Fuzzy sets applied to the building reuse systems design

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Abstract

When the decision about the project's characteristics depends on complex variables influenced by temporary and space approaches, the uncertainty in the definition should be quantified and translated into objective terms. The fuzzy principles (TCD) can be used in order to consider the different approaches that are part of the design system for the use of the rainwater and water reuse as, for example, the future demand definition, the building purpose, the user's profile, the local precipitation where the building will be or is located, as well as the rationalization measures of consumption, etc.. The application of TCD is a promising tool when the uncertainty, that is inherent in the phenomena to be considered in the project, is an important element for its definition. The great difference that exists between analyzing the group of available data for the dimensioning of a water reuse system or of a rainfall use system through the fuzzy sets' or through the classic groups is that in the first case, it allows to vary the pertinence degree of each element in a considered project, while in the second, the limits of the project variables should be strictly defined. In this paper, the fuzzy sets are applied to design the water reuse system and rainwater use in buildings with the purpose of characterizing appropriately the variables to be used.

Keywords

Water reuse; Rainfall use; Fuzzy sets

1 Introduction

The design of hydraulic structures of water supply building system, as the case of the reservoir project, is usually defined in function of demand, cost, benefits, structural safety of the building when it is added to a pre-existent situation, and available water. Concerning the available water, according to CHOW, MAIDMENT and MAYS (1988) the water volume in the world is estimated in 1,338x109 km3. Out of this volume, 96,5% is meet in the oceans and seas, 1.69percent is groundwater, 0.0012percent is in the form of soil humidity, 1.725percent is polar ice, 0.013percent is fresh and saline lakes, 0.0008percent is in swamps, 0.0002percent is in rivers and 0.001percent, in the atmosphere, and out of the total amount, just 2.5 percent is fresh water. In comparison to the total, the fresh water has a low potential use and is not well distributed. Out of the 577000 km^3 per year of effective precipitation, less than 20.6 percent occurs on the continents and islands.

Although irregularly distributed and with variable frequency, the potential water resource from the effective precipitation should be used in areas with minimum rainwater, as a complementary source of water for the non-potable uses, once it requires almost no treatment.

It can be obtained substantial economy in areas with reasonable rainwater distribution as the city developments intensify the pollution and the competition for potable water.

The decision about water reuse or rainwater use is part of the water resources management and besides the legal, administrative, economic and social aspects, it is considered in the planning stage, concerning the available water versus demand. For the accomplishment of an appropriate planning, the modeling and the making decision tools. They contribute to the macro system design, planning to water resource of the watershed, or of the micro system, planning of the system for building water supply, generally according to the following stages (GANOULIS, 1994): the problem identification; important factors and variables analysis, objectives determination in terms of the selected variables; development of mathematical model to relate the system inputs and outputs; of project alternatives identification; great solution selection and sensibility analysis, examining the results influence due to the values alteration in the variables and hypotheses considered.

The design procedure suggested above is interesting because it can be used either in situations in which uncertainties degree in the selected variables is low, and the system is approached by a determining system, or when uncertainty in the variables is big. The Fuzzy set theory is a great tool to consider the involved uncertainties and also the possibility of characterizing them through a flexible form and considering the judgment possibility, in studies like this: sizing a rainwater reservoirs to assist buildings.

Based on the application of the Fuzzi set theory , this paper expands the studies of SOARES, ROESNER and GONÇALVES (2000) and it tries to direct a solution to a certain region with its typical distribution of rainwater, concerning the great sizing of the reservoir to the rainwater use, of the questions: In what situation will the rainwater supply be insufficient to assist toilet flushing?; How often will the complementation of potable water be necessary? What volume of potable water will be probably used according to a rainwater reservoir volume given?; For a specific situation, is the use of rainwater viable? and decide about using or not of the rainfall water.

2 Building systems and sustainable development

The proposal of sustainable development in micro scale, either in buildings or in small communities, is impelled by the limitations of the fresh water reservation in the planet and the demand increasing for domestic, industrial or agricultural uses.

MIERZWA and HESPANHOL (1999) suggest the proposal of a program to promote the rational use of water resources, concerning the case of water management and effluents focusing the water reuse in macro scale.

For the implementation of the alternative solutions like the water reuse and rainwater use, one incentive policy from the government may be necessary. These financial incentives could be loans with subsidized rate or taxes incentives that can contribute to the increase of the necessary time for the solution of the conflict among offer and demand.

