Product Quality Assessment and Capacity Utilisation Model of Selected Waterworks in South-Western Nigeria.

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Abstract

Availability of personnel in right mix, number and quality water is also an essential factor of production to achieve optimum production capacity. This work therefore seeks to assess the water quality characteristics and benchmarking it with the World Health Organisation's (WHO) standard. It also attempts to generate a mathematical model for optimising capacity in relation to mix and number of technical personnel. Data on water quality characteristics was gathered and subjected to statistical analysis. Failure records on each production equipment were obtained from the maintenance unit of the respective plants to calculate failure rate, *F* and reliability, λ. Regression analysis was performed on the data to generate the correlation and coefficient tables hence the model. The result revealed that none of the waterworks perform all the 14 mandatory tests (due to paucity of test equipment). Capacity utilisation, CU of the water production plant is weakly dependent on number of engineers, e; number of technologists, T, number of technicians, t; number of craftsmen, c while it is strongly a factor of the plant's reliability R_p. The equation $CU = 35.664 - 0.969e + 1.027T + 0.026t - 0.216c + 53.441R_p$ was found to be a valid model for optimising capacity utilisation of the selected plant.

Keywords:
Water quality characteristics, capacity utilisation, plant's reliability.

1. Introduction

Water is a compound of hydrogen and oxygen (H_2O) that can be found in lakes, rivers, seas and wells. Healthy people and good environment flourish where water is available in adequate quantity and acceptable quality. Life expectancy has been shown to have a relationship with water supply. In Africa for example, life expectancy has been reported to increase with water supply coverage (UNICEF, 1997). It has also been shown that there is a strong correlation between access to safe water and survival of children less than five years of age for selected countries (Engelman and Leroy, 1993). Good sanitation and general hygiene require availability of water at all times. Simple washing of hands after using the toilet can reduce incidence of diarrhoea, which is one of the greatest causes of death in children in Africa (Sule, 2003). Water quality is compromised when chemical supply and use at the production/treatment plants is not adequate. Inadequate supply of chemicals can result in poor-quality drinking water, many illnesses are caused by usage of poor-quality water and studies have identified about 30 diseases, which are linked to water (Feachman, *et al*., 1997). According to the World Health Organisation,WHO (1995), water-borne diseases are responsible for more than six million deaths worldwide every year (WHO, 1995). Presence of heavy metal in water is dangerous, according to the United States Environmental Protection Agency, USEPA (1996), the health effects of lead (Pb) are most severe for infants and children and may result in delays in their physical or mental development. The source of lead in drinking water could be through residential plumbing fixtures and solder joints.

Total *coliform* bacterial count is used as indicator of microbial contamination. Faecal *coliform* bacteria and in particular E. *Coli* are members of the *coliform* bacterial group originating in the intestinal tract of warm-blooded animals and are passed into the environment through faeces.

Despite the pre-chlorination and post-chlorination processes, some micro-organisms may still escape into the service tank and subsequently piped to the consumers. For instance, it was reported that 400,000 people in Milwaukee became ill and more than 100 died in 1993 as a result of an intestinal parasite, Cryptosporidium, in drinking water (USEPA, 1996). In the same year residents of Manhattan and others in Washington D.C. area were advised to boil their water when unexpected number of *E. coli* bacteria began to show up in their drinking water despite heavy doses of chlorine (USEPA, 1996). As a result of heavy doses of chlorine, it was realized that a by-product of the disinfecting process, called trihalomethane, might be causing about 10,000 cancer cases per year in the United States (Shifrin, *et al.*, 1996).

Table 1 - WHO guideline values for drinking water quality.

