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A Comparative Evaluation of the Water Quality Standards of Different Countries

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Abstract: Twenty five countries, evenly distributed across the continents were used for this study. The water quality standards of these countries were used to assess water quality data from a water monitoring exercise, based on the CCME water quality index. The ratings obtained were used as a measure of the liberality or strictness of water quality standards of these countries. Afterwards, water quality indices were computed for each of acceptability, health and toxicity. The CCME was then modified to reflect the varying importance of different parameters. The modified water quality index is called the importance averaged water quality index (IAWQI). Going by the overall water quality indices, Australia, UAE, India and Japan seem to have the most stringent drinking water standards; while Jamaica, Peru, Mexico and UAE seem to possess the most liberal drinking water quality standards. England, Italy, Nigeria and Spain have very little or no deviations from WHO guidelines for overall water quality index. Countries such as Jamaica, Peru, USA, Mexico, Ecuador, Rwanda and Ghana have the most negative deviations from the WHO guidelines. In IAWQI, acceptability has a weight of 1.00, health has a value of 11.08 and toxicity has a value of 2.74. A comparison of the CCME WQI and the IAWQI shows that the CCME WQI generally overestimates the quality of water. The IAWQI values of countries such as Sudan, Ghana and Rwanda are much higher than their corresponding WQI values. These three countries located in Africa are among countries with the lowest water poverty indices (WPI).

Key words: Water quality index, water quality standard, water, water stress.

Introduction

The main issues of water concern are access to safe drinking water and sanitation services, as well as water quality management (Ali, 2008). In 2000, 1.1 billion people lacked access to improved water supply, and 2.4 billion to adequate sanitation, more located in rural than urban areas (WHO/UNICEF, 2000). According to reports worldwide, over a million deaths per year have been attributed to unsafe water and poor sanitation, with close to 90% of these deaths occurring in children under five years of age (Dunn and Derrington, 2010). The provision of clean drinking water and discharge of adequately treated wastewater is a fundamental requirement for human life. Stipulation of water quality standards at both local and international levels became necessary because of the increasing impairment of water resources due to anthropogenic activities connected to industrialization, increased population density and present high rate of urbanization.

Water quality standards are regulations that: define the water quality goals of a water body, or segment thereof, by designating the use or uses to be made of the water; criteria necessary to protect the uses; and protect

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the water quality through anti-degradation provisions. Water quality standards are adopted to protect public health or welfare and enhance the quality of water. The major focus of drinking water standards is to safeguard public health. Enforcement of standards is as important as setting of standards yet the problem of enforcement is very critical in most developing countries where regulations exist only on the pages of paper.

Insufficient amounts of water for basic hygiene can contribute to poor hygiene practices, which in turn can lead to skin and eye diseases, and act as a key factor in the transmission of many diarrhoeal diseases (Ince et al., 2010). At present, the monitoring of surface and ground water in most developing countries is carried out mostly by individual researchers in universities, research institutes, government agencies and some other organisations. Such exercises are usually haphazard, short term and based on individual interest and the reagents and equipment available to the scientist. According to Whitfield (1988), the goals of water quality monitoring should be directed towards expansive information needs, determination of compliance within objective and standard framework, assessment of environmental trend and effects, mass transport estimation, and performance of general surveillance. It is therefore necessary to set up monitoring goals, which must be carried out with an appropriate sampling plan, where collected data could be periodically reviewed.

Care must be taken when collecting water samples to ensure that it is truly representative of the source and that it is handled in such a way that it does not deteriorate or become contaminated before analysis. In general, the suggested maximum time as reasonable for samples for physical and chemical analysis is 72 hours for unpolluted water, 48 hours for slightly polluted water and 12 hours for polluted water. When taking water from a tap, the nozzle should be clean and the tap opened for a few minutes to waste before filling the bottle. Samples from wells/boreholes should be collected after they have been pumped for a sufficient time to ensure that the sample will represent the composition of the ground water which feeds the well. When sampling for a river/stream, samples are best taken from the middle and at mid depth because analytical values vary with depth, stream flow and distance from the shore and from one shore to another.

Several attempts have been made to classify water quality using different approaches. Water quality index (WQI) is a dimensionless number that combines multiple water quality factors into a single number to show the overall rating of the water. It is a simple indicator of water quality and gives the public a general idea on the possible problems with a water sample. Some common water quality indices are the US National Sanitation Foundation Water Quality Index – NSFWQI (Brown et al., 1972), Canadian Council of Ministers of the Environment Water Quality Index – CCMEWQI (CCME, 2001), British Columbia Water Quality Index – BCWQI, and Oregon Water Quality Index – OWQI (Debels et al., 2005; Kannel et al., 2007; Abbasi, (2002). Factors included in WQI vary depending upon the designated water uses of the water body and local preferences. The Heber water quality index (HWQI-1) developed by the Bishop Heber College is based on a statistical approach (Rajendran et al., 1998). The limitation of this approach is its use of a limited number of water quality parameters viz: temperature, turbidity, total solids, dissolved oxygen, bio-chemical oxygen demand (BOD), pH, nitrate, phosphate, and fecal coliform. Though these parameters are indicative of one form of pollution or the other, the possibility of a wide range of pollutants as well as emerging pollutants presents an increased probability of narrow assessment.

The British Columbia water quality index reduces technical water quality information to a simple description of the state of water quality. The Index is based on the attainment of water quality objectives. The CCME (Canadian Council of the Ministers of Environment) Water Quality Index (1.0), also known as the Global Water Quality Index, is a modification of the British Columbia Water Quality Index (CCME, 2001). Other less popular water quality indices are: the Centre St Laurent (CSL) of Environment Canada; the Quebec index based on an approach originally developed in New Zealand; Alberta Water Quality Index. The CCME water quality index was adopted for this study.

