The application of rural threshold water consumption model in water supply studies

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Abstract The development of the Rural Threshold Water Consumption (RTWC) model for solving rural water problems has contributed valuable data in hydrological sciences modelling. The model objective is to quantify domestic water consumption, generate a threshold value and delineate areas of deficits, balances or surpluses at regular and supplemental periods using local techniques. The end result is the prediction of risks, as well as solutions to rural water problems. The paper thus establishes the use of the RTWC model as an analytical tool, and a planning kit for water sector planners and decision makers for sustainable year-round domestic usage water allocation.

Key words RTWC model; rural water supply; Nigeria

INTRODUCTION

The major thrust of the rural water supply programmes in Nigeria is to ensure provision of adequate drinking water supply to rural communities. The government acts as a service provider with minimum involvement of the local communities in the planning process and the implementation activities. Thus, rural domestic water consumption, in terms of quantity and quality, was not adequately considered in most subvention programmes. These have resulted in several rural water supply developmental programmes not meeting the needs of the rural populace. It is against this background that the paper applies the Rural Threshold Water Consumption (RTWC) model, which is a mass balance approach to water quantification to predict rural domestic water consumption in parts of Anambra State of southeastern Nigeria. The model integrates both domestic and local processing activities for effective predictions in rural areas. It simulates water demand and consumption considering human behavioural patterns, and rural variables such as small-scale industrial activities and agricultural water-use activities. In particular, the model calculates domestic water consumption at regular and supplemental periods. The model also establishes a control variable, which identifies areas of water deficit, surplus and balance. It is thus vital, since the participation of water consumers is paramount for planning and execution of rural water projects.

The RTWC model is developed based on the assumption that domestic water is a necessity in rural communities, with the existence of variations in water demand and consumption vis-a-vis the population figure. Conceptually, as shown in Fig.1, it adopts community water supply management (CWSM), water supply protection (WSP) and threshold concepts structure coupled with water quality and access data for reliable prediction and solution to rural water consumption problems. The concept of community water supply management (IRC, 2003) advocates active participation of local communities in providing water services, while the water supply protection, as demonstrated by Okeke & Oyebande (2009) using field exercises, water sampling and analysis, ensures environmental health and safety of rural water consumers. The threshold constant (K) was generated as a planning guideline, which (Abrahams, 1996) described as a framework for effective capacity building at the local government and community levels to ensure sustainable water supply and sanitation services.

STUDY AREA

The study was carried out in six local government areas of Anambra State, southeast of Nigeria. The study area in Fig. 2 comprises Ekwusigo, Nnewi South, Ogbaru, Ihiala, Idemili North