Parameters (units)	Guideline value*	Health hazard(s) of exceeding guideline values	Ref.
Microbiological quality			
Faecal coliforms (Number/100mL)	Zero[a]	Diarrhea, cramps, nausea, and possibly jaundice	DOH (2011)
Coliform organism (Number/100mL)	Zero[a]	Diarrhea, cramps, nausea, and possibly jaundice	Choong et al., (2007)
Inorganic constituents			
Arsenic (Mg/L)	0.05	Skin damage or problems with circulatory systems and may have increased risk of getting cancer of the lung and skin.	Choong et al., (2007)
Cadmium ((Mg/L)	0.005	Risk of kidney damage	Jarup et al., (1998)
Chromium ((Mg/L)	0.05	Increased stomach and lung cancer risks.	Smith and Steinmaus (2009)
Cynide (Mg/L)	0.1	Nerve damage or thyroid problems	Shifrin et al., (1996)
Fluoride (Mg/L)	1.5	Bone disease (pain and tenderness of the bone); children may get mottled teeth.	Ayoola and Guptaa (2006)

Similarly, in developing countries like Nigeria, a number of health hazards result from poor-quality drinking water, the quantity of desirable ions in pipe-borne water in Ilorin Township falls below the threshold (Kayode, 2001). The outbreak of typhoid/paratyphoid fever and dysentery in Ago-Iwoye, South-Western Nigeria was a result of high level of contaminants in particular treated water piped to consumers (Ojelabi, *et al*., 2001). It is therefore a necessity to evaluate the quality of water piped to consumers for drinking. The WHO Guideline for drinking water quality is presented in Table 1.

Table 1b – WHO guideline values for drinking water quality

Parameters (units)	Guideline value*	Health hazard(s) of exceeding guideline values	Ref.
Lead (Mg/L)	0.05	Infants and children may have delay in physical or mental development, children could show slight deficit in attention span and learning abilities while adults may have kidney problems and high blood pressure.	Jarup (2003)
Mercury (Mg/L)	0.001	Kidney damage.	Aschengrau *et al*., (1989)
Nitrate (Mg/L)	10	Infant below the age of six months who drink water containing nitrate in excess of the Maximum Contaminant Level, MCL, could become seriously ill and if untreated, may die. The symptoms are shortness of breath and blue-body syndrome.	Fan and Steinberg (1996)
Selenium (Mg/L)	0.01	Hair or finger loss, numbness in fingers or toes and circulatory problems.	Vinceti *et al*. (1996)
		Aesthetic Quality	
Aluminium (Mg/L)	0.2	Alzheimer's disease; a progressive mental deterioration that can occur in middle or old age, due to generalized degeneration of the brain.	McLachian *et al*. (1996)
Chloride (Mg/L)	250	Hinders the synthesis of thyroid hormones; which regulate the body's metabolic rate as well as heart and digestive function, muscle control, brain development and bone maintenance.	Urbansky and Schock (1999)

Table 1c – WHO guideline values for drinking water quality

Parameters (units)	Guideline value*	Health hazard(s) of exceeding guideline values	Ref.
Colour (True Colour Unit, TCU)	15		
Copper (Mg/L)	1.0	No acute or chronic adverse consequences of consuming water with copper content of 2 mg/L were detected.	Olivares *et al.* (1998)
Hardness (Mg/L; as $CaCo_3$)	500		
Iron (Mg/L)	0.3	Warding off fatigue and anaemia	McFarlad and Dozier (2001)
Manganese (Mg/L)	0.3	Neurological disorder at the age of 50 years and above	Xenophon *et al*. (1989)
PH	6.5 to 8.5		
Sodium (Mg/L)	200		
Solids, Total Dissolved Sulphate (Mg/L)	400	Not reported hazards.	Rozelle and Wathen (1993)
Taste and odour	Inoffensive to most consumers		
Turbidity (NTU)	5		
Zinc (Mg/L)	5.0	Short-term disease called metal fume fever, which is generally reversible once exposure to zinc ceases.	Anderson (1997)

[a] Treated water entering the distribution system.