The development is related to the idea of progress, but this progress of the environmental view point has natural limits that impel the atmosphere sustainability, by new methodologies researches, planning and strategies that provide the society balanced interaction, economy and environmental, in the resources allocation along the time and space.

According to the definition of BRUNDTLAND commission in 1987, mentioned in AZAPAGIC (2000), sustainable development is the one that is appropriated to the present needs without implicating the future generations capacities of assisting their own needs. The sustainable development components are the atmosphere (matter, energy, emissions, residues), the economy (economic system) and the society (goods and services). The proper coexistence of these components might result in a sustainable environment.

PRONK and HAQ (1992), mentioned in POMPÊO (2000), affirm that the sustainable development is related to the process of policies formulation that allows a development that is sustainable concerning the economic, social and ecological viewpoint.

The social component that presses the demand is undoubtedly the populational growth and it may be a directive parameter to the urgency in the searches for conservation methodologies and rationalization of the water use. According to SAGE (1994), in 2025 we will be something around 7.6 to 9.4 billion of people in the planet. By this time around two thirds of the world population will be living in areas with shortage of water resources. Comparing the urban populational growth rate in Latin America and with the world rate, both are around 3percent and that is worrying in the cases of mega cities like São Paulo, which is the focus study.

3 Fuzzy risk

The project activities, generally involve situations, actions or variable subject to uncertainties. The fuzzy sets become more attractive then the Theory of the Probabilities to evaluation of the risks like the occurrence of unexpected values or situations, the dependency of great subjectivism, or lack of knowledge about the quantities of measurements (VIEIRA, 1999).

GALVÃO (1999) classifies the fuzzy methods as " possibilistic " due to the fact that its use implies in a class definition and uncertainty related to the meaning. Although the probabilistic methods deal with the uncertainty involved in the phenomena, they also need the deterministic definition of these values. One of the probabilistic methods used to be compared with the fuzzy methods is the Theorem of Bayes, because it makes possible the expression of the probabilities implication occurrence about the definition of the variable meaning.

According to VIEIRA (1999) , the following stages are generally necessary for understanding, quantification, evaluation and possible actions related to the risks involved in the project or in the product of this project: the risks identification or qualification; risks quantification, risks minimization, and mitigation of the risk consequences. In this case, the risk in the building system is the possibility of a potable water rationing. The risk can be quantified with deterministic base, using mathematical programming, or fuzzy methods, as in these study, due to problems of high uncertainty in the variables considered and insufficient input data series. The great reservoir sizing to assist objective and subjective criteria of the problem is related too the risk mentioned. Also, the consequence of the problem mitigation is water saving obtained with application of the rain water use system to a certain region subject to a peculiar precipitation.

4 Fuzzy set application

According to ZADEH (1965), ZIMMERMAN (1987) and GANOULIS (1994) the fuzzy set theory is a mathematical method used to characterize and quantify the uncertainty and imprecision in the data and functional relations. The fuzzy sets are especially useful when the number of data is not sufficient to characterize uncertainty by means of standard statistical measures involving the estimation of frequencies (e.g. mean, standard deviation and distribution type).

The fuzzy sets, also known as misty, are a generalization of the Classic Set Theory concept and they are denominated this way for representing situations in which the pertinence set functions cannot just be defined only as pertaining or not to a determined set, there is they reflect the situation in which the set limits are not clearly defined. Thus, with the fuzzy logic the transition between the situation of pertaining or not to a certain set becomes gradual instead of abrupt and so, it's possible to reduce the problem complexity.

Formally a fuzzy set is defined as (GALVÃO, 1999):

$$\tilde{A} = \{(x, \mu_A(x)) / x \in X\}$$

where X is the universe in which the x elements are defined, and $\mu_A(x)$ is the pertinence function of x in $\tilde{A}$. It should be noted that the fuzzy systems deal with the class definition concept of uncertainty related to the meaning.

The fuzzyfication is necessary if the system variables are not described in the fuzzy way, concerning the problem studied (GALVÃO, 1999), that is, the transformation of the deterministic value of the variable into fuzzy value. Maybe it will be necessary to transform this fuzzy value in a deterministc value after the quantification of the phenomena for taking a practical decision. OLIVEIRA (1999) give us some defuzzification methods.

Another important component in the FST application process is the linguistic variables definition, that are the base of the fuzzy propositions construction. According to OLIVEIRA (1999), the linguistic variables should have three main characteristics: they should have variable content; they should assume linguistic values as high, medium and low, for instance and; they should have nominal identification.