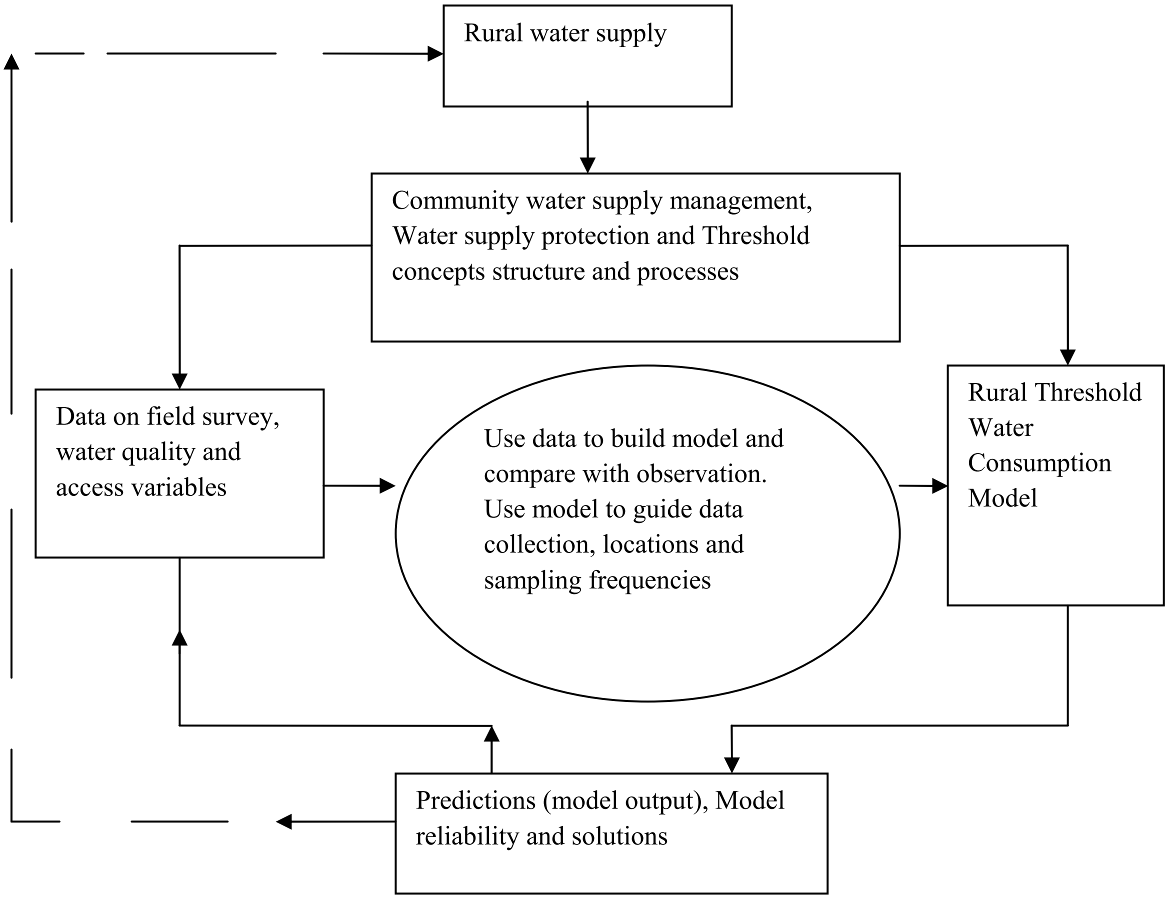

Fig. 1 The rural water supply model concept. Source: Okeke (2009).

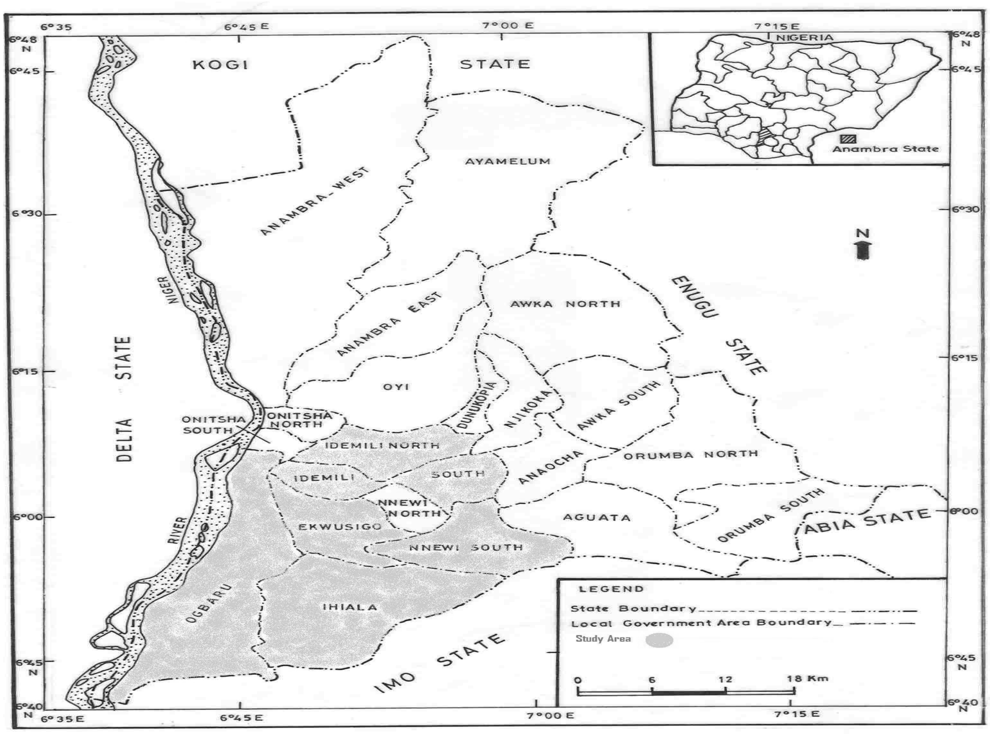

Fig. 2 LGAs with rural communities within southwestern Anambra State. Source: Anambra State Survey Awka (1997).

and Idemili South. The selected local government areas (LGAs) are domicile in the southwestern parts of Anambra State and are made up of several rural communities. The climate of Anambra State is tropical, with distinct wet and dry seasons. Rainfall is the major source of water for domestic, agricultural and local industrial purposes. The interaction of the tropical continental and maritime air masses ($_{C}T$ and $_{M}T$) at the Inter-tropical discontinuity (ITD) zone result in high- and low-rainfall months. The vegetation is the tropical rainforest and the people are mostly farmers, industrialists and skilled workers.