The risk of skin and lung cancer is higher for consumers of potable water with arsenic concentration higher than the WHO value (Ayoola and Guptaa, 2016). Kidney may get damaged for consuming water with high cadmium concentration (Jarup *et al.*, 1998). Consuming high cynide-containing potable water could lead to nerve damage or thyroid problem (Rozelle and Wathen, 1983). Adult consumers of portable water with high fluoride concentration are exposed to high risk of bone disease, while infant could have mottled teeth (Aschengrau, *et al*.,1989). Adult could have kidney problem and high blood pressure, while infants and children could have retarded mental and physical growth, in addition to deficit in attention span and learning ability, if they consume water with high lead content (Järup, *et al.*, 1998). Consumption of water with high mercury content could lead to kidney damage (Anderson, 1997). Drinking of high nitrate-concentrated water may not be harmful to adults, but infant consumers may suffer shortness of breath and blue body syndrome, which could lead to death if untreated (Fan and Steinberg, 1996). Hair or finger loss, numbness in fingers or toes and circulatory problems are imminent to consumers of potable water with high celenium concentration.

In Africa for example, life expectancy has been reported to increase with water supply coverage (UNICEF, 1997). It has also been shown that there is a strong correlation between access to safe water and survival of children less than five years of age for selected countries (R, E., and P, L., 1993). Although water from public water production plant is assumed to be clean and safe for drinking but they often come out with particles of dirt, offensive odour and colour. Whereas a lot of hazards can be attributed to poor-quality drinking water, many illnesses are caused by usage of poor-quality water and studies have identified about 30 diseases, which are linked to it (Feacham, *et al*., 1997).

The shortage of trained personnel is readily apparent in the water treatment plants of developing countries, where at least 50% of the installations lie idle in disrepair after construction (McGarry and Schiller, 1981). In fact, a 1990 WHO survey of 86 developing countries regarding which of eight constraints to developing water supplies was most significant; found that lack of trained personnel was rated as the second most serious constraint after insufficient internal financing (WHO,1993).

Preliminary survey of public water supply systems in selected part of south-western Nigeria shows that the facilities are not functioning as expected, For instance in Ilesa, Osun State, the public water facilities installed in the late sixties is no longer functional and the inhabitants now depend on well water and surface run-off water to meet their water demand. The public water facilities installed in front of Oke-Awesin in Erin Osun ceased to function after three months of operation. Similarly that of Olu-Ode compound in Okuku (Odo-Otin Local Government Area of Osun State) was not spared.

The inadequate quantity and quality of water supply could be linked to shortage of trained personnel and finances. Some of the factors that affect the capacity utilisation are inadequate technical manpower and supply of production and maintenance materials. The following research questions would therefore be considered in finding solutions to the problem of inadequate provision of drinking water.

a. What is the state of processing equipment in terms of technical adequacy, availability and reliability?
b. Can the water demand be measured or accurately forecast?
c. How adequate is the technical staff in water processing plants?
d. What are the critical engineering components required for sustaining the capabilities of the public water facilities? What are the other critical factors required for the provision of adequate drinking water?

The objective of this study therefore is to generate a model for relating capacity utilisation to reliability of the plant and number of technical staff i.e. number of engineers, technologists, technicians and craftsmen. The model is expected to predict capacity utilisation from the number and mix of technical staff and plant's reliability of the selected waterworks.

2. Methodology

In order to estimate the quality of water produced by a waterworks, sample results of laboratory tests on treated water for a period of about 12 months were obtained from the waterworks' laboratories. The average values were used to calculate the population mean using a statistical tool called t-test.

The data on capacity utilisation and number of technical crew in each of the six selected water production plants were collected from the waterworks. Number of failure of each component in a subunit (such as low lift pump with 11 components) was obtained from the maintenance unit of the respective plant from which the failure rate, F, and reliability,λ, was calculated. The system network for such subunit was drawn, its reliability equation derived to calculate the numeric value. Subsequently the system network for the entire plant was drawn; its reliability was obtained from the reliability equation.