Methodology

The summary of the methodology applied in this research is as follows: (i) collation of drinking water quality standards in five countries of each of the continents of Africa, Asia, Europe, North America and South America. (ii) streamlining/trimming of water quality parameters in order to achieve homogeneity of parameters, (iii) obtaining of result of water quality monitoring exercise, (iv) application of the CCME water quality index calculation on the parameters, using each country's standard and (v) modification of the CCME water quality index. Table 1 gives a summary of the parameters used as well as their health effects, detection limits, methods of analysis, apparatus and toxicity concentration.

Table 1: Important information about selected parameters

S/ No.	*Parameters*	*Toxicity/Health effect*	*Detection limit (mg/l)*	*Apparatus/Equipment used*	*Method of analysis*	*Toxicity conc. (mg/l)*
1	Aluminium	Current weight of evidence does not indicate adverse health effects at levels found in drinking water	0.05	Varian Vista ICP-AES (Inductively coupled plasma atomic emission spectroscopy)	Measured by a range of methods: ion chromatography, colorimetry, ICP-MS, ICP-AES, flame ASS, graphite furnace ASS, or cold vapour generation AAS methods.	0.2
2	Antimony	Microscopic changes in organs and tissues (thymus, kidney, liver, spleen, thyroid)	0.001	HP4500 ICP-MS (Inductively coupled plasma mass spectrometry)	Same as above	0.02
3	Arsenic	Cancer (lung, bladder, liver, skin) (classified as human carcinogen). Skin, vascular and neurological effects (numbness and tingling of extremities)	0.001	HP4500 ICP-MS (Inductively coupled plasma mass spectrometry)	Same as above	0.01
4	Barium	Increases in blood pressure, cardiovascular disease	0.01	Varian Vista ICP-AES (Inductively coupled plasma atomic emission spectroscopy)	Same as above	0.7
5	Boron	Reproductive effects (testicular atrophy, spermatogenesis). Limited evidence of reduced sexual function in men	0.05	Varian Vista ICP-AES (Inductively coupled plasma atomic emission spectroscopy)	Same as above	2.4
6	Bromate	Renal cell tumours (classified as probable carcinogen)	0.05	Dionex DX-120 IC (Ion chromatograph)		0.01
7	Cadmium	Kidney damage and softening of bone	0.0001	HP4500 ICP-MS (Inductively coupled plasma mass spectrometry)		0.003
8	Calcium hardness ($CaCO_3$)	Although hardness may have significant aesthetic effects, a guideline has not been established because public acceptance of hardness may vary considerably according to the local conditions; major contributors to hardness — calcium and magnesium — are not of direct public health concern	1	Calculation	Acidity and alkalinity method 2310 B and 2320 B (APHA, 1998). Also in accordance with AS 3550.3:1992	200
9	Chlorine	Guideline value not necessary due to low toxicity at concentrations found in drinking water	1	Dionex DX-120 IC (Ion chromatograph)		5

Table 1 (*Contd.*)

S/ No.	*Parameters*	*Toxicity/Health effect*	*Detection limit (mg/l)*	*Apparatus/Equipment used*	*Method of analysis*	*Toxicity conc. (mg/l)*
10	Chloride	No health effect	1	Dionex DX-120 IC (Ion chromatograph)		250
11	Chromium	Enlarged liver, irritation of the skin, respiratory and gastrointestinal tracts from chromium (VI)	0.001	HP4500 ICP-MS (Inductively coupled plasma mass spectrometry)	Measured by a range of methods: ion chromatography, colorimetry, ICP-MS, ICP-AES, flame ASS, graphite furnace ASS, or cold vapour generation AAS methods.	0.05
12	Colour (TCU)	No health effect but may interfere with disinfection; removal is important to ensure effective treatment	2 TCU	TechniconAutoanalyser, Nesleriser, Hazen Colour Disc		15 TCU
13	Conductivity (µs/cm)	No health effect	5 (µs/cm)	PC-Titrate conductivity/pH/ Alkalinity system	Measured electrometrically with (or without) temperature compensation and is calibrated against a standard solution of potassium chloride. Measurement of Conductivity Method 2510 (APHA, 1998).	1500 (µs/cm)
14	Copper	Copper is an essential element in human metabolism. Adverse health effects occur at levels much higher than the aesthetic objective	0.001	HP4500 ICP-MS (Inductively coupled plasma mass spectrometry)	Measured by a range of methods: ion chromatography, colorimetry, ICP-MS, ICP-AES, flame ASS, graphite furnace ASS, or cold vapour generation AAS methods.	2
15	Cyanide	No clinical or other changes at the highest dose tested		HP4500 ICP-MS (Inductively coupled plasma mass spectrometry)		0.07
16	Flouride	Moderate dental fluorosis (based on cosmetic effect, not health)	0.01	Dionex DX-120 IC (Ion chromatograph)		1.5
17	Iron	No health effect but based on taste and staining of laundry and plumbing fixtures; no evidence exists of dietary iron toxicity in the general population	0.01	Varian Vista ICP-AES (Inductively coupled plasma atomic emission spectroscopy)	Measured by a range of methods: ion chromatography, colorimetry, ICP-MS, ICP-AES, flame ASS, graphite furnace ASS, or cold vapour generation AAS methods.	0.3
18	Lead	Biochemical and neurobehavioural effects (intellectual development, behaviour) in infants and young children (under six years). Other: Anaemia, central nervous system effects; in pregnant women, can affect the unborn child; in infants and children under six years, can affect	0.001	HP4500 ICP-MS (Inductively coupled plasma mass spectrometry)	Same as above	0.01

