An expert system for the identification of influent factors in the urban water consumption

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Abstract
Identifying the factors that affect urban water consumption is very important to the management of available regional water resources. The conventional approach used to identify these factors needs large amount of data, besides being difficult to obtain. The objective of this paper is to identify the factors that affect the water consumption using an alternative methodology, the expert system approach. This methodology comprises: (1) literature review and analysis; (2) proposal of typical rules expressed in an 'if (condition) – then (action)' format, based on the literature, interviews with experts, and observation; (3) development of prototype expert system (codification of the knowledge explicit in these rules); and, (4) evaluation of the developed prototype expert system. It was possible to conclude that the expert system approach has showed adequate for the identification of influent factors in the urban water consumption.

Keywords: influents factors; knowledge system; artificial intelligence

Introduction

The concerns raised with the reality of water resources have led the world to a series of government social measures in order to enable the continuity of the various public and private activities that focus on fresh waters, particularly those that directly affect the quality of life (Machado, 2001). A diagnosis of various forms of use of water resources has led, especially over the past four decades, to a process of reviewing the duties of the State, of the water users, and also of the water use (Machado, 2003). Questioning the current behavioral model of the actors involved in the phenomenon of water consumption brings the following issue: how to implement technical and economic feasibility of water resources management? Taylor *et al*. (2005) proposes a cycle planning, grounded in a logical sequence of steps driven by the ongoing events in support of management, composed by such phases: (1) government commitment, (2) preparation of work plan and participation of stakeholders; (3) construction of strategic vision, (4) analysis of the current situation, (5) definition of management strategies, (6) development and approved the plan, (7), and implementation and evaluation. A more comprehensive view for water resource management, conservation actions and rational use of water is a vital element required to conceive an integrated system of watershed management and urban planning (Silva and Porto, 2003). This type of conception is largely based on demand management actions, which are not always well understood in its scope and breadth (Silva and Porto, 2003). The behavioral knowledge of the demand for water in watersheds is an essential requisite to increase the water supply by the urban water supply system.

The focus conventionally used to identification of influential factors in systems refers to multivariate statistical techniques and structural analysis. This study has the objective of identification of factors influencing the consumption of water in urban environments from the knowledge of experts. The present study is structured into five sections. Section 1 refers to the introduction to the work. Section 2 presents a brief review on related themes. Section 3 presents the methodology. Section 4 presents the results and Section 5 presents the conclusions of the study.

Review of related research

Lertpalangsunti *et al.* (1999), having the objective to assist the management decisions in the waterworks (i.e. a combined water purification plant and pumping station) of Regina City, Canada, developed an hybrid system that combines the techniques of fuzzy logic, based on cases, and knowledge-based system. The study was conducted in the following steps: acquisition of the commercial expert system shell G2; collection of data together the water supply system operator; collection of data together the Canadian environmental agency; development of the system combining different techniques; and results verification. The data sources were reports available from the operating system of water supply and the institution of weather monitoring in Canada. The historic data relates to the period from 1992 to 1994. The data used included the period of operation of pumps, flow hourly supply, reservoir levels, temperature and relative humidity of air. Conclusions of the study were that the developed model showed good results, the temperature was the most

important factor in forecasting demand and hybrid systems are presented as a viable alternative to the study of problems of great complexity.

León *et al*. (2000) developed a hybrid system called EXPLORE, which combines optimization techniques with Expert System. The system development was motivated by the need to reduce costs with electric power, optimizing operational and management actions in demand of water in the water supply system the city of Seville, Spain. The main objective of the EXPLORE was to ensure the water supply. To achieve this purpose, the EXPLORE should decide the daily flow to be treated by the water treatment plant, using the demand forecast and reservoir levels as security margins. The second objective of EXPLORE was to reduce the cost of electric power supply in water treatment plants. This objective must be achieved satisfying the demand. The bombs constitute the components of biggest electric cost and the system cannot reduce the total amount of the consumed energy because it depends only on water demand, a factor that can not be controlled externally. However, as the energy rate is different during the daytime hours, it is possible to reduce energy costs by pumping during times of lower tariff. A main objective of the system was to maintain the water quality. To achieve these goals, the EXPLORE should accomplish two tasks: (1) integration of control and information - all the information about the conditions of the water distribution network should be directed to the operation control center of the water supply system, and the operators should decide what actions should be performed; and (2) use of history data of water demand - the operators could not easily use the history of water demand, an automation of historic data should allow the realization of demand forecasting, information essential to reducing costs with electric power. EXPLORE was developed considering three main processes: (1) configuration of process; (2) process operation; and (3) process simulation. The results indicated a 25% reduction of energy costs and the additional benefits of the system refer to the possibility of qualifying for less experienced operators, obtaining a guide to the operation of the water supply system, and ability to simulate different management strategies. It is also mentioned that the hybrid system is highly flexible, can be applied to other water supply systems, although the forecasting model showed significant errors and needs more study.