The procedure employed in arriving at the plant's reliability has been extensively discussed in our previous work (Abdul, *et al.*, 2009). Regression analysis was performed on the data using two different software i.e. sigma plot and Statistical packages for Social Scientist SPSS; the correlation and coefficient tables were generated to obtain the model.

3. Results and Discussion

The reliability of the plants has been extensively evaluated in our previous work (Abdul, *et al*., 2009), The summary of result for each of the six States is presented in Tables 2.

Table 2 - Summary of data obtained from the selected waterworks.

Production variables	Iju	Ede	Asejire	Ero	Ondo /Owena	Abeokuta MS
No. Engineers	38	18	25	18	14	2
No. Technologists.	20	20	12	18	9	3
No. Technician.	107	16	17	14	25	17
No. Craftsmen	8	4	13	4	6	8
Reliability of plant	0.98	0.93	0.76	0.67	0.95	0.72
Capacity Utilisation, CU(%)	72.8	88	62	72	82.5	74.0

Regression analysis was performed on Table 2, the correlation and unstandardized coefficient tables generated from the analysis is presented in Tables 3 and 4 respectively.

Table 3 - Correlation between dependent and independent variables

		CU	e	T	T	c	R_p
Capacity Utilisation	Pearson Correlation	1	-0.295	0.085	0.50	-0.738	0.588
	Sig. (2-tailed)		0.571	0.873	0.313	0.094	0.220
	N	6	6	6	6	6	6

Table 4 - Coefficient table generated from regression analysis

Unstandardized Coefficients		
Independent variables	*B*	Std. Error
(Constant)	35.664	.000
No. of engineers, e	-0.969	.000
No. of technologists, T	1.027	.000
No. of technicians, t	0.026	.000
No. of craftsmen, c	-0.216	.000
Reliability, R_p	53.441	.000

Dependent Variable: CU

$$CU = 35.664 - 0.969e + 1.027T + 0.026t - 0.216c + 53.441R_p \quad (1)$$

Where CU = Capacity Utilisation, e = Number of engineers, T = Number of technologist, t = Number of techniciansc (craftsmen), R_p = Reliability of Plant. The field data was used to test the model and result of the test is shown on last column in Table 5.

Table 5 - Comparison of field result and the model.

Name of waterworks	E	T	T	c	Reliability	Field C.U.(%)	Model C.U. (%)
Iju	38	20	107	8	0.98	72.8	72.80818
Ede	18	20	16	4	0.93	88	88.01413
Asejire	25	12	17	13	0.76	62	62.01216
Ero	18	18	14	4	0.67	72	72.01347
Ondo/Owena	14	9	256	6	0.95	87.5	87.46995
Abeokuta MS	2	3	17	8	0.72	74	73.99852

Figure 1 shows the graphical comparison of the actual and calculated (modelled) capacity utilisation.

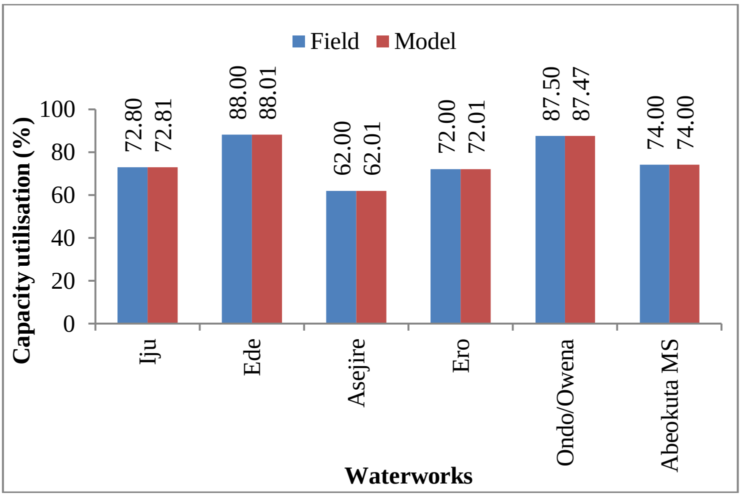

Figure 1: comparison of actual and modelled capacity utilisation

Summary of water quality in the selected waterworks is shown in Table 6.

