Fuzzy Logic Application in Water Supply System Management: A case study

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Abstract **- Infrastructure development with focus on water supply system management has assumed significant importance in the recent past in India, and in this endeavour attempts are being made to provide 24 hours continuous safe water supply to the consumers. The important three elements of any water supply system augmentation include: population projection, per capita water needs for full satisfaction and the financial out lay. We address, in this paper, application of fuzzy logic based to project the future water needs.**

Ever increasing pollution levels due to rapid urbanization and industrialization, especially in developing countries with minimal focus on adequate pollution abatement strategies, result in impairing natural environment such as river, air, land, and alike. Protection of drinking water resources for public water supplies, therefore, assumed vital significance in the context of present times. The practice in vogue of classifying water quality for variety of usage is by computing water quality indices [2]. Why compute a numeric water quality index, and then describe water quality? Why not apply describe water quality, for the defined usage, straightway in linguistic terms with some degree of certainty attached to each linguistic description?

In this paper, we present two need based research studies: First case study relates to the estimation of per capita water needs for full satisfaction of the consumers in (Pimpri Chinchwad Municipal Corporation (PCMC – city with a population of 1.8 million) area, India, while the second study refers to fuzzy description of raw water quality near the intake of PCMC war treatment facility.

I. INTRODUCTION

Infrastructure development with focus on water supply system management has assumed significant importance in the recent past in India, and in this endeavor attempts are being made to provide 24 hours continuous safe water supply to the consumers. The important three elements of any water supply system augmentation include: population projection, per capita water needs for full satisfaction and the financial out lay. Per capita daily water consumption expressed in liters/day is an important parameter in the design and augmentation of water supply systems and is dependent on several factors such as climate, propagation of sewerage facilities, economic standard of consumer etc, National Guidelines on per capita water supply in practice are based on city /town population *but do not include consumer's perception about their water needs.*

Information on the status of environmental quality is necessary to formulate sound public policies and effective implementation of environmental quality programs. One of the effective ways of communicating such information in general, and river water quality in particular to policy makers and the end users, is with indices.The efforts on the development of water quality indices started in 1990's in USA and are generally considered a subset of indices used to measure environmental quality on an ordinal scale. Water quality index (WQI) is therefore in essence, a function used to simplify large quantities of data into a more useful form in order to convey an image of overall quantity to a variety of different users the most critical deficiency of the selected indices is the lack of dealing with uncertainty and subjectivity present in this complex environmental problem. In spite of the best efforts, there has been no general acceptance of WQI for the intended usage. There exists imprecision or *fuzziness* in the perception of individuals about their water needs and also in perception of domain experts about rating water quality parameters in various linguistic terms , termed as *epistemic*

uncertainty -an unavoidable feature of most humanistic systems. In water meter data and the parametric data used in describing water quality there is statistical or *aleotary uncertainty*. Fuzzy logic concepts could be considered as a useful formalism for modeling aleotary *and epistemic uncertainty*.

II. CASE STUDY

Application of fuzzy logic based the methods developed in references [4] [5] is the objective of the paper. Theory put into practice has been a long standing need while dealing with engineering system in general and water supply systems in particular. The case study detailed herein relates to the two important issues of vital significance in the water supply system management The first study refers to per capita water consumption needs based on consumer' perception while the second describes Pawana river water quality at the intake well in water treatment facility in PCMC, The outcome of the studies is proposed to be implemented by the municipal authorities in the near future. The results and discussion are presented in each of the research studies.

A. Per Capita Water Consumption Needs Based on Consumer's Perception

Planning of a research study on perception based modelling based water needs was carried out in two income groups in PCMC area in India.

Consumer's perception survey with a structured questionnaire and the data on per connection water meter readings were collected in Low Income (LIG) and the Middle Income Group (MIG) spread in PCMC city limits. There has been no appreciable difference observed in MIG and HIG, and therefore, HIG was ignored from the small sample study. The basis of referring LIG and MIG, in this study, is as follows:

Low Income group – These houses generally fall in the unorganized housing category: Water users with only one room kitchen house or group housing where each family has a room/ where 30 – 50 people or 10 or more houses depend on one water connection, consumers in living in slum areas/ undeveloped areas or in congested areas/ living in houses whose area is less than or equal to 25 sq.m, and Old core area of the city.

Middle Income group – These houses generally fall in the organized housing category: Consumers with a house with only 1 BHK or 2 BHK/ or living in houses whose area is between 25 to 140 sq .m, and consumers owning a Four wheeler.