METHODOLOGY

A structured questionnaire using random sampling techniques was used to collect information on rural domestic, industrial, agricultural and miscellaneous water consumption within the study area. Based on the elicited data, which where both qualitative and quantitative, a mass balance model (RTWC) was developed to explain the domestic water consumption pattern of the study area. The approach is a mathematical indicator of input and output expressed at minimum, maximum and threshold levels with a mathematical equation:

$$Q_1 = d_1 + i_1 + a_1 + m_1 \quad (1)$$

$$Q_2 = d_2 + i_2 + a_2 + m_2 \quad (2)$$

$$K = \frac{1}{2} \sum_{n=1} (d_n + i_n + a_n + m_n) \quad (3)$$

where Q_1 = total minimum volume of water used daily by households; d_1 = minimum volume used for domestic functions; i_1 = minimum volume used for small-scale commercial and industrial functions; a_1 = minimum volume used for household agriculture; m_1 = minimum volume used for miscellaneous purposes; Q_2 = total maximum volume of water used daily by households; d_2 = maximum volume used for domestic functions; i_2 = maximum volume used for small scale industrial functions (food processing, local soap making); a_2 = maximum volume used for household agriculture (vegetable gardens "mbubo"); m_2 = maximum volume used for miscellaneous purposes; K = threshold balance (planning constant or control variable for rural water supply); *s*ource, Okeke (2009).

This model was used to quantify domestic water demand of the study area for both regular water supply periods and deficit water supply periods and was further validated to check for the reliability of its application to other rural environments with similar characteristics.

RESULTS AND DISCUSSION

Table 1 show values that are derived from regular household water consumption variables generated from questionnaire survey and field work records in the study area. The domestic, industrial, agricultural and miscellaneous water uses were recorded. Thus, on a regular basis, an individual consumes an average of 25–29.2 L/d of water. A similar quantification could also be carried out at supplemental or periods of extra consumption to generate 37.5–41.7 L/d. The survey presents high values of domestic water consumption, thus validating the assumption that domestic water is a basic necessity in the rural communities of southwestern Anambra State.

The Q_1, Q_2 and K water consumption values in Table 2 are generated from summation of the variables in Table 1. Thus, the computation of minimum consumption Q_1 = 103 L, maximum consumption Q_2 = 175.01 L and threshold constant K = 139 L. The exceedence of the K value indicates surplus water zones while non-attainment relates to zones of scarcity thereby establishing the water consumption variation assumption.

Table 1 Regular water consumption values (L/d) in Anambra State.

Period	LGA	V	d_1	i_1	a_1	m_1	V	d_2	i_2	a_2	m_2
Regular water consumption	Ekwusigo	Min = 25 L	76.7	2.7	19.2	1.4	max= 29.2 L	134.2	4.73	33.6	2.45
	Nnewi South		93.5	5.4	1.1	0		163.6	9.45	1.93	0
	Ogbaru		66.3	12	18.8	2.9		116.03	21	32.9	5.08
	Ihiala		84.8	9.3	4.1	1.7		148.4	16.3	7.18	2.98
	Idemili South		92.6	3.2	3.2	1.1		162.1	5.6	5.6	1.93
	Idemili North		92.6	2.1	3.3	2.1		162.1	3.68	5.76	3.68
	Average		84.4	5.8	9.9	2.7		148	10.1	14.5	2.7

d_1 = minimum volume used for domestic functions; i_1 = minimum volume used for small-scale industrial functions (food processing and local soap making); a_1 = minimum volume used for household agriculture (vegetable gardens "mbubo"); m_1 = minimum volume used for miscellaneous purposes; d_2, i_2, a_2, m_2 = maximum volumes used; V = volumes of water (L). Source: Field survey (2009).

Table 2 Q_1, Q_2 and K computations (L/d) at regular periods in Anambra State.

LGA	$Q_{1(min)}$	$Q_{2(max)}$	K
Ekwusigo	100	174.9	137.45
Nnewi South	109.9	174.9	142.4
Ogbaru	100	175.01	137.51
Ihiala	107.9	174.84	141.37
Idemili south	100.1	175.2	137.65
Idemili North	100.1	175.2	137.65
Average	103	175.01	139

Q_1 = total minimum volume of water used daily by households; Q_2 = total maximum volume of water used daily by households; K = threshold balance (planning constant or control variable for rural water supply). Source: Field survey (2009).

