the world, the rain water cistern systems have been in use in many regions, as in many rural parts as in Kentucky and in many islands as Caribbean Islands, Hawaii, Bermuda, Mexico, Thailand, Philippines, Malaysia, Indonesia and several countries in Africa where the annual rainfall depth are very small. And this system sometimes called as water catchment or water harvesting system.

So this paper studied on the potential utilization quantity of rainwater cistern systems by the basic analysis of daily precipitation data, and examined to estimate and design the scale of cistern storage by the simulation of the store, and added the regional comparisons of the probability of the systems.

II Components of rain water catchments systems

1 A roof catchments system[1]

Rain water catchments systems are called to have three types as rock catchments, ground catchments and roof catchments. Here we treat roof catchments. For roof catchments, the rainfall is collected from a roof and channeled through a gutter into a storage tank for use by individual household or that building. And this system has the following components, as popularily used in south Asia and south Africa.

1) Roof Catchment—available large roof as catchment area must be determined. The roof must be made of materials such as G. I., cement, or any other smooth surface with minimal seepage.

2) Storage Tank—this must be durable low cost and can be easily maintained.

3) Gutter System—effective guttering is an important of the rain water roof catchment. Water must be efficiently conveyed from the roof to the tank to meet the owner's demands. Then a good gutter material should be lightweight, water resistant, and easy to join. To reduce the number of joints and thus the likehood to leakages, a materials which is available in long, straight sections is prefered.

Examples of materials used for gutters include bamboo, wood and sheet metal.

2 Examples of roof catchments in surveryors mamuals in semi-arid Africa[2)]

We can see some examples in semi-arid Africa as Fig. 1. There a cylindrical tank with a volume of 21,000 litres made of ferro-cement and roofed with iron sheets. Water is drawn from the tank by gravity to a water tap placed at the floor of the tank. And here the total of rainfall is estimaded about 300 mm at rainy season and it will provide 120 litres per day for length of dry period (180 days without rain) with the area of roof is 72m². And nextly down part of Fig. 1 shows a hemishperical under ground tank with a volume of 78,000 litres. If the tank is full at the start of a six months of dry season, it will provide 459 litres per day with little loss evaporation, with the area of 175m² of roof and added 30m² of the roof of the tank where average annual rains is estimaded as 811mm.

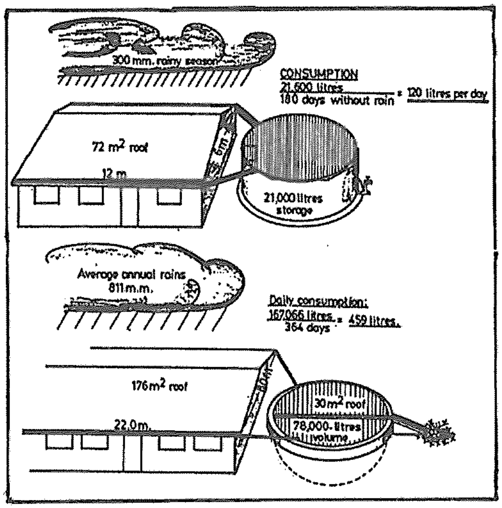

Fig. 1 Examples of roof catchment of rain-water in semi arid Africa (quoted from Dr. N. Potersen and Dr. M. Lee)

3 Some reports about maintaining and improving water quality in semi-arid Africa

We could find that there are several actions that can be taken to improve water quality. Firstly, water is washed from a relatively clean roof, gutters and tank those are washed periodically to prevent leaves, dust and dead animals and insects, and reducing the polutants washed into the water and the number of insects that breed in the tank. Nextly, when cistern stored water is used for drinking purpose, water-testing, to at least determine the presence of coliforms, disinfection methods as chlorination, ultra-violet radiation and boiling etc. are included[3)].

In addition to this bacteriological contarmination, the study about heavy metal and the comparison with the standard with WHO[4)] gathered much attention.