Table 1 (*Contd.*)

		intellectual development, behaviour, size and hearing; classified as probably carcinogenic to humans				
19	Magnesium	Guideline value not necessary, as there is no evidence of adverse health effects from magnesium in drinking water	1	Varian SpectrAA 220-FS	Same as above	
20	Manganese	No health effect but based on taste and staining of laundry and plumbing fixtures	0.01	Varian Vista ICP-AES (Inductively coupled plasma atomic emission spectroscopy)	Same as above	0.4
21	Mercury	Irreversible neurological symptoms	0.0001	CETAC M6000A	Same as above	0.006
22	Nickel		0.01	Varian Vista ICP-AES (Inductively coupled plasma atomic emission spectroscopy)	Same as above	0.07
23	Nitrate (as NO_3^-)	Methaemoglobinaemia (blue baby syndrome) in infants less than three months old (short term). Classified as possible carcinogen	0.05	Dionex DX-120 IC (Ion chromatograph)	Filtered sample is placed into a different sample bottle, after rinsing. Ensure sample bottle is pre-rinsed three times with filtered sample water (3 × 20 mL) before final collection. Automated cadmium reduction method 4500-NO_3^- F (APHA, 1998)	50
24	Nitrite	Methaemoglobinaemia (blue baby syndrome) in infants less than three months old (short term). Classified as possible carcinogen	0.05	Dionex DX-120 IC (Ion chromatograph)	Same as above	3
25	Odour	Important to provide drinking water with no offensive odour, as consumers may seek alternative sources that are less safe		Clean odour-free glassware		
26	pH	No health effect but it can influence the formation of disinfection by-products and effectiveness of treatment		PC-Titrate Conductivity/pH/ Alkalinity system	pH is measured electrochemically using a combination electrode (glass plus reference electrode) and is calibrated against two or three commercially available buffer solutions. Electrometric method for pH value analysis 4500-H+ B (APHA, 1998)	8.5
27	Selenium	Essential nutritional element. Hair loss and weakened nails at extremely high levels of exposure		HP4500 ICP-MS (Inductively coupled plasma mass spectrometry)	Measured by a range of methods: ion chromatography, colorimetry, ICP-MS, ICP-AES, flame ASS, graphite furnace ASS, or cold vapour generation AAS methods.	0.04

Table 1 (*Contd.*)

S/ No.	*Parameters*	*Toxicity/Health effect*	*Detection limit (mg/l)*	*Apparatus/Equipment used*	*Method of analysis*	*Toxicity conc. (mg/l)*
28	Sulphate	High levels (above 500 mg/L) can cause physiological effects such as diarrhoea or dehydration	0.05	Dionex DX-120 IC (Ion chromatograph)		250
29	Sodium	No health effect but based on taste; where a sodium-based water softener is used, a separate unsoftened supply for cooking and drinking purposes is recommended	0.05	Varian SpectrAA 220-FS		50
30	Temperature (°C)	Temperature indirectly affects health and aesthetics through impacts on disinfection, corrosion control and formation of biofilms in the distribution system		Turbidimeter or pH meter	Meter should be kept in gentle motion through the water column while a reading is being taken. Allow several minutes for the reading to stabilise while a reading is being taken.	
31	Total Dissolved Solids	Based on taste; TDS above 500 mg/L results in excessive scaling in water pipes, water heaters, boilers and appliances; TDS is composed of calcium, magnesium, sodium, potassium, carbonate, bicarbonate, chloride, sulphate and nitrate	5	Calculation		600
32	Turbidity (NTU)	Indirect associations: particles can harbour microorganisms, protecting them from disinfection, and can entrap heavy metals and biocides; elevated or fluctuating turbidity in filtered water can indicate a problem with the water treatment process and a potential increased risk of pathogens in treated water.	0.1 NTU	HACH 2100N Turbidimeter	Meter should be kept in gentle motion through the water column while a reading is being taken. Allow several minutes for the reading to stabilise. Surface and deeper in clear waters to ensure that there is no influence from ambient light. Measurements using probes must be made at least 1 m below the water	5 NTU
33	Zinc	Water with zinc levels above the acceptability tends to be opalescent and develops a greasy film when boiled; plumbing should be thoroughly flushed before water is consumed	0.01	Varian Vista ICP-AES (Inductively coupled plasma atomic emission spectroscopy)	Measured by a range of methods: ion chromatography, colorimetry, ICP-MS, ICP-AES, flame ASS, graphite furnace ASS, or cold vapour generation AAS methods.	3

Computation of Water Quality Indices

The CCME approach uses three criteria to ascertain the level of water pollution. The first is the scope of exceedance (F_1), which represents the percentage of test parameters that exceed the standards of interest; the second is the frequency of exceedance (F_2), which represents the percentage of individual test that exceed the guideline; and the third is the amplitude of exceedance (F_3), which represents the degree by which individual test results exceed the standard of interest. This method of water quality rating requires that at least four parameters must be monitored in not less than four sampling exercises. This is referred to as the four–by–four rule. The computation of F_1 and F_2 is both straightforward and simple, but that is not the case with F_3 whose computation requires four steps.

$$F_1 = \frac{N_{fp}}{N_p} \times 100$$

$$F_2 = \frac{N_{ft}}{N} \times 100$$

where N_{fp} is number of failed parameters, N_p = number of parameters, N_{ft} = number of failed tests and N = total number of tests.

In order to facilitate the computation of F_3, the four steps have been aggregated into one step following the procedure below. The use of four steps makes F_3 computation cumbersome for a large number of parameters and sampling. In fact, Khan et al. (2005) observed that the computation of WQI is generally involving.

$$\text{Excursion} = \frac{X_f}{X_G} - 1 \qquad \text{Step 1}$$

where X_f is failed test value and X_G is guideline value for the parameter of interest.

$$\text{Sum of excursion} = \sum\left[\frac{X_f}{X_G} - 1\right]$$

$$\text{Sum of excursion} = \Sigma\frac{X_f}{X_G} - N_{ft} \qquad \text{Step 2}$$

N_{ft} = total number of failed tests for the parameter of interest

Normalized sum of excursion (NSE)

$$= \frac{1}{N}\left[\Sigma\frac{X_f}{X_G} - N_f\right]$$

$$\text{NSE} = \frac{1}{N}\Sigma\frac{X_f}{X_G} - \frac{N_f}{N} \qquad \text{Step 3}$$