Table 3 Total domestic water consumption in Anambra State (L/d).

LGA	Population	Minimum vol. (L/d	Total minimum vol. (L/d)	Maximum vol. (L/d)	Total maximum vol. (L/d)
Ekwusigo	158 231	25	3 955 775	29.2	4 620 345
Nnewi South	233 658	25	5 841 450	29.2	6 822 814
Ogbaru	221 879	25	5 546 975	29.2	6 478 867
Ihiala	302 158	25	7 553 950	29.2	8 823 014
Idemili South	207 683	25	5 192 075	29.2	6 064 344
Idemili North	430 783	25	10 769 575	29.2	12 578 864
Total	1 554 392		38 859 800		45 388 248

Source: NPC (2006) and Field survey (2009).

At the minimum level of consumption (103 L/d), inadequate water consumption plans could be made for a community, while at the maximum consumption level (175.01 L/d), there may be the case of excessive planning and thus not being able to meet the budget. Thus, Nnewi South and Ihiala LGAs with above threshold values of 142.4 and 141.37 L, respectively, are identified as probable water surplus zones, while Ekwusigo, Ogbaru, Idemili South and North LGAs are areas of possible water supply deficits. The threshold value of 139 L/d is therefore recommended for optimal planning. Similar computations are carried out for supplemental water consumption to generate zones of balance. Supplemental water is needed when regular water allocations of 25–29.2 L per individual or 100–175 L per household are insufficient to satisfy daily domestic needs.

Water consumption increases with population growth rate and activities, as shown in Table 3. Idemili North and Ihiala LGAs with high population record of 430 783 and 302 158 thus records high water consumption values of 12 578 864 and 8 823 014 L/d, respectively. On the other hand, Ekwusigo LGA with least population of 158 231 records the lowest consumption values of 4 620 345 L/d. Most importantly, the threshold constant needs to be factored in for these consumption values to be attained.

Implications of water quality on domestic water consumption

In Table 4, the water quality and access variables were used to complement the demand or consumption variables as pathways to security and sustainability (Okeke & Oyebande, 2009). The RTWC model helps to predict and project water consumption especially with variations in seasons thereby providing quick solutions especially for the deficit regions such as rainwater gathering for the dry seasons and creation of new water facilities such as boreholes and pipe-borne water to meet the demand for each region.

Table 4 Water quality implications on domestic water consumption.

LGA	RTWC threshold (K = 139 L)	Zones	Water quality assessment	Implications on domestic water
Ekwusigo	137.45	Deficit	High total bacterial count	Susceptible to disease causing organisms
Nnewi South	142.4	Surplus	High COD thus high oxidizable organic matter	May be unfit for drinking
Ogbaru	137.51	Deficit	High iron, turbidity and COD values.	Impairs acceptability and is susceptible to pollution
Ihiala	141.37	Surplus	High BOD_5 and COD, thus likely pollution source	Unfit for domestic consumption
Idemili South	137.65	Deficit	High BOD_5 thus presence of high oxidizable organic matter	Unfit for domestic consumption
Idemili North	137.65	Deficit	High BOD_5 thus presence of high oxidizable organic matter	Susceptibility to pollution

Source: Field survey (2009).

However, the domestic water quality for consumption in these study local government areas needs to be treated and preserved through boiling, a method commonly recommended, widely understood and used to minimize risks of infections, water-borne diseases and in severe cases death of rural consumers. The addition of chemicals such as alum for purification is also acceptable.

CONCLUSION AND RECOMMENDATIONS

Supply and demand are important rural water variables that revolve around aspects of water consumption, distribution and availability. The quantification of water consumption at different periods has shown that inadequate water availability in the rural areas could lead to poor health, low productivity and food insecurity. The model application and generated threshold constant (K = 139 L) establishes a balance and is a key variable to help regulate water supply allotcation in the study area.

The study therefore recommends the application of the RTWC model in identifying the water needs of the rural populace, optimal planning as well as effective monitoring and design of rural water systems. Education and awareness campaigns for adequate supply and consumption of good quality water cannot be overemphasized. Finally, water treatment is recommended for cases of doubtful water quality, so as to remove or destroy pathogenic micro-organisms present in the water.

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