III Statistical analysis of rainfall and design of cistern system

Here 3 observation stations of the daily precipitation (rainfall) were selected. 2 were in remote islands in Seto Inland Sea in Ehime prefecture, and 1 was in Maizuru city in Kyoto prefecture that locates in the middle part of the seashere along the Sea of Japan, and this was added for comparioson of this analysis.

Fig. 2 is the map of Japan and the locations of the islands and Maizuru City.

Firstly, to determine the maximum utilization quantity of water by every day with rainfall, we examined the average daily rainfall or annual precipitation depth.

Secondly the continuous no rainy days were examined. Where the longer periods of no rainy days happen in so many time, the bigger storage tanks are needed.

The maximum utilization quantity of water by every day Q_{max} is gained by eq. (1) and the daily water use Q is determined with the coefficient K as $K * Q_{max}$.

Here the variation of cistern store volume in the tank with water use and daily rainwater everyday, were simulated and plotted, with the initial store volume of the cistern system. This plot curve is gained by eq. (2), (2)′

Fig. 3 is the flow chart of this calculation.

$$Q_{max} = \frac{\sum_{i=1}^{M} \sum_{j=1}^{L} C*A*R_{ij}}{L*M} \qquad (1)$$

$$\frac{dV}{dt} = C*A*R-Q \qquad (2)$$

eq. (2) is reformed into (2)′

$$V_{i,j} = V_{i,j-1} + (C*A*R_{ij} - K*Q_{max}) \qquad (2)'$$

$$V_{max} = \max(|V_{i,j}|) \qquad (3)$$

$$V_S = \{|\min(V_{i,j})|\} \qquad (4)$$

$R_{i,j}$: Rainfall at the i th year and the jth day

$V_{i,j}$: Store of water by rain fall water use in cistern system

Q_{max} : Potential maximun water utilization

Q : Quantity of water use per day, defined as $K * Q_{max}$

C : Coefficient of runoff

K : Coefficient of water use against the maximum quantity

A : Area of the watershed (here the area of roof 100m²)

V_{max} : Maximun storage volume for cistern tank

V_s : Supplementary water to maintain the stable water supply Q

L : Maximum length of days of each year

M : term of years of each data

And this method include the carry over into next year. And with the value of K, the storage volume of the tank could be examined with daily data.