Standardizing

$$F_3 = \frac{NSE}{0.01NSE + 0.01} = \frac{100\,NSE}{NSE + 1} \qquad \text{Step 4}$$

The above expression for F_3 is what is commonly used in water quality monitoring literature. But the computation of F_3 is cumbersome for a large pool of data, hence the need to re-write the expression for F_3 into a format that eases computation. Aggregating the above four steps into one homogenous expression gives:

$$F_3 = \frac{\left[\frac{1}{N}\Sigma\frac{X_f}{X_G} - \frac{N_{ft}}{N}\right]\times 100}{\frac{1}{N}\Sigma\frac{X_f}{X_G} - \frac{N_{ft}}{N} + 1}$$

$$F_3 = \frac{\left[\frac{1}{N}\Sigma\frac{X_f}{X_G} - \frac{N_{ft}}{N} - 1 + 1\right]\times 100}{\frac{1}{N}\Sigma\frac{X_f}{X_G} - \frac{N_{ft}}{N} + 1}$$

$$F_3 = \frac{\left[\frac{1}{N}\Sigma\frac{X_f}{X_G} - \frac{N_{ft}}{N} + 1 - 1\right]\times 100}{\frac{1}{N}\Sigma\frac{X_f}{X_G} - \frac{N_{ft}}{N} + 1}$$

$$= \left[\frac{\frac{1}{N}\Sigma\frac{X_f}{X_G} - \frac{N_{ft}}{N} + 1}{\frac{1}{N}\Sigma\frac{X_f}{X_G} - \frac{N_{ft}}{N} + 1} - \frac{1}{\frac{1}{N}\Sigma\frac{X_f}{X_G} - \frac{N_{ft}}{N} + 1}\right]\times 100$$

Simplifying by crossing out common terms, and multiplying the numerator and denominator of the second term by N, we have:

$$F_3 = \left[1 - \frac{N}{N - N_{ft} + \Sigma\frac{X_f}{X_G}}\right]\times 100$$

The above expression is for one parameter. Extending the above procedure to all parameters involved (i = 1 to N_p) and all tests (j = 1 to N).

$$F_3 = \left[1 - \frac{N}{N - N_{ft} + \sum_{i=1}^{N_P}\sum_{j=1}^{N}\frac{X_f}{X_G}}\right]\times 100$$

The above expression can further be simplified by dividing both numerator and denominator by N, and noting that

$$\frac{N-N_{ft}}{N}=1-\frac{N_{ft}}{N}=1-0.01F_2$$

$$F_3=\left[1-\frac{1}{1-0.01F_2+\frac{1}{N}\sum_{i=1}^{N_P}\sum_{j=1}^{N}\frac{X_f}{X_G}}\right]\times 100$$

Using the above expression, the computation of F_3 is very much simplified, with the aid of Microsoft Excel. The above simplification is peculiar to this research and can be generally applied to simplify the computation of WQI. The index produces a number between 0 (worst water quality) and 100 (best water quality). It is recommended that a minimum of four parameters sampled at least four times be used in the calculation of index values. It is also expected that the parameters and objectives chosen will provide relevant information about a particular site. The data for the comparative analysis was obtained from a water quality monitoring of boreholes in Eastern Obolo, IkotAbasi, IkotEkpene and Uyo local governments of AkwaIbom State, Nigeria. A total of thirty-three (33) physicochemical parameters and heavy metals were monitored. Parameters like colour, odour, temperature, turbidity, dissolved oxygen, pH, conductivity and total dissolved solids (TDS) were measured in situ at site using relevant meters.

Many countries do not have water quality guidelines for some parameters such as boron, bromate, nickel, nitrite, magnesium, cyanide, colour, potassium, sulphate and uranium. Due to this inconsistency, twenty-one (21) parameters common to all the standards were selected for the calculation of the water quality index (WQI). Overall water quality index was first computed using all the parameters. However, overall water quality index usually has the tendency to mask salient facts about water quality. In order to expose such hidden information, parameters were decomposed into three categories viz. acceptability, general health concerns and heavy metal toxicity. This also is unique to this research.

Results and Discussion

Since water quality index is a composite term that incorporates such factors as acceptability, health concerns and toxicity, it is necessary to decompose water quality parameters into these component parts with a view to ascertaining the relative performance of different water quality standards with respect to these factors. This is not an attempt to pass judgement on the status of any country's water standard. Khan et al. (2005) highlighted the need to revise water quality standards to reflect the naturally high (or low) site specific background concentrations of many pristine water bodies. However, this paper may be a guide to help some countries have a second look at their water quality standards. Moreover, very stringent water quality guidelines may be too idealistic for developing countries where quality standards are hardly adhered to and available water resources per capita is low. Effective water quality standards should satisfy the following requirements: (i) completeness, (ii) enforceability and (iii) protectiveness. Completeness has to do with the number of water quality parameters covered.

Reliability of water quality monitoring exercise increases with the number of parameters monitored and the frequency as well as the duration of monitoring exercise. The number of parameters covered in the water standards of various countries has been presented in Table 2. Enforceability has to do with the ability of relevant agencies to ensure that water supplied to the masses by either public or private water companies comply with stipulated guidelines. It also includes the availability of necessary mechanism such as water treatment facilities and pollution control measures that will ensure the protection of water resources. Protectiveness refers to the consumer safety consciousness inherent in the guidelines. The primary objective is to ensure that drinking water does not pose any threat to the lives of consumers.