Relating to the precipitation data, the following methodology was used:

a) the total data set was organized;
b) the non read data were taken out;
c) the data were classified according to a pre-defined percentage;
d) the average intensity of each considered class was calculated;
e) to a pre-defined harvesting area, it was calculated the necessary reservoir volume, the potable water volume saved in the considered period, with the same maximum

precipitation as the average precipitation class considered and the necessary potable water volume to supply toilet flushing, if it is necessary;

f) the pertinence functions for the benefits and costs of the system were calculated;

g) the operations were made with the fuzzy numbers to obtain the best relationship between benefit and cost, from what pertinence degree the (B/C) ≥ 1;

h) the fuzzy risk was evaluated.

To determine each class values, item (d) above, the days when the precipitation was zero or when the precipitation was not evaluated were not considered.

Also, the dry days were not considered because the intention is to know what is the probability of a date to happen, among the rain occurred.

The chosen precipitation value, that was made according to the occurrence probability, substitutes the evaluated precipitation value, every time that this is larger than the first, that is, no precipitation should be larger than the chosen. This value is the average of the class.

Considering this way, all the precipitation considered, will have a probability of happening the same as chosen and so, if the dimensioning of reservoir is done to the driest month of the year. The calculated volume of the potable water will always be superior to the one consumption in the other months. It can be verified if sizing of each month is done.

While classifying the data, all the data registered in the historic series of 12 years were used. It was done like this because the same reservoir will assist the toilet flushing during all the year months, once the occurred precipitation is larger than the one used in the calculus.

Table 1 – Occurrence precipitation data.

Frequency (%)	90	80	70	60	50	40	30	20	10	< 10
Number of data per class	114	229	343	457	571	686	800	914	1029	1143
Interval of data	1-114	115-229	230-343	344-457	458-571	572-686	687-800	801-914	915-1029	1030-1143
Interval of precipitation (mm)	0.1-0.6	0.6-1.6	1.6-3	3-4.6	4.7-7.3	7.4-10.1	10.3-14.8	14.8-21.6	22-34.4	34.5-200
Average preci-pitation of the class * (mm)	0.33	1.08	2.27	3.81	5.81	8.79	12.46	17.99	27.37	53.36
Simple Average of the class** (mm)	0.35	1.10	2.30	3.80	6.00	8.75	12.55	18.20	28.20	117.25

* Average precipitation of the class: is the average among every values of the chosen interval. This is the chosen value for the calculus.

** Simple average: is the simple average between the first and the last interval chosen value.

Considering that the reservoir will be built and not considering the cost of its building, it can be assumed that:

a) The project benefits correspond to the water volume saved, due to the rainwater use, that is, the rains with frequency lower than 40% will contribute even more to the potable water savings.

b) The project cost will be given by the water volume necessary to the supply.

Table 2 – Determination of the reservoir volume, of the potable water volume used and the volume of potable water saved, in litters per toilet assisted, and in percent, when the harvesting areas is 60 m^2 per toilet assisted.

Frequency (%)		90	80	70	60	50	40	30	20	10	< 10
Reservoir volume		84	84	84	85	148	189	224	254	325	386
Potable water needed (litters) *		2407	2220	1958	1674	1376	1073	816	610	344	156
Potable water saved**	(litters)	113	300	562	846	1144	1447	1704	1910	2176	2364
	(%)	4.5	11.9	22.3	33.6	45.4	57.4	67.6	75.8	86.3	93.8
Total water required per toilet (litters)		2520	2520	2520	2520	2520	2520	2520	2520	2520	2520
B/C Relationship		0.05	0.14	0.29	0.51	0.83	1.35	2.09	3.13	6.33	15.15

* Cost = volume of potable water needed (litters).

** Benefits =volume of potable water saved (litters).

According to the Table 2, it is observed that the B/C relationship increases the more it's decreased the rain frequency[1]. Considering a rain that occurs 90% of the times, that is, the maximum rain considered is the average of the class occurred 90% of the times, it would have a small value. In this case, it can be observed that the B/C relationship is equal to 0,047, and shows that if rains are always lower than 0,33 mm, it is not viable the rainwater use.

To the frequency of 40%, the maximum precipitation is 8,79 mm, that is, rains with frequency lower than 40% and consequently precipitation larger than 8,79 mm, will be contributing in the reduction of the necessary potable volume, with a relationship B/C equal 1,35.