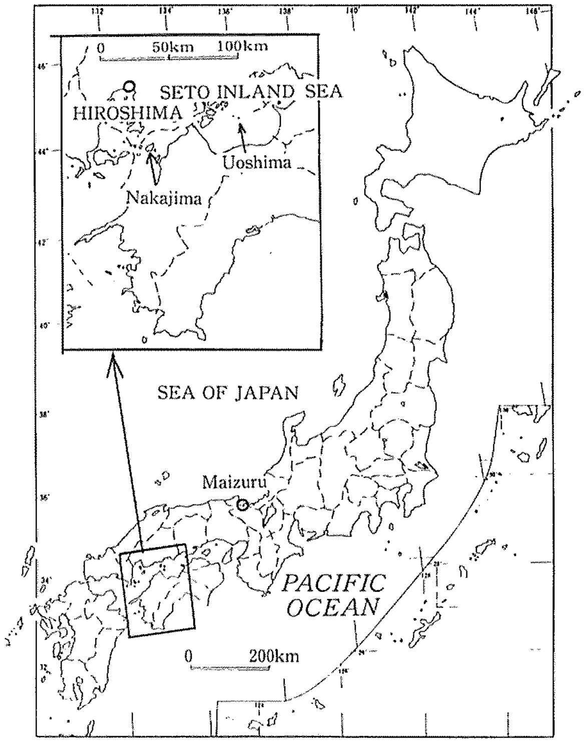

Fig. 2 Map of Japan and the locations of the remote islands and Maizuru City

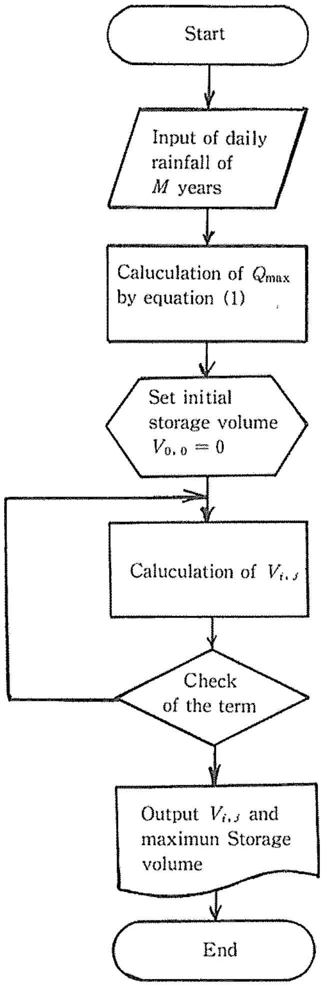

Fig. 3 Flow chart of this caluculation

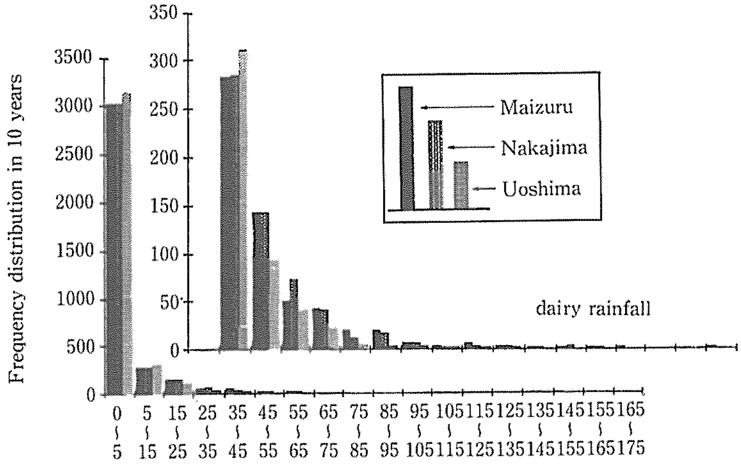

Fig. 4 Distributions of daily precipitation depth, frequency of each class was converted into that of 10 years

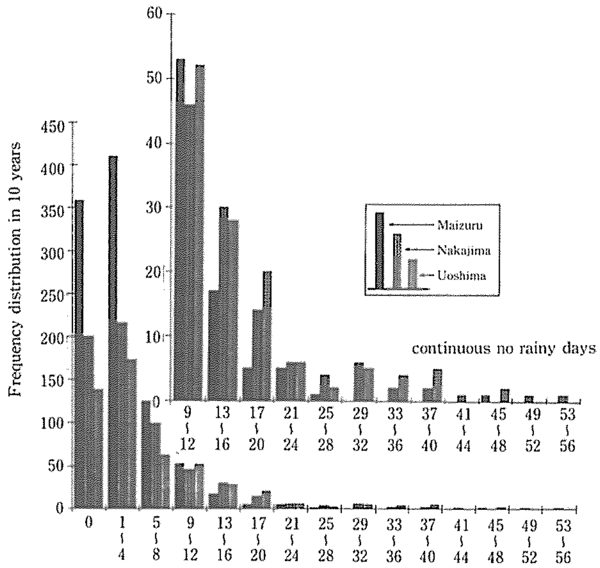

Fig. 5 Distributions of continuous no rainy days, frequency of each class wan converted into that of 10 years

Table 1 Annual precipitation depth and potential of daily water use by cistern system

	Maizuru	Nakajima	Uoshima
average annual precitation depth	1837mm	1588mm	798mm
potential maximum water utilization	502 ℓ/day	437 ℓ/day	218 ℓ/day

Table 2 Continuous no rainy days

	Maizuru	Nakajima	Uoshima
frequency more than 25 days in 10 years	1.33	15.0	18.0
average	2.7	4.6	5.7
standard deviation	3.8	6.7	7.7

III Results and Disccusions

In these 3 stations, the term of the data at Nakajima island was 14 years (1976～1989) and the average annual precipitation depth in this term was 1558 mm, and this is estimated as large as about 87 % of all Japan. Nextly, at Uoshima island, the value was very small as 798 mm and this was about 44 % that of all Japan.