Froukh (2001), in order to contribute to policy formulation of water resources in the city of Swindon, UK, carried out studies with the purpose to integrate mathematical and heuristic approaches for forecasting and demand management of domestic water. For this, the author developed a hybrid system that integrated technical expert system for geographical information system, multi-criteria methods of decision support, knowledge based system and mathematical modeling. The hybrid system developed was able to forecast demand of domestic water, to calculate the effective conservation of water (from the implementation of different management actions), to forecast consumption per unit of water in different units (person, household and water connection), and to develop different scenarios through changes in water policy. The possible input data in the hybrid system include the historic water demand of the urban area, the number of residents per household, residential consumption of water, the water tariff, rainfall, temperature, volumes consumed by the machine washing dishes, the shower, the tub, the toilet, kitchen sink, among others. Also, information such as educational level, socioeconomic and demographic factors can fuel the hybrid system. In the purpose to give security to the responses produced by the hybrid system, the system was tested on two main criteria. The first relates to the tests with the models being used for this comparison of results obtained by the hybrid system with the results obtained, when performing the same analysis using Excel. The second involves checking the answers provided by the hybrid system. This was done to compare the responses obtained by the hybrid system and the responses obtained by experts. An application of the developed hybrid system was held in the city of Swindon, using data from the waterworks operator. As conclusion, the author mentions that the hybrid system has been tested and showed good results in city of Swindon.

Corral-Verdugo (2003) proposed a model of psychological and situational factors affecting water consumption. The model was specified and tested with 500 individuals living at two cities of Sonora, in Mexico, used as subjects for this study. One of those cities experienced a chronic scarcity of water, while the other one had a sufficient supply of the liquid. Direct observations of individuals' water consumption (in different activities) and of their conservation skills were conducted. Also, their utilitarian beliefs regarding the use of water, and their conservation motives were assessed using a questionnaire. The possession of furniture for using water was considered as one situational factor promoting water consumption, and water scarcity was considered as a potential inhibitor of that consumption. These variables were incorporated in a structural model. Results of this model revealed that water consumption was significantly and positively influenced by utilitarian beliefs and the possession of furniture, while conservation motives, conservation skills and water scarcity inhibited such consumption. Conservation motives were positively affected by water scarcity and conservation skills, and negatively influenced by utilitarian beliefs. Significant co-variances between the determinants of water consumption revealed the interdependence of situational and psychological variables affecting water use.

Tillman *et al*. (2005) developed studies with the objective of to point out existing risks of current design and management strategies in waterworks and to identify possible ways of designing and operating schemes which minimize these risks. The paper is motivated by the observation that existing design principles and engineering rules (best management practice - BMP) seem to cope insufficiently or even conflict with current trends of declining water demand. A model based on agents (Agent-Based Model) was developed. The methodology developed comprises the following steps: (1) proposal of typical rules for influential agents (stakeholders) in the system of water supply through rules 'if (condition) – then (action)' format, obtained by consulting the literature, interviews and observations; (2) discussion, analysis, change and adequacy of the rules from participatory process involving directly stakeholders; (3) development and validation of the computational model; and (4) tests with multiple scenarios exploring different strategies for management and engineering. As conclusions, the authors mention that the agent-based model showed a promising tool in planning waterworks (emphasizing more the actions of stakeholders and less technical characteristics of the systems), the path to achieve the BMP undergo management tools with incentives tariffs and information campaigns to manage short-term extreme events.

Methodology

The methodology of this work comprised: (1) revision and analysis of the literature; (2) proposal of typical rules expressed in an 'if (condition) – then (action)' format, based on the literature, interviews and observation; (3) development of prototype expert system (codification of the knowledge explicit in these rules); and (4) evaluation of the prototype expert system development.

For the literature review (1) publications related to the planning system of urban water supply were consulted and analyzed. To obtain the domain of knowledge (2) literature and experts (specialists in water resources planning) were consulted. For the development of the prototype expert system (3) the Shell CLIPS (C Language Integrated Production System), version 6.3 was employed. The representation of knowledge was given by production rules of the type "if (condition) - then (action)". To perform the inference, it was used the technique of chaining (forward chain). The evaluation of the prototype expert system development (4), a method employed by Collier *et al*. (1999) was applied.