Table 6 - Summary of water quality analysis for selected waterworks in South-Western Nigeria.

SN	Characteristic	WHO	Iju				Asejire				Owena			
			LL	UL	Av.	SD	LL	UL	Av.	SD	LL	UL	Av.	SD
1	Faecal coliform (Number/100mL)	0	0.00	0.00	0.00		0.00	0.00	0.00		0.00	0.00		
2	Coliform organism (Number/100mL)	0	0.00	0.00	0.00		0.00	0.00	0.00		0.00	0.00		
3	Arsenic (Mg/L)	0.05	_	_			_	_	-		_	_		
4	Cadmium (Mg/L)	0.005	_	_			_	_			_	_		
5	Cyanide (Mg/L)	0.1	_	_			_	_			_	_		
6	Fluoride (Mg/L)	1.5	_	_			_	_			_	_		
7	Lead (Mg/L)	0.05	_	_			_	_			_	_		
8	Mercury (Mg/L)	0.001	_	_			_	_			_	_		

Table 6 continued

SN	Characteristic	WHO	Iju				Asejire				Owena			
			LL	UL	Av.	SD	LL	UL	Av.	SD	LL	UL	Av.	SD
9	Nitrate (Mg/L)	10	13.70	14.20	13.95	0.39	_	_			_	_		
10	Selenium (Mg/L)	0.01	_	_			_	_			_	_		
11	Colour (TCU)	15	4.86	5.82	5.34	0.75	4.80	5.40	5.10	0.54	1.53	2.47	2.00	0.75
12	pH	6.65-8.5	6.68	7.32	7.00	0.50	6.65	7.05	6.80	0.40	6.88	7.52	7.20	0.50
13	Total Dissolved Solids (Mg/L)	400	125.34	127.79	126.57	1.93	9.59	9.79	9.60	0.30	34.88	45.12	40.00	8.06
14	Turbidity (NTU)	5	2.36	5.47	7.01	2.43	5.47	8.71	7.01	2.43	3.05	3.56	3.31	0.40

Note: UL – Upper Limit, LL – Lower Limit; Av – Average; SD – Standard deviation

Table 6 continued. Summary of water quality analysis for selected waterworks in South-Western Nigeria.

SN	Characteristic	WHO	Ero				Erinle				Abeokuta Mains			
			LL	UL	Av	SD	LL	UL	Av	SD	LL	UL	Av	SD
1	Faecal coliform (Number/100mL)	0	0.00	0.00			0.00	0.00			0.00	0.00		
2	Coliform organism (Number/100mL)	0	0.00	0.00			0.00	0.00			0.00	0.00		
3	Arsenic (Mg/L)	0.05	_	_			_	_			_	_		
4	Cadmium (Mg/L)	0.005	_	_			_	_			_	_		
5	Cyanide (Mg/L)	0.1	_	_			_	_			_	_		
6	Fluoride (Mg/L)	1.5	_	_			_	_			_	_		
7	Lead (Mg/L)	0.05	_	_			_	_			_	_		
8	Mercury (Mg/L)	0.001	_	_			_	_			_	_		
9	Nitrate (Mg/L)	10	_	_			9.49	10.45			_	_	9.97	0.8

SN	Characteristic	WHO	Ero				Erinle				Abeokuta Mains			
			LL	UL	Av	SD	LL	UL	Av	SD	LL	UL	Av	SD
10	Selenium (Mg/L)	0.01	_	_			_	_			_	_		
11	Colour (TCU)	15	1.53	2.47	2.00	0.75	4.80	5.40	5.25	0.75	4.87	5.82	5.10	0.5
12	pH	6.65-8.5	6.88	7.52	7.20	0.50	6.65	7.05	7.20	0.60	6.68	7.32	6.80	0.4
13	Total Dissolved Solids (Mg/L)	400	34.88	45.12	40.00	8.06	9.59	9.79			_	_	9.64	0.3
14	Turbidity (NTU)	5	3.05	3.56	3.31	0.40	2.36	7.04	1.50	0.07	1.46	1.56	3.00	1