And this is the reason that it is called that the water supply condition in Uoshima is very severe. The distance between the two islands is not so far, but in topograhic conditions, two islands are different as found in Fig. 2.

And at Maizuru City, the average annual precipitation depth in the 14 years (from 1975～1989) was 1837 mm,that is estimated as a little more than the average one of all of Japan that is about 1800 mm. And from these data, the potential maximum daily utilization of water by cistern system of them were gained as Table 1. Here the Q_{max} is gained with 100m² of roof area, and the runoff coefficient was regarded as 100 % . This table shows that the potential water utilization at Nakajima was not so less then that's at Maizuru. And in these two districts, water utilizations by rainfall cistern system Q_{max} might be recognized about two times as much as in Uoshima.

Nextly Fig. 4 shows the frequency distributions of daily precipitation of each class that were converted into the term of 10 years.

In this figure, some parts where the daily precipitation depths were larger than 5～15mm are enlarged. And it shows that in the larger parts than 55mm per day, data of 2 islands, especially at Uoshima, the parts that were larger than 55mm per day were far few than that at Maizuru City.

Nextly Fig. 5 shows the comparisons of the frequency of continuous no rainy days (periods) of three districts. Here, for convenience, when the daily precipitation depth was less than 4 mm, that was treated as no rainy days.

At Maizuru, it very often had the continuous rainy days (sometimes the snow fall included) and it is very rare to observe the period that no precipitation continued more than 25 days. But at Nakajima and Uoshima this data means very severe problem for water

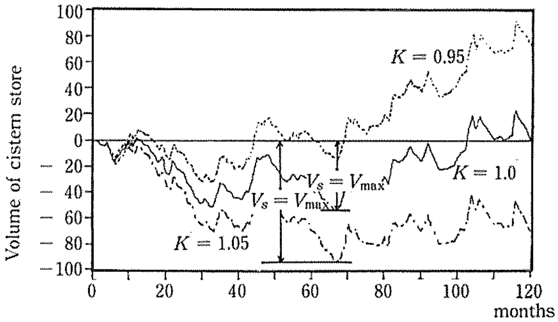

Fig. 6 Simulation of storage store with the input of daily rain and water use those were multiplied k to maximum utilization for comparisons at Maizuru

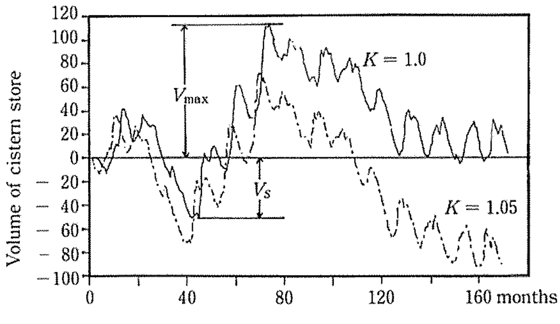

Fig. 7 Simulation of storage store with the input daily rain and water use those were multiplied k to maximum utilization for comparisons at Nakajima

Table 3 Maximum storage volume of the tank

	Maizuru			Nakajima		Uoshima
K	0.95	1.0	1.05	1.0	1.05	1.0
suplemenrary water for stable water use	33.1	23.7	92.8	75.1	85.1	33.0
maximum designed volume of the tank	92.3	53.8	92.8	113.3	85.1	41.0

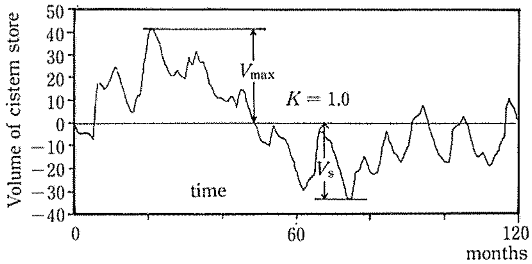

Fig. 8 Simulation of storage store with the input of daily rain and maximum water use at Uoshima island

supply. Table 2 shows this comparisons and the severe condition of rain fall for cistern system at Uoshima very clearly.