Results

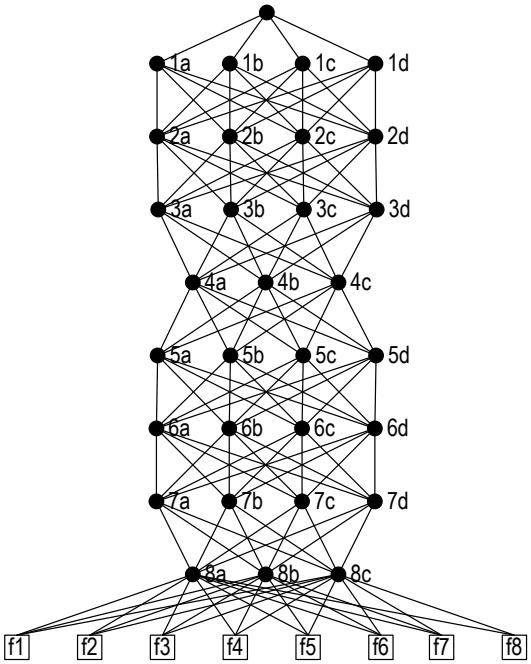
The literature review indicated that a large number of factors may influence the urban consumption of water, as shown in Table 1.

Table 1. Influential factor in water consumption.

Item	Factor	Item	Factor
1	Population Growth Rate [n=8]	20	Constructed area [n=1]
2	Population density [n=4]	21	Number of rooms [n=1]
3	Socioeconomic status [n=8]	22	Abundance or scarcity of water sources [n=6]
4	Educational level [n=2]	23	Losses in supply network [n=2]
5	Level of industrialization [n=5]	24	Identification of family sócia [n=4]
6	Air temperature [n=9]	25	Existence and type of municipal water resources policy [n=2]
7	Relative humidity [n=7]	26	Acceptance of the population to assist conservation and rational use of water [n=1]
8	rainfall amounts [n=11]	27	Predominant housing typology [n=1]
9	Seasonality [n=11]	28	Types of consumers [n=1]
10	Size and the topographical features of the city [n=3]	29	Type of the city [n=2]
11	Percentage of hydrometering [n=4]	30	Predominant function of urban environment [n=1]
12	Water rates charged [n=12]	31	Existence of policies to encourage water conservation [n=2]
13	Type of tariff policy [n=11]	32	Intermittent supply of water [n=1]
14	Existence of the sewage disposal system [n=1]	33	Energy consumption [n=2]
15	Municipal human development index [n=2]	34	Existence of regulatory policy consumer [n=2]
16	Average pressure in the distribution network [n=3]	35	Existence of educational campaign [n=3]
17	Existence of conservation habits [n=3]	36	Belief: water is a resource cheap and nexhaustible [n=1]
18	Number of equipment per household hydrosanitary [n=7]	37	Number of rooms [n=1]
19	Type of equipment per household hydrosanitary [n=7]	38	Abundance or scarcity of water sources [n=6]

Note: "n" is the number of studies that considered influential factor
Source: Silva e Souza (2010)

From these influential factors in urban consumption of water, the most important were selected to be considered in the prototype of expert system. Those factors already considered in at least five studies, as shown in Table 1, were adopted as most important factors. Then, considering these factors of greatest importance, a cognitive model of the problem was proposed, as shown in Figure 1.



Note: f1 is the population growth rate; f2 is the socioeconomic level; f3 is the level of industrialization; f4 is the characteristic climate; f5 is the water rates charged; f6 is the type of tariff policy; f7 is the number and type of equipment per household hydrosanitary; f8 is the abundance or scarcity of water sources.

Figure 1. Schematic representation of the cognitive model

The description of the elements of the cognitive model is presented in Table 2.

Table 2. Description of the elements of the cognitive model.