Figure 1 shows the relative ranking of the drinking water standards of the twenty-five (25) countries (including the WHO) considered in this study. The values of water quality index obtained for a water sample using two different standards will vary, depending on the level of strictness or liberality of the standards. While a very liberal water quality standard may rate a water sample to be excellent (95–100%), a very strict water quality standard may rate the same water sample to be of fair (65–79%) or marginal (45–64%) quality. Hence Figure 1 is an indirect comparison of the liberality of the water quality standards of different countries. Higher values indicate liberality while low values signify strictness. Going by the overall water quality indices, Australia, UAE, India and Japan seem to have the most stringent drinking water standards; while Jamaica, Peru, Mexico and UAE seem to possess the most liberal drinking water quality standards. In Figure 1, higher WQI values represent liberal assessment of water quality which is

Table 2: Summary of guideline particulars of countries of interest

Country	*No of parameters*	*Agency*	*Guideline name*	*Year established*
Argentina		Ministry of Health of Argentina and Social Action	WHO guideline for Drinking Water	1994
Australia	56	National Health and Medical Research Council	Australian Drinking Water Guidelines	2004
Brazil	48	Ministry of Health		2004
Canada	98	Federal-Territorial-Provincial Committee on Drinking Water	Canadian Drinking Water Quality Guidelines	1968/2012
Cuba		The State and Environmental Protection Agency	EPA guideline for Drinking Water	
Ecuador		Ecuadorian Standardization Institute	Agua Potable. Requisitos	2010
England	44	UK Technical Advisory Group on the Water Framework Directive		1998
Germany	95		Germany Drinking Water Quality Guideline	
Ghana	48	Ghana Standard Board	Ghana Standard Board Limits for Drinking Water	2005
India	46	Bureau of Indian Standards	Drinking Water - Specification	1983
Italy		WHO drinking water standard	Drinking Water Quality guideline	1983
Jamaica	82	National Water Commission		
Japan	56	Ministry of Health, Labour and Welfare	Waterworks Law, Drinking Water Quality standards	1958
Mexico		US Environmental Protection Agency	Drinking Water Quality in the US-Mexico Border Region	
Nigeria	42	Nigerian Council for Water Resources	Nigerian standard for drinking water quality	2005
Pakistan	48	Pakistan Standards Institute	Drinking Water Quality Guidelines and Standards	2002
Peru		Ministry of Health	Reglamento de la Calidaddel Aqua paraConsumoHumano	2010
Rwanda	75	Technical Committee on Environment, Health and Safety	Rwanda Water Standard	2009
S/Africa	42	Department of Water Affairs and Forestry	South African Water Quality Guidelines for Domestic Use	1996
Spain		International Water Association		
Sudan	42	The Government of Southern Sudan	-	2008
U.A.E	76	Regulation and Supervision Bureau		
U.S.A	62	Environmental Protection Agency	Water Quality Standard for North America	1975
Uruaguay		Ministry of Health		1994

indicative of liberal water quality guidelines. Hence, countries with higher WQI have less stringent standards than those with lower WQI values.

It can be seen that all 25 countries rated the water to be of a poor quality with different WQI values. Variations in the WQI values are as a result of difference in guideline values of different countries for the same parameter. For instance South Africa, WHO and Japan have a guideline value of 0.7 mg/l for barium, England and Canada have a value of 1.0 mg/l, while the USA has a value of 2.0 mg/l. The lower the guideline value, the more the excursion and hence the lower the WQI. This

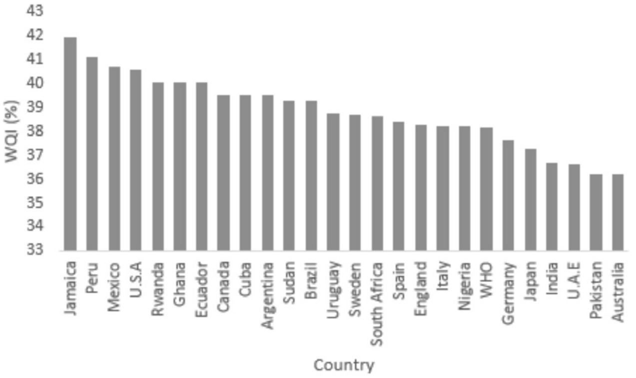

Figure 1: Overall water quality indices for all countries.

variation in guideline values results in differences in the number of failed parameters for different countries, thereby affecting the values of F_1 (scope of exceedence) and F_2 (amplitude or frequency of exceedence). Failed parameters are parameters that exceeded guideline values. There are seven failed parameters for the WHO, South African, Rwanda and Nigerian; eight failed parameters for Japan, Australia and Pakistan; and nine failed parameters for India. Discrepancies in WQI results can also differ as a result of the total number of tests that exceeded guideline values.

Figure 2 compares the acceptability water quality index (AWQI) with the overall water quality index (WQI) shown in Figure 1. Figure 2 was obtained by computing water quality index with only those parameters that affect acceptability, and excluding those relating to health and toxicity. The degree of variation between the acceptability water quality index (AWQI) and the overall water quality index (WQI) indicates to what extent acceptability parameters influence water quality index. The more the difference between the two, the less the effect. Based on this, it can be seen that for countries such as Australia, Sudan, Pakistan, Italy and Nigeria, overall water quality indices are least influenced by acceptability parameters, compared to other countries. The percentage difference between the AWQI and WQI values of these countries are the least compared to other countries (49.2%, 48%, 47%, 46.5% and 46.5% respectively). While for countries such as USA, Germany, Sweden, India (including WHO), overall water quality indices are substantially influenced by acceptability parameters. The percentage difference between the AWQI and WQI values of these countries (31.1%, 34%, 34.4% and 39.6% respectively) have the least values compared to other countries. This implies that these countries place a relatively high premium on acceptability parameters.

The differences in acceptability WQI values of different countries were not so much due to: (i) reduced number of parameters used, (ii) less number of failed parameters and (iii) reduced number of failed tests. Figure 2 is very instructive. It shows that a lumped or composite water quality index as shown in Figure 1 does not contain all the information needed to draw conclusions on the actual quality of water samples. Figure 2 shows that India, Sweden, USA and Germany (including WHO) ranked the water samples as fair (65–79%) in terms of acceptability while all the other countries ranked them as marginal (45–64%). Comparing acceptability water quality indices with the overall water quality indices reveals that acceptability parameters have a tendency to boost the overall water quality indices, hence giving a false assessment of water quality.