Here we examine the maximum storage volume of the tank and supplementary water to maintain the stable water supply by the simulation.

Here when K = 1.0, the storage volume ended with empty, theoretically, at the last day of the term. And with the variation of K value (0.95～1.05) , the minimum storage volume (in negative) and maximum volume was gained with the water supply.

And Fig. 6, 7, 8 were gained for these cistern systems.

Then it must be understood that with this volume of supplementary water, this cistern system could be maintained to supply the designed water in the term and made carry over to next term. And the maximum volume in absolute value throughout the term, must be unserstood that this volume of the tank as Table 3 was necessary to maintain the designed water supply through the term.

Lastly, the rain water cisterns have been in use in many regions of the world and in potentially a safe and economic supply of water. In Uoshima island too, the rain water cistern system has worked very much. But today many pollutions as acid rain have been enlarging and serious. In Uoshima the chlorination has been added to improve the water quality. So we must pay much attention to this problem for performing the effective rain water cistern systems.

IV **Conclusion**

This paper showed the potential of rainwater cistern systems by their daily precipitation data in 2 remote islands in Seto Inland Sea where water supply was so severe, and the data at Maizuru city in Kyoto prefecture was added for comparisons. The data lengh of these 3 stations were more than 10 years. The average annual precipitations depths were compared. At Nakajima island it is 1558mm and estimated as 87 %, at Uoshima island 798mm as 44 % that of all Japan. And at Maizuru, that was 1837mm, where the depth value was a little more than that. Here the potential maximum water utilization in a day of each district was examined. At Uoshima it was about 218 litres per day with the roof of 100m² in area.

Nextly, the basic analysis showed that the severe conditions for the rain water cistern system were caused by the small annual precipitation depth, the frequency distribution of daily precipitation and the frequent existance of long periods of continuous no rainy days as more than 25 days, in the distribution.

Lastly, it was found that the simulation of the cistern store with daily precipitations and water use was very significant to determine the storage volume of the tank and supplementary water in the system. And the stable maintenance of the cistern system and stable carry over into the next term could be performed.

Acknowlegement

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摘　　要

雨水（降水量）を簡単にして安全な水資源として開発することが今日世界的に注目されている．本研究はこれまでアフリカの半乾燥地や東南アジアで使用されてきた,屋根と溝と貯水タンクの方法を紹介し，併せて我が国で水利用が厳しいとされる瀬戸内海の離島のなかで，愛媛県の中島と特に厳しい条件を備えると言われる魚島について，雨水資源化の可能性を検討した．また比較のために冬期には降雪も見られる京都府の舞鶴市でのデータと比較した．これらの日降水量のデータはいずれも10年以上におよぶものである．

まず，基礎的な統計処理によって潜在的利用可能水量を評定し，かつ日降水量と連続無降雨日数の頻度分布を調べた．魚島では25日以上連続した無降雨が頻発することが，雨水資源化への大きな問題となったことが改めて確認された．さらに降水量と設計使用水量によって，貯水タンク内の貯水容量についてコンピュータシミュレーションを行った．これにより，設計利用水量とタンクの規模の設計指針，とくに安定した水利用を目的の期間に実現しようとするときの必要補給水量との関係が判明した．

Reference

1）Emelina S. Almario (ed.), WATER from the SKY, CAPIZ DEVELOPMENT FOUNDATION, INCCAPIZ, PHILIPPINES 1989.

2）E. Nissen Peterson, Michael Lee, HARVESTING RAINWATER IN SEMI-ARID AFRICA No. 21 p. 12, 1990.

3）J. Harikrishna, Improving Cistern Water Quantity, p. 46～51, Proc ofthe 5th Conf., on R. W. C. S. 1991.

4）W.Wirojnagud, Rain Water Quality : Pathogens and Heavy Metals, p. 52～68, Proc ofthe 5th Conf., on R. W. C. S. 1991.