Input layer	Possible alternatives	Source
C1. Rate of population growth:	1a. Negative (up 0.00%). 1b. Low (0.00% to 1.73%). 1c. Average (1.73% to 4.27%). 1d. High (over 4.27%).	Adapted from IBGE (2000)
C2. Socioeconomic level of the population:	2a. Class A. 2b. Class B 2c. Class C. 2d. Class D.	Adapted from ABPE (2011)
C3. Level of industrialization of the city (percentage of GDP due to the industry):	3a. Very low (0.0% to 10%). 3b. Low (10% to 20%). 3c. Moderate (20% to 30%). 3d. High (over 30%).	Adapted from IBGE (2000)
C4. Climatic conditions of the city:	4a. There is a strong presence of seasonality. 4b. There is a moderate presence of seasonality. 4c. There is a scant presence of seasonality.	Adapted from INMET (2010)
C5. Water tariff charged in the city:	5a. Allows financial sustainability. 5b. Financial sustainability partial (up to 67% of costs). 5c. Financial sustainability partial (10% to 33% of costs). 5d. o not allow financial sustainability (up to 10% of costs).	Adapted from Savenije e Van der Zaag (2002)
C6. Type of tariff policy applied:	6a. Growing by blocks of consumption. 6b. Descending by block. 6c. Uniformly by volume consumed. 6d. Fixed tariff.	Pedrosa (1999)

Table 2. Description of the elements of the cognitive model (continued).

Input layer	Possible alternatives	Source
C7. Number and type of equipment hydro-sanitary per household:	7a. Lack of efficient equipment. 7b. Small amount of efficient equipment (up to 30%). 7c. Reasonable amount of efficient equipment (30% to 60%). 7d. High amount of efficient equipment (over 60%).	Adapted from Corral-Verdugo (2003)
C8. Abundance or scarcity of water for the supply:	8a. Watershed satisfactory. 8b. Watershed still satisfactory, more alert state. 8c. Watershed vulnerable.	Conejo *et al*. (2009)

The acquisition of knowledge resulted in a set of 30 rules, and some of these rules are presented in Table 3.

Table 3. Rules set used in this study

ID. of Rule	Rule	ID. of Rule	Rule
1	***if*** C1 is 1f ***and*** C2 is 2a ***and*** C3 is 3d ***and*** C4 is 4a ***and*** C5 is 5d ***and*** C6 is 6d ***and*** C7 is 7a ***and*** C8 is 8a ***then*** f1, f2, f3, f4, f5, f6, f7	2	***if*** C1 is 1a ***and*** C2 is 2d ***and*** C3 is 3a ***and*** C4 is 4c ***and*** C5 is 5d ***and*** C6 is 6a ***and*** C7 is 7d ***and*** C8 is 8c ***then*** f5, f8

Note: ID. Identification of the rule. The terms presented in the rules are presented in Table 2.

The Figure 2 shows an example of a rule used in the expert system to ask the user information needed for decision making.

```
(defrule regra
   (node (name camada1)
         (type decision)
         (question ?question))
   =>
   (printout t ?question "
1a -> negativa (ate 0,00%).
1b -> baixa (0,00% ate 1,73%).
1c -> média (1,73% ate 4,27%).
1d -> alta (mais de 4,27%).
Resposta (1a, 1b, 1c, 1d): ")
   (assert (answer (read))))
```

Figure 2. Representation of a code of rules used by the prototype of the Expert System.

The Figure 3 presents a prototype expert system developed in shell CLIPS (C Language Integrated Production System).

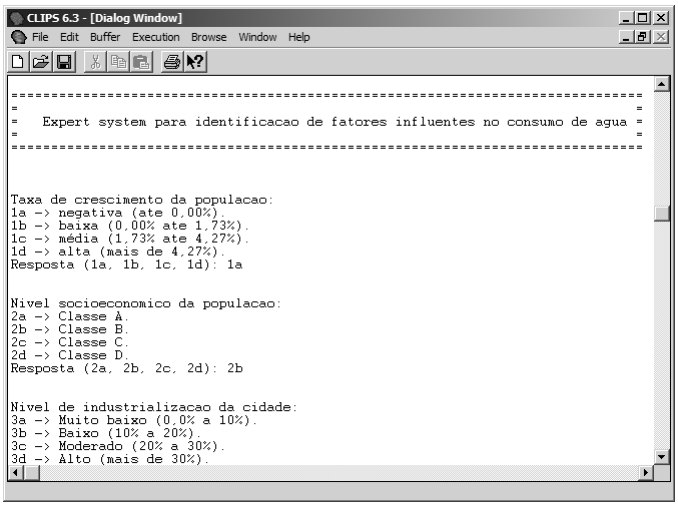


Figure 3. Prototype expert system developed

The result of evaluation of the prototype expert system, according to the method of Collier *et al.* (1999), showed a value of 4.3 on a scale ranging from 1 to 7 (1 = very bad, 4 = reasonable, 7 = very good). This

result indicated that expert system approach can be considered reasonably adequate to identify the factors influencing the water consumption. However, these results were produced form mixed data from human experts and literature review, consequently care should be taken if these factors are employed for planning purposes.