A water sample may be heavily polluted and yet appear clean. Acceptability parameters are parameters that will provide assessment of the public's perception of the quality of water, rather than specific health issues. They are parameters that may cause unacceptable taste or odour; or outright objection by consumer even before the water is consumed. Acceptability parameters have no health implications for water consumers; they only affect the readiness of consumers' acceptance. Hence, in order to perform a comprehensive water quality assessment, water quality indices should be calculated for all aspects of concern. For drinking water, water quality assessment should be performed for acceptability, health concerns and toxicity in order to uncouple the interaction between these factors which often lead to a false assessment. It may be necessary to downplay acceptability criteria (parameters) in areas and periods of water stress, since the primary objective of water supply is to provide adequate safe water to consumers. In such areas, water quality should be assessed based on health and toxicity criteria.

For health concerns, parameters were chosen that will provide a more objective assessment of water quality as it includes only parameters that have the potential to result in adverse health effects in humans. It can be seen, from Figure 3, that all the 25 countries including WHO rated the water to be of a poor quality (33% ≤ WQI ≤ 40%). The differences in WQI results are not so much but there are still variations in countries' parametric limit which leads to different WQI result for each country. Sudan and Cuba have 0.005 mg/l as the limit for cadmium, while Japan has 0.01 mg/l as its limit. The number of failed parameters for each country ranges between 4 and 6. From the analysis carried

Figure 2: Water quality indices for acceptability.

out, the water test result exceeded four parameters for Brazil, Peru and Argentina. Five parameters exceeded the WHO, Cuba, Sudan, England and Italian standard. India, Australia and Pakistan had six parameters that exceeded the limits.

From Figure 3, it can be seen that health parameters are the most important determinants of water quality index. The percentage difference between the health water quality index (HWQI) and WQI ranges from approximately zero for Sudan, Ghana and Rwanda to approximately 7% for Jamaica, Australia, Japan and UAE. A careful examination of these results shows that for most countries, health parameters affect water quality index as much as ten times as acceptability parameters.With respect to health concern, it appears that Australia, Pakistan, UAE, Japan, India, Germany and England have the most stringent guidelines, while Rwanda, Ghana, Peru, Sudan, Ecuador and USA have the most liberal guidelines. As can be seen from Figure 3, for countries such as Sudan, Ghana, Rwanda, Argentina, Sweden and Ecuador, health parameters do not have much influence on the overall water quality index. It is obvious that water from a particular source will be perceived to be of varying qualities by different countries' water guidelines. This is a pointer to the serious disparity in water quality guidelines as a result of specific concerns of individual countries. Countries under severe water stress may downplay certain parameters that have no effect on the wellbeing of consumers (acceptability for instance) and focus on health and toxicity parameters. This is why it is almost impracticable for developing countries to adopt WHO guidelines or those of developed countries without adequate measures and commitment to enforce these guidelines.

For toxicity, it can be seen that all the 25 countries including the WHO rated the water to be of poor quality (27% ≤ WQI ≤ 40%). From Figure 4, Rwanda with the highest WQI value is not severe in ranking the water quality when compared with Australia, the country with the strictest ranking. In the rating of the countries strictness, Sudan is the weakest while Australia is the strictest. Countries like Germany, Pakistan and Argentina are a little bit liberal with respect to toxicity limit; while Spain, Nigeria and England are also strict.

In order to assess the performance of countries' drinking water quality standards with respect to the WHO guidelines, the deviations from WQI obtained using WHO standards were calculated. In this analysis, WHO standards were used as benchmark. The plots are shown in Figure 5. Negative deviations imply less stringent guidelines than those of the WHO, while positive deviations imply more stringent guidelines than those of the WHO. Figure 5a shows that England, Italy, Nigeria and Spain have very little or no deviations from WHO guidelines for overall water quality index. It is known that some countries, for instance Nigeria, developed their water quality standards by partly or wholly adopting the WHO guidelines. Australia, Pakistan, UAE, India, Germany and Japan have the highest positive deviations from the WHO guidelines. This implies that these countries have more stringent

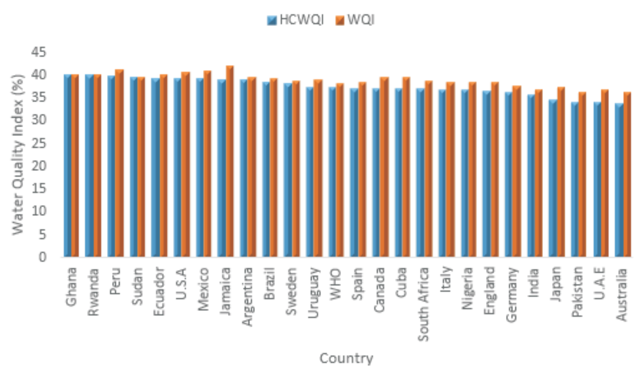

Figure 3: Water quality indices for health.

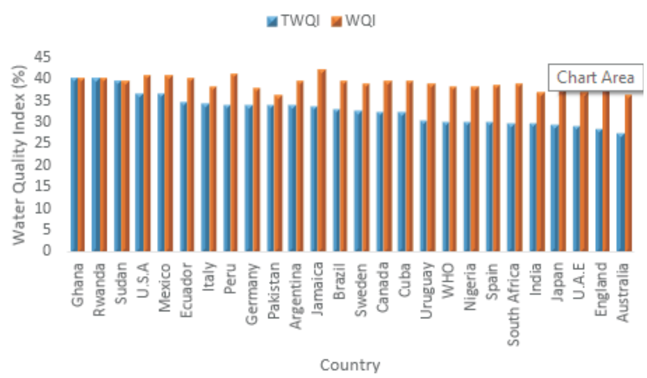

Figure 4: Water quality indices for heavy metal toxicity.