Note: UL – Upper Limit, LL – Lower Limit; Av – Average; SD – Standard deviation

4. Discussion of Results

Two variables are strongly dependent if the correlation between the variable is 1, while two totally non-dependent variables have zero correlation. A negative correlation value shows inverse relationship and vice versa.

Table 3 shows that more than any other contributing factors, there is a stronger correlation (~0.6) between capacity utilisation and reliability of the plant. This fact is further corroborated by the coefficient of plant's reliability, R_p (53.44) in equation 1. Other factors that contribute positively to optimising the C.U. are the number of technologists and technicians. Implying that if the reliability of the plant could be improved upon and appropriate number of technologist and technicians are put in place, the capacity utilisation will be greatly enhanced. The strong relationship between the plants' reliability and capacity utilisation is further corroborated by the Table 4. The positive correlation between T, t and R_p and CU is also in agreement with Table 3.

Table 5 shows that the value of CU calculated from Equation 1 and those from the field data are similar. The correlation between the two sets of data is 0.999, an indication of validity of the Equation 1.

Table 6 shows that in all the water processing plants, the taste of the water was inoffensive and the number/100ml of faecal *coliform* and *coliform* organism was zero; however other characteristics have values either within or outside the WHO acceptable range. Tests on arsenic, cadmium, cyanide, fluoride, lead, mercury and selenium were not performed in any of the waterworks, whereas they constitute high potential health hazards. High arsenic constitutes high risk of skin and lung cancer (Ayoola and Guptaa, 2006); high cadmium concentration damages the kidney (Jarup *et al.,* 1998); high cynide-containing-potable water could lead to nerve damage or thyroid problem (Rozelle and Wathen, 1983); consumers of high fluoride containing water are exposed to high risk of bone disease and infant could have mottled teeth (Aschengrau *et al.,* 1989). Adult consuming water with high lead content risks kidney problem and high blood pressure, while infants and children could have retarded mental and physical growth, in addition to deficit in attention span and learning ability (Jarup, 2003). consuming water with high mercury content could lead to kidney damage (Anderson, 1977); drinking of nitrate-concentrated water may not be harmful to adults, but infant risks shortness of breath and blue body syndrome, which could lead to death if untreated (Fan and Steinberg, 1996). Drinkers of water with high celenium concentration risks hair or finger loss, numbness in fingers or toes and circulatory problems are imminent.

5. Recommendations and Conclusions

Quality assessment of selected waterworks in South-Western Nigeria has been conducted and capacity utilisation model derived. The main findings are

(i) The two microbiological tests faecal *coliform* and *coliform* organism test were performed and guideline standard met.
(ii) Most of the aesthetic and inorganic constituent tests mentioned in Table 1 (WHO guideline for drinking water quality) were not performed in all the waterworks, whereas high constituent of inorganic and aesthetic matters constitute serious health risks.
(iii) Capacity utilisation is strongly dependent on reliability of the plant, number of technician and technologists and less dependent on the number of engineers and crafts men.
(iv) Ede waterworks had the highest CU (88%), while the CU at Asejire was found to be the least (62%).
(v) The generated model fits into the field data as shown in Figure 1.

In order to avoid the health hazards from poor quality drinking water, facilities for the conduct of the aesthetics and the inorganic tests should be provided and staff trained on its use. The capacity utilisation model shows that the installed capacity of the plants could be enhanced by employing/training more technologists and technicians. This is an indication that middle level manpower is more relevant to optimising the capacity of a waterworks, while number of engineers and craftsmen could be minimum.

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