Conclusions

Factors influencing the consumption of water in urban environments could reasonably be identified from the knowledge of experts. The expert system approach can be considered appropriate to identify the influential factors in water consumption. It is suggested to include a larger number of rules in the system, which would increase the knowledge base about the problem.

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References

ABEP, 2011. Critério de Classificação Econômica Brasil [on line]. Available at: http://www.abep.org/novo/Utils/FileGenerate.ashx?id=164 [Accessed 20 February 2011].

Collier, P.A.; Leech, S.A.; Clark, N., 1999. A validated expert system for decision making in corporate recovery. *International Journal of Intelligence System in Accounting, Finance & Management*, 8, 75–88.

Conejo, J.G.L.; Soares, S.R.A.; Juliatto, E.S., Pereira; C.A.A.O., Oliveira; D.D., Grisotto, L.E.G.; Moraes Junior, J.M. (2009). Panorama da oferta de água nos grandes centros urbanos do país a partir dos resultados do atlas regiões metropolitanas. In: Proceedings/Actes: XVIII Simpósio Brasileiro de Recursos Hídricos. Campo Grande, Brasil, 2009 – O Desafio da Prática da Sustentabilidade na Gestão dos Recursos Hídricos: Natureza, Gente e Desenvolvimento. Porto Alegre: ABRH.

Corral-Verdugo, V. (2003). Determinantes psicológicos e situacionais do comportamento de conservação de água: um modelo estrutura. *Estudos em Psicologia*, 8(2), 245–252.

Froukh, M.L. (2001). Decision-support system for domestic water demand forecasting and management. *Water Resources Management*, 15, 363–382.

IBGE. (2000). Série de relatório metodológicos: metodologia do censo demográfico 2000. [on line]. Available at: <http://www.ibge.gov.br/home/estatistica/populacao/censo2000/metodologia/metodologiacenso2000.pdf> [Accessed 04 July 2010].

INMET. (2009). Normais Climatológicas do Brasil 1961–1990. Brasília, 465p.

León, C., Martín, S., Elena, J.M., Luque, J. (2000). EXPLORE – Hybrid expert system for water networks management. *Journal of Water Resources Planning and Management*, 126 (2), 65–74.

Lertpalangsunti, N.; Chan, C.W., Mason; R., Tontiwachwuthikul, P. (1999). A toolset for construction of hybrid intelligent forecasting systems: application for water demand prediction. *Artificial Intelligence in Engineering*, 13(1), 21–42.

Machado, C.J.S. (2003). Recursos Hídricos e Cidadania no Brasil: Limites, Alternativas e Desafios. *Ambiente e Sociedade*, 6(2), 121–136.

Machado, P.A.L. (2001). Direito Ambiental Brasileiro. 9 ed., São Paulo: Malheiros Editores.

Pedrosa, V.A. (1999). Instrumentos econômicos no gerenciamento da demanda de água para sistemas urbanos domiciliares. In: Proceedings/Actes: XIII Simpósio Brasileiro de Recursos Hídricos. Belo Horizonte, Brasil, 1999 – Água em quantidade e qualidade: o desafio do próximo milênio. Porto Alegre: ABRH.

Savenije, H., Van der Zaag, P. (2002). Water as an economic good and demand management – Paradigms with Pitfalls. *Water International*, 27(1), 97–104.

Silva, R.T.; Porto, M.F.A. (2003). Gestão urbana e gestão das águas: caminhos da integração. *Estudos Avançados*, 17(47), 129–145.

Silva, W.T.P.; Souza, M.A.A. (2010). Mathematical modelling of urban water supply system crisis. In: Proceedings/Actes: IX Urbenviron international seminar on environmental planning and management. Niterói, Brazil, 2010 – Sustainable cities for the new millennium. Niterói: URBENVIRON.

Taylor, P., Jonker, L., Donkor, E., Guio, D., Mbodji, I., Mlingi, C., Hassing, J., Lopez, D. (2005). Planejamento para a gestão integrada de recursos hídricos: Manual de Capacitação e Guia Operacional. Brasília: Cap-Net e GWP, 100p. Available at: <http://www.cap-net.org/captrainingmaterialsearchdetail.php?TM_ID=67>. [Accessed 29 October 2007].

Tillman, D.E., Larsen, T.A., Pahl-Wostl, C., Gujer, W. (2005). Simulating development strategies for water supply. *Journal Hidroinformatics*, 7(1), 41–51.