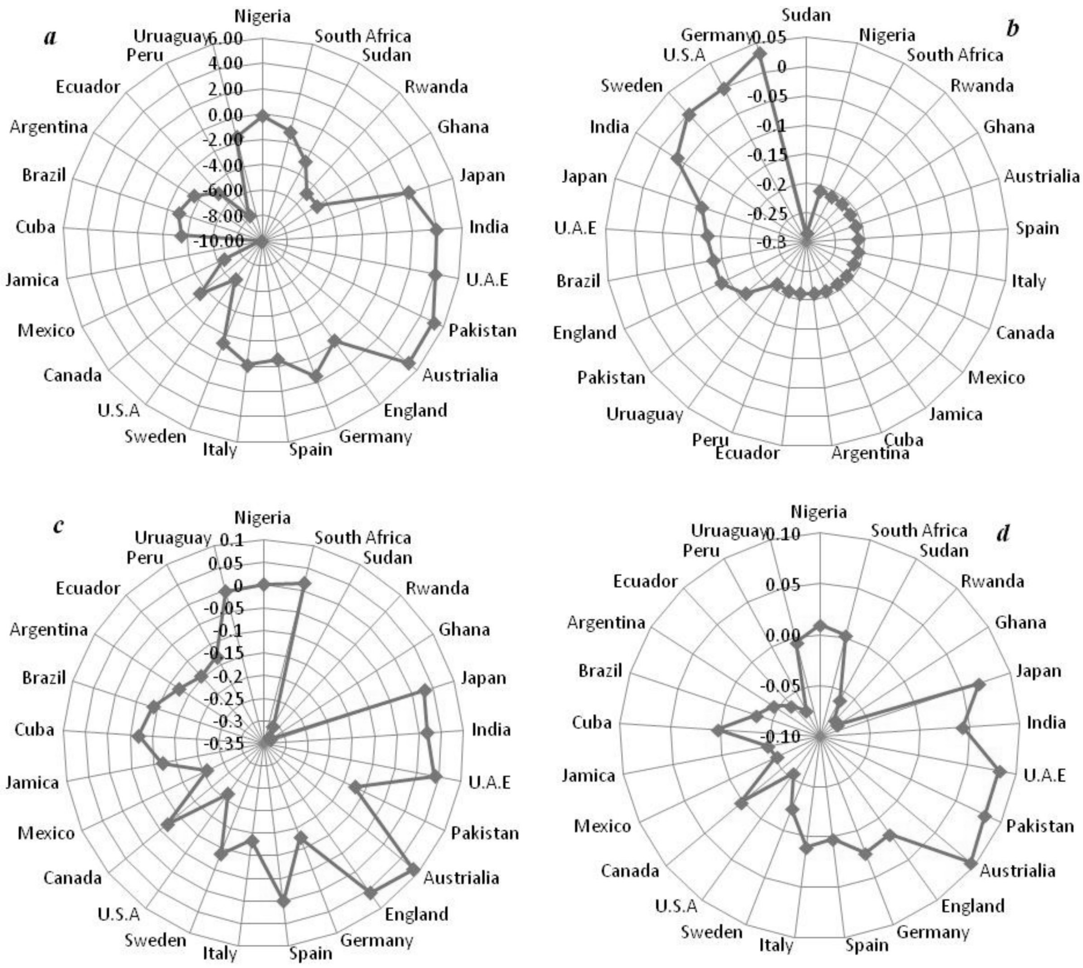

Figure 5: Deviation of WQI using countries, standards from WHO WQI: (a) overall WQI, (b) acceptability, (c) Heavy metal toxicity and (d) health concern.

guidelines than the WHO. Countries such as Jamaica, Peru, USA, Mexico, Ecuador, Rwanda and Ghana have the most negative deviations from the WHO guidelines. The explanation for these variations can be seen in Figures 5a to 5d. Figure 5b shows that the USA and Sweden totally agree with the WHO on acceptability. Germany (a developed country) has the most stringent guidelines for acceptability while Sudan (a developing country) has the least stringent guideline for acceptability parameters.

From this analysis, it appears that most developed countries set very high standards for acceptability parameters, while the reverse is the case for developing countries. The reasons for this are not farfetched. Developed countries have the resources and technology to provide clean, potable water for their citizens. Moreover, these countries have much higher GDP per capita. The result is that citizens can afford to be more selective of the water they drink. They can also afford to pay higher prices for good drinking water than their counterpart in developing countries. Figure 5c shows that Nigeria, Uruguay and Spain agree with WHO guidelines on health parameters. On the other hand, Australia, England, Japan, UAE, India, Spain and South Africa have higher guidelines for health parameters than the WHO.

The major deficiency of CCME WQI is that it assigns equal weight (importance) to all parameters.The fact that WQI for acceptability (AWQI) values are nearly twice as high as the water quality index for health (HWQI), indicates that water that is generally acceptable to people may not necessarily be safe. Hence the need to assign appropriate weights to each component of the WQI. Based on the foregoing argument, we have modified the CCME WQI to objectively reflect the different degrees of importance associated with the acceptability, health and toxicity components. In order to arrive at empirically correct weights for the three components of interest, first we took the means of the percentage differences between the WQI and the three components (AWQI, HWQI and TWQI). The average percentage difference obtained are 42.871, 3.868 and 15.626 for AWQI, HWQI and TWQI respectively.

It has earlier been observed that the percentage difference between WQI and any of the components is inversely proportional to the degree of effect it has on the value of WQI. Hence, the inverse of the means were taken to reflect this fact and then the resulting values were divided by the smallest of them to obtain the appropriate weights. From the foregoing, acceptability has a weight of 1.00, health has a value of 11.08 and toxicity has a value of 2.74. The modified CCME WQI has been termed the Importance Averaged Water Quality Index (IAWQI) and is defined as

$$IAWQI = \frac{AWQI + 11.08\,HWQI + 2.74\,TWQI}{14.82}$$

where AWQI is the acceptability water quality index, HWQI is the health water quality index and TWQI is the toxicity water quality index.