B. Agreement Index

A frequency plot of the data on water supply on per connection per day basis has invariably shown a positive skewed pattern and, assuming it follows one of the exponential family of distribution and looks somewhat like a log normal distribution. While using fuzzy logic fuzzy logic, it is not mandatory to fit a particular type of statistical distribution as fuzzy logic concepts deals with possibility and not with probability. Based on approximate reasoning principle, a convex normalized fuzzy number (CNFN) for the water meter data was constructed. In order to decide on the lower and upper bound for the construction of (CNFN), 25th and 75th percentile values of water meter data were considered.

Uncertainty due to fuzziness in human thinking on water needs for their full satisfaction. (Satisfaction expressed in linguistic terms- *linguistic variable*) was considered as a triangular convex fuzzy set which can be referred as the possibility distribution for the water needs for full satisfaction of the consumers in the study area. The agreement between the water supplied and the perception of the consumers about their water need for full satisfaction was computed using the following formulation [4]:

$$AgI\ H(A) = \{\int \mu_A \cap \mu_H(x)\,dx\} / \{\int \mu_A(x)\,dx\},\ x \in X$$

The index value signifies the overall extent to which the consumers are satisfied in relation to the prevailing supply conditions. Accordingly, the Center of Area (COA) of fuzzy number A gives the measure of per capita per day consumption according to expression [Figure 1].

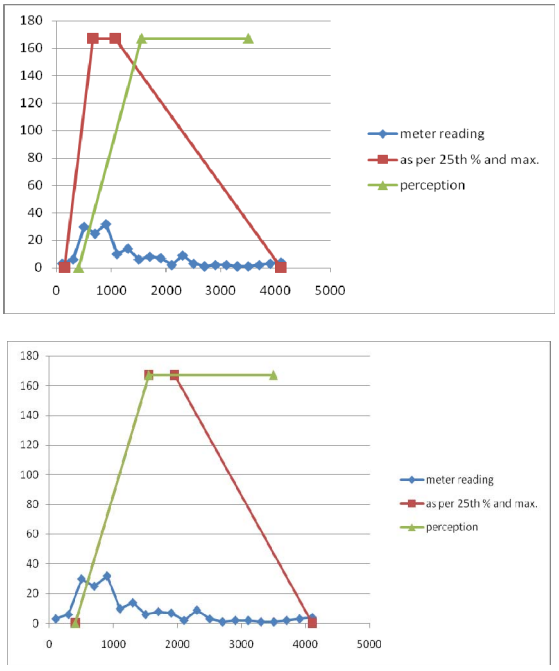

Fig. 1 Agreement Index for water supplied and for full satisfaction of the consumers in MIG area, PCMC

C. Results and Discussion

It could be inferred from the limited research study that PCMC supplied water to the consumers @140 liters per capita day (lpcd) in low income group, while for middle income group consumers; it is @200 liter per capita per day. The consumers from LIG and MIG expressed their satisfaction on their water needs. Based on the perception of the consumers, it could be argued that the consumers would be fully satisfied if PCMC will supply 180 lpcd and 280 lpcd water, LIG and MIG residents, respectively. This calls for switching over to 24 hours water supply on a continuous basis (so called 24 x7 water supplies). The computed lpcd figures for full satisfaction could be considered as guide line for the overall future (till 2041) water needs of the PCMC area.

Water resource planning described in the paper will hopefully, reduce water shortage at the end of the planning period (in present case- 2041). Planning, initially, water @ 160 lpcd and then get into trouble at a later stage and look for new resources is a common scene in the developing countries. At least five decades of experience shows that population projection seldom matches with any of the population projection methods due to several reasons, therefore adequate water resource planning based on the scientific investigations is necessary.

Low pressure in consumer taps was the general complaint of many consumers in the study area. This is because of the because of the fact that during intermittent supply hours the peak factor goes as high as 6-8, thereby excessive frictional loss in old metallic pipes resulting in low pressures in consumer's taps. Willingness To Pay (WTP) for municipal water supply is an open ended research.

The consumers in PCMC area are not willing to pay more for water. The consumers consider the issue of municipal services in totality, i.e., charging for treated water

supply, sewerage system and upcoming sewage treatment facilities and the solid waste management. Water politics plays an important factor as the consumers are sometimes, discouraged not to pay more for the water supply. The situation may change once 24 hours water supply is implemented in PCMC. Per capita water consumption will definitely reduce if the consumers are provided with 24 hours of water supply on a continuous basis.