Using the linear interpolation, the B/C relationship will be 1 when the reservoir volume is 175 litters per toilet assisted. So, any volume higher than 175 litters will lead us to a lower water consumption and a larger B/C relationship.

Considering the use of fuzzy set concepts in the characterization of the benefits and cost and considering the variation of ± 10%, it is obtained:

$\widetilde{B} = (1302{,}3; 1447; 1591{,}7)$, and,

$\widetilde{C} = (965{,}7; 1073; 1180{,}3)$, so, the relationship benefits/costs relationship in the fuzzy form will be:

$$\widetilde{B} : \widetilde{C} = (1302{,}3; 1447; 1591{,}7)(:)\,(965{,}7; 1073; 1180{,}3)$$

The relationship above can be graphically expressed like in figure 1, 2 and 3.

$$\widetilde{B} : \widetilde{C} = (1302{,}3/1180.3; 1447/1073; 1591{,}7/965.7)$$

$$\widetilde{B} : \widetilde{C} = (1.10; 1.35; 1.65)$$

In a numerical way, we have:

Benefits (figure 1)

[1] The rain frequency used is due to the ocurrency probability of a rain larger or equal to de value of calculated value, that is, the average volume of each frequency class.

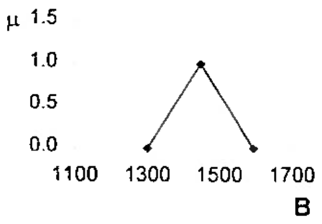

Fig. 1 – Benefits $\widetilde{B}$

Fig. 2 – Cost $\widetilde{C}$

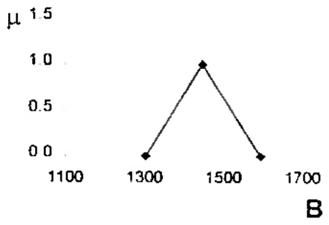

Fig. 3 - Relationship between Benefits/Cost $\widetilde{B}(:)\widetilde{C}$

Benefits:

$\mu_B(x) = 0$	for $x \leq 1302.7$
$\mu_B(x) = (x-1302.3)(1447-1302.3) = (x-1302.6)/144.7$	$1302{,}3 \leq x \leq 1447$
$\mu_B(x) = (1591.7-x)(1591-1447) = (1591.7-x)/144.7$	$1302{,}3 \leq x \leq 1447$
$\mu_B(x) = 0$	for $x \geq 1591.7$

Cost:

$\mu_C(x) = 0$	for $x \leq 965.7$
$\mu_C(x) = (x-965.7)(1073-965.7) = (x-965.7)/107.3$	$1302{,}3 \leq x \leq 1447$
$\mu_C(x) = (1180.3-x)(1180.3-1073) = (1591.7-x)/107.344.7$	$1302{,}3 \leq x \leq 1447$
$\mu_C(x) = 0$	for $x \geq 1180.3$

Pertinence interval:

Interval B_α (from figure 1)

$\alpha = (b_1 - 1302.3)/144.7$ $\qquad b_1 = 144.7\alpha + 1302.3$

$\alpha = (1591.7 - b_2)/144.7$ $\qquad b_2 = 1591.7-144.7\alpha$

where α is the pertinence degree of the b_i

$B\alpha = [(144.7x + 1302.3)/(1591.7-144.7\alpha)$

Interval C_α (from figure 2)

$\alpha = (c_1-965.7)/107.3$ $\qquad c_1 = 107.3\alpha + 965.7$

$\alpha = (1180.3-c_2)/107.3$ $\qquad c_2 = 1180.3-107.3\alpha$

Relationship between Benefits/Cost for several levels of pertinence α

$B\alpha\ (:)\ C\alpha = (b1/c2;b2/c1)$

$B\alpha\ (:)\ C\alpha = [(144.7\alpha + 1302.3)/(1180.3-107.3\alpha);(1591.7-144.7\alpha)/(107.3\alpha + 965.7)]$

For example: if x=0.5, we have:

$B\alpha\ (:)\ C\alpha = (1.22;1.49)$

5 Conclusion

The reservoirs sizing to the rainwater use through the FST is a promising tool, once this sizing depends on the variables with uncertainty degrees and these degrees can be considered more properly. Thus, it's easier to make decisions about what value class and pertinence degree to choose to a certain project.

Besides the consideration of the variables uncertainties considered, it can be pointed out the programming easiness of the operation rules with fuzzy numbers making it a simple analysis.

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