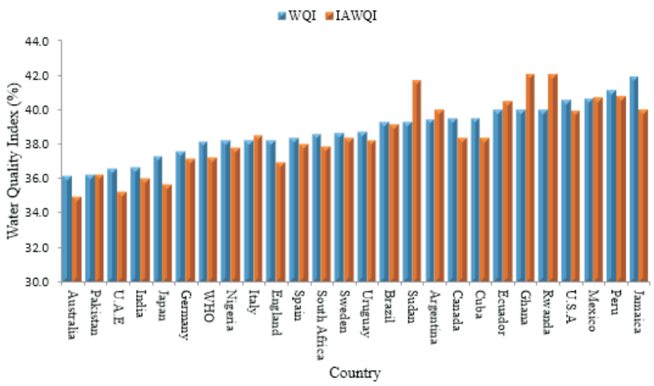

Figure 6: Comparison of WQI and IAWQI for various countries.

AWQI values plotted in Figure 6 show the effect of the importance weighting on water quality index. It can be seen that the CCME WQI generally overestimates the quality of water. This is clearly demonstrated by the fact that the IAWQI values are lower than the WQI values for most countries. The IAWQI values of countries such as Sudan, Ghana and Rwanda are much higher than their corresponding WQI values. Referring to Figure 7, these three countries located in Africa are among countries with the lowest water poverty indices (WPI). Water poverty index is a measure of water availability and its impact on human populations. (Lawrence et al., 2002). These countries are also among countries with the lowest Falkenmark Index of Water Stress (FIWS) which is a measure of water resources per capita per year (Lawrence et al., 2002). High IAWQI values is an indication of liberal water quality standards. It can also be seen from Figure 7 that WPI is negatively correlated with water standard liberality measured in terms of IAWQI. This can be interpreted to mean that countries under water stress adopt water quality standards which are more permissive than those of countries with adequate water resources. This they do by downplaying on certain parameters which they deem less important, or by not setting guideline limits for certain parameters.

In developing countries, people have little or no option but to accept water sources of doubtful quality, due to lack of better alternative sources or due to economic and technological constraints to treat the available water adequately before use (Calamari and Naeve, 1994; Aina and Adedipe, 1996). On the other hand, countries whose IAWQI values are less than their corresponding WQI values are countries that seem to have placed very high premium on acceptability

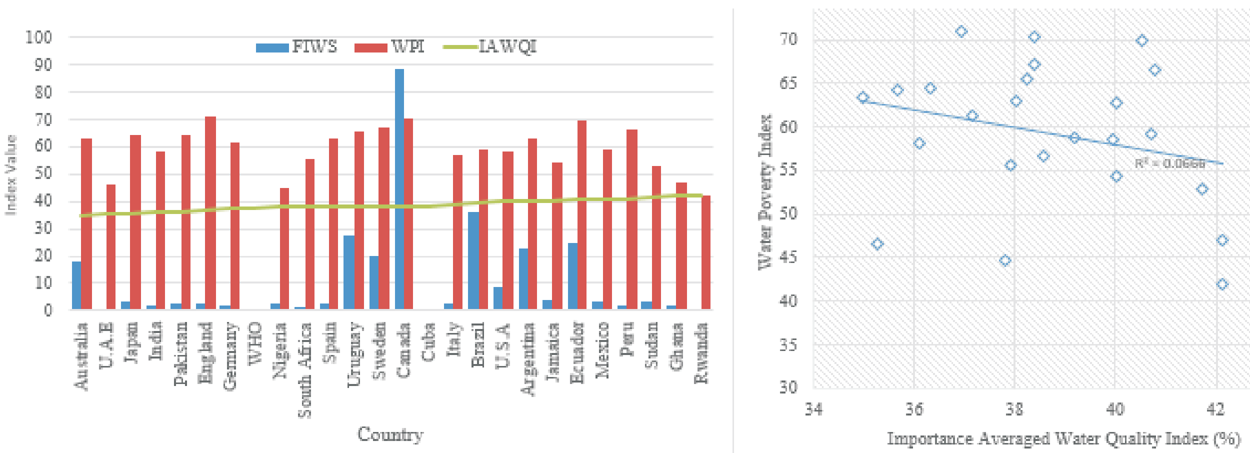

Figure 7: (a) Comparison of Falkenmark Index of Water Stress (FIWS), Water Poverty Index (WDI) and IAWQI as a measure of water standard liberality. (b) Correlation between WDI and water standard liberality (measured by IAWQI).

parameters, most likely as a result of abundant water resources coupled with requisite technology and policies to maintain high water quality. Figures 6 and 7 show that countries such as Canada, Uruguay, Sweden, Brazil and Australia fall within this category. These figures also show that countries such as UAE, Pakistan, Japan, India, Germany and Italy with the lowest IAWQI values seem to have stringent standards notwithstanding that they have very low water resources per capita.

Conclusion

It can be clearly seen that some countries like Jamaica, Peru and Mexico, amongst others are not strict in water analysis because of the toxicity limits set in some parameters in their standards and this affects the overall rating of the water sample. Countries like Japan, India, U.A.E, Australia, etc. have strict water quality standards despite limited water resources per capita per year. The breaking down of these general parameters into categories of acceptability, general health concerns and toxicity limits show the category of parameters that really affect the quality of the water sample. Acceptability limit parameters for the 25 countries gave the water a marginal and a fair rating, while general health concerns and toxicity limit gave it a poor rating. The CCME WQI is deficient in that it assigns equal importance to all parameters used in water quality assessment. The importance averaged water quality index (IAWQI) was introduced to overcome this deficiency. In general, each country has the responsibility of regulating her standards to the benefit of its citizens. Water quality standards have to be updated regularly to reflect prevailing situation.

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