Designing water rate structure, need for educating the consumers on safe water supply systems, efficacy of effective water metering are the issues of immediate relevance. Universal water metering without testing and repair facility will be a drain on public funds.

D. Fuzzy Description of Pawana River Water Quality

The developing countries have been witnessing pollution of water resources which has assumed a serious threat to mankind due to increase in the incidence of water related diseases.

The World Health Organization (WHO) in their report (2002) states that around 21% of communicable diseases in India are water related, and out of these, diarrhoeal diseases alone killed over 700,000 Indians in the year 1999 [1]. The study reported herein is, therefore, important as it refers to the water quality near intake well of water treatment plant of PCMC India. This is the only important source of water supply for PCMC area. Figure 2 depicts a pictorial view of the location of the intake well and the details of *Pawana River* from where water is abstracted and treated in water treatment facility.

Fig. 2 Intake well and Water Treatment Plant at Rawet, PCMC India

Fuzzy expert system formalism using the concept of Degree of match [3] was used for describing the water quality at the intake well in linguistic terms. Figure 3 and Figure 4 presents typical fuzzy rules and the hierarchical structure of fuzzy rule based system. Fuzzy expert system formalism using the concept of Degree of match was used for describing the water quality at the intake well in linguistic terms. Figure 3 and Figure 4 presents typical fuzzy rules and the hierarchical structure of fuzzy rule based system [5].

- **IF** BOD is *Good* (*DM*) **AND** DO is *Very Good* (*DM*) **AND** pH is *Very Good* (*DM*) **THEN** Biochemical status of water is *Good* (*DM*)

- **IF** Bacteriological status of water is < *Fair* > (*DM*) **AND** Biochemical status of water < *Very Good* > (*DM*) **AND** physical status of water < *Very Good* > (*DM*) **THEN** over all water quality at water Intake well is <*Fair*> (DM).

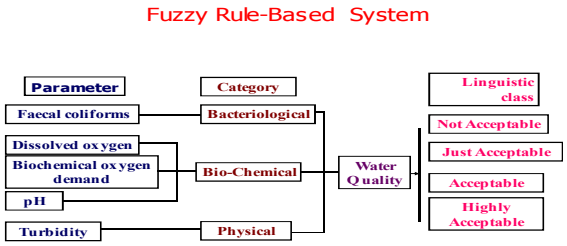

Fig. 3 A Hierarchical Structure for Water Quality Classification

TABLE I

FUZZY DESCRIPTION OF WATER QUALITY WITH DEGREE OF CONFIDENCE

Linguistic Description	Degree of certainty (DC)
Very Good	0
Good	0.2
Fair	**0.75**
Poor	0.1

Water Quality at PCMC is Fair with degree of certainty 0.75, Good with DC = 0.2 and Poor with DC = 0.1

It could be inferred from fuzzy modelling that the water quality at Intake well of WTP is *fair* with degree of certainty 0. 75 and is tending towards *good* with degree of certainty 0.2. It is necessary to improve Pawana river water quality as *Very good with high degree of certainty*. The strength of fuzzy logic concepts lies in defining, in this case, river water quality at intake, straightway in linguistic terms with some degree of certainty attached to each linguistic terms.

There is visible organic pollution due to domestic waste water from the nearby villages. A few industrial discharges are also located in about 2 kms of the intake well. Therefore, there will be increase in Bio chemical oxygen demand resulting in high bacteriological load in Pawana river water.

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III. CONCLUDING REMARKS

The two valued logic and probability theory is the basis of prospect theory. It is a deep-seated tradition in science to employ the conceptual structure of bivalent logic and probability theory as a basis for formulation of definitions and concepts [6]. What is widely unrecognized is that, in reality, most concepts are fuzzy rather than bivalent, and, in general, it is not possible to formulate a co-intensive definition of a fuzzy concept within the conceptual structure of bivalent logic and probability theory.

Fuzzy logic via computing with words is a human centric logic which has been successfully used where the perceptions of the human or domain experts are of primary concern. This is more relevant in decision making wherein the decision makers have no or less numerical information on the governing parameters. It is well known that the expert knowledge base uses only linguistic terms. Why not compute with words and why always numbers?

In addition, there is need to address the issue of integrating the field data and the perception of the end users. The analytical methods in vogue do not consider the opinion of the consumers at every stage of planning and implementation process, and are based on two valued logic.

The research study has conclusively demonstrated the utility soft computing techniques with focus on fuzzy logic in water supply system management. It could be an eye opener for those who are engaged in infrastructure development in general, and water supply systems in particular.

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