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Multi-criteria spatial decision analysis for forecasting urban water requirements: a case study of Dehradun city, India

K.H.V. Durga Rao*

Water Resources Division, National Remote Sensing Agency (NRSA), Department of Space, Balanagar, Hyderabad 500037, India

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Abstract

A uniform spatial water distribution system will help in distributing domestic water equally to all places with proper pressure. It will avoid the probable risk of failure in the complete distribution system and can make the system cost effective. In the present study a scientific approach has been adopted to compute drinking water requirements at present and in the near future in a spatial environment using multi-criteria decision analysis techniques. Drinking water problems in the city of Dehradun, India, have been studied and causes of drinking water scarcity have been analysed. Different thematic layers required for the study such as, road network map, landuse/landcover, have been prepared in a Geographic Information System environment using very high-resolution digital data of IKONOS satellite coupled with the field data. Future drinking water demand areas have been identified considering numerous variables such as: distance from the main city, road distance, topographic slopes, landuse/landcover, present population density, soils, floodplains, and the existing water supply system. A questionnaire has been conducted to compute the weights for these variables. Additional supplies that have to be provided for the next two decades have been computed and analysed with the present supply system. A spatial future water demand map has been prepared to produce more thorough and accurate means of assessing city development, and allow the planning and construction of optimum and efficient water supply system.

Keywords: Spatial decision support system; Geographic information system; Remote sensing; Drinking water; Multi-criteria; Water demand areas; Spatial forecasting

1. Introduction

It is often argued that water is not an economic good like any other. Rather, it is claimed to be unique because, it is so immediately necessary to life. According to this argument, domestic uses of water, if not all urban uses, are fixed by the needs of people. They respond little, if at all, to economic incentives or other policy interventions. Water is a requirement; it is not subject to taste, fashions, or desires (Baumann et al., 1998). The volume of public water use depends on the size of an urban population and the services and utilities provided, such as the extent of pipe networks for supply and sewerage, or centralised hot-water supply where available. Climatic conditions also have a large influence on the volume of water consumption. The demands for water supplies and the purpose they serve continue to grow throughout the world. Recent population explosions in developing countries have resulted in a growing need for the provision of safe and adequate water and sanitation, and will impose a large demand for further water development and management projects. Safe water is essential for sustenance of

* Tel.: +91-40-23884534; fax: +91-40-23878868.
E-mail address: khvdrao@hotmail.com (K.H.V. Durga Rao).

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life and is required in households for drinking, cooking, washing and cleaning, as well as agricultural and horticultural needs. The fundamental issue in relation to water supply is that of availability, the cost of development of more efficient systems of water provision and the development of management strategies. In many developed large cities, present water withdrawal amounts to 300–600 litres per capita per day (lpcd). In many developing countries public water withdrawal is a mere 50–100 lpcd (UNESCO, 2000).

In India, domestic water requirements are increasing with growth of population and increase in living standards. However, water resources availability has not followed the growth in population, and there currently exists a deficit between the supply and demand for adequate water resources. Forecasted domestic water requirements in India by 2050 are around 110 and 90 km^3 for urban and rural areas, respectively (Ministry of Water Resources, India, 1999). Many parts of India have been experiencing a shortage of drinking water especially in dry periods; this may be due to non-availability of water resources or to an improper distribution system or management. Although some cities are supported by reasonable water supplies, some pockets within cities suffer from a shortage of domestic water because of the influence that topography can play upon the pressure heads of the water supply. In this context, there is a necessity to estimate the domestic water requirements at present and in the near future and to plan distribution systems in the spatial domain, for the optimum management, and the subsequent efficient supply of domestic water requirements.

Leipnik et al. (1993) have discussed the various kinds of hardware and software available in implementing geographical information systems (GIS) in water resources management. Rogers (1993) discussed the economic aspects of planning for urban water use and the role of institutions. A recent publication (Lund and Israel, 1995) addressed the need for optimisation of transfers in urban water supply and planning. They have developed a mathematical programming formulation that illustrates the potential value of system-analysis techniques in designing urban water systems with supply uncertainty, water conservation, and several types of water transfers.

Andreu et al. (1996) have discussed the generic decision support system that was originally designed for the planning stage of decision-making associated with complex river basins. The developed model capability includes basin simulation and optimisation modules, an aquifer flow-modelling module and two modules for risk assessment. The Segura River Basin in Spain and Tagus River Basin in Iberian Peninsula have been used as case studies in the development and validation phases. Reitsma (1996) has made an attempt to formulate the needs and opportunities relating to decision support system technology for environmental management in general and water resources management in particular. Results from an analysis of the Colorado River were used to interpret the otherwise vague and confusing concept of semi-structuredness of the decision support system.

Randall et al. (1997) developed a simulation model to be used for water supply planning by metropolitan water utilities. Their model has been used successfully by the Alameda Country Water District (California) for their long range planning of water resources for urban use. Veldkamp et al. (1997) developed a decision network for sustainable urban water management; they considered the soil characteristics, surface water, groundwater, and pollution aspects by giving priority to develop sustainable techniques for urban water management.

Tkach and Simonovic (1999) have developed a spatial multi-criteria decision-making technique with GIS technology. This technique addresses uneven spatial distribution of criteria values in the evaluation and ranking of alternatives. The analysis of floodplain management strategies for the Red River Valley region is chosen as a case study to illustrate the application of their technique. Cheng and Masser (2003) have demonstrated a spatial data analysis method to seek and model major determinants of urban growth in the period 1993–2000 using a case study of Wuhan city in China. The method comprises exploratory data analysis and spatial logistic regression technique. The former is able to explore visually the spatial impacts of each explanatory variable. The latter can provide a systematic confirmatory approach to comparing the variables. The study shows that the major determinants are urban road infrastructure and developed area.

Dehradun, the area of study in this paper, has expanded rapidly in the last decade due to migration and tourism, supporting a current population of nearly