A Comparative Appraisal of Water Resources Sustainable Development for African Urban Areas

Manouchehr Vaziri and Reza Tolouei

Abstract

Around the globe, the increasing use of water coupled with the environmental deterioration calls for sustainable development of the limited water resources. Indeed, the challenges of water resources sustainable development are enormous. Globally, some 1.1 billion people lack access to safe water and 2.6 billion lack access to safe sanitation when 1.7 million premature deaths are attributable to unsafe water, poor sanitation, and poor hygiene. A number of urban areas in Africa are currently facing a crucial shortage of freshwater that threatens public health and impedes social, environmental and economic development. As urbanization continues to increase, continuous, comprehensive, coordinated and cooperative water resources management is required for sustainable future of urban areas in Africa. The objective of this study was to assess water resources sustainable development for selected urban areas in Africa. Using centralized databases of international agencies, for the period of 1993 to 1998, urban information pertinent to water resources were collected, analyzed and modeled. The study database consisted of information regarding urban water accessibility, consumption, price, wastewater treatment, and other pertinent social, environmental and economic indicators. After preliminary evaluation of more than 150 cities in African region, due to data inaccessibility, incompleteness and missing, 39 cities were selected for detailed analysis. The statistical analyses for the selected cities showed interesting results and relations in connection with urban water resources sustainable development in different countries. For the period of 1993 to 1998, elasticity of database variables were developed. Using elasticity's, a composite urban water resources sustainability ranking was suggested. The developed elasticity's and composite rankings were used in taxonomy of the selected cities, and reflected considerable variations in urban water demand and supply development. As each urban area is unique in many historical, geographical, cultural, social, political, environmental and economic aspects, any comparative appraisal needs due considerations of local factors and issues. Nevertheless, the applied comparative appraisal methodology is suggested as a compliment to any other type of appraisal to enhance urban policies in support of sustainable urban water resources development. The study confirmed the significance of African urban areas water resources sustainability challenges of the 21st century.

Key words: Water resources management, sustainable development, water accessibility, water consumption, comparative analysis and evaluation.

Introduction

The last forty years of population, urbanization and economic growths have raised many concerns of undesirable socio-environmental impacts around the globe. The publication of “Our common future” known as Brundtland Report, introduced sustainable development as a key concept addressing the intimate relationships between economic activities and ecology. The Brundtland Report acknowledges that the basic needs of all people should be met with due consideration of future generations (World Commission on Environment and Development, 1987). The report emphasizes on inter and intra generational equitabilities, in the sense of fairness and sharing. Sustainable development favors solutions that effectively integrate economic, environmental and community considerations, and is expected to be one of the major challenges of 21st century. In the last two decades, it has become the development focus of the global community and increasingly has been discussed at different levels of many governments and civil societies. Consequently, a massive literature on sustainable development has grown up from the concerns about the relationships among economic activities, social aspects, and environmental considerations (Elliot 2001, Hardi, et. al. 1997, Moffatt, et. al. 2001, Vaziri and Rassafi 2001 & 2003).

The concepts of sustainable development for different sectors, such as water resources, are often derived from the Brundtland Report general terms. Water resources sustainable development implies provision of required water while protecting human health and the environment by optimal use of scares resources over a long-time perspective. Around the globe, the increasing use of water coupled with the environmental deterioration calls for sustainable development of the limited water resources. As a significant part of the world’s population still lacks access to safe water and adequate sanitation, and as global urbanization continues to increase, continuous, comprehensive, coordinated and cooperative water resources management is required at all levels for a sustainable future (Bossel 1999, Lundin, et. al. 1999, Morrison, et. al. 2001).

The challenges of water resources sustainable development are enormous in the African region. Countries are considered water scarce when annual internal renewable water resources are less than 1,000 cubic meters per capita per year. Below this threshold, water availability is considered a severe constraint on socioeconomic development and environmental quality. By 2020, it is likely that the number of water-scarce countries will approach 35, and the number of water-scarce African countries could double to 18 (Rosegrant and Perez 1997).

The objective of this study reported herein was to comparatively assess water resources sustainable development for selected urban areas in Africa during the last decade. Using centralized databases of international agencies, for the period of 1993 to 1998, urban information pertinent to water resources were collected, analyzed and modeled. The study database consisted of information regarding urban water accessibility, consumption, price, wastewater treatment, and other pertinent social, environmental and economic variables. Due to data incompleteness and missing values, and after several screening stages, only 39 urban areas were selected for detailed analysis. The subsequent analyses and modeling for the selected urban areas showed interesting results and relations in connection with water resources sustainable development. The study confirmed the significance of urban areas water resources sustainability challenges of the 21st century.

Database

To address sustainable development of urban water resources, relevant time-series water, social, environmental and economical information was gathered and analyzed. The limited study resources confined the data collection to information gathering from the international databanks (UN 2001, UN Habitat 2004, World bank 2002). The main encountered problem was the availability and accessibility to comparable water data on demand, supply, utilization and impacts at the urban level. After evaluation of the centralized and accessible time-series databases and their completeness, the limited study resources confined the study scope to preliminary selection of 151 urban areas and time-series period of 1993 to 1998. The selected urban areas were from 46 countries . The process of data refinement and reduction included several stages of univariate and multivariate statistical analyses, especially factor analysis. Due to time-series data incompleteness and missing values, and after several screening stages, only 39 urban areas from 32 countries were selected for detailed analysis for the period of 1993 to 1998. Table 1 shows the final study database structure and variable details.

Table 1. Description and structure of the study database variables

Category	No.	Name	Description
Water	1	WUHA	Urban households with access within 200 meter in %
	2	WUHC	Urban households with connection in %
	3	WUPR	Urban water price in $ per cubic meter
	4	WUCO	Urban daily consumption in liter per capita
	5	WUST	Urban water sewage treated in %
	6	WUHS	Urban households with sewage connection in %
Socio-demographic	7	SUPU	Urban population in thousand
	8	SUPH	Urban households below poverty line in %
	9	SUMF	Urban annual mortality rate for age 5 and below in %
	10	SNPG	National annual population growth in %
	11	SNPD	National population density in persons per square kilometer
	12	SNUP	National population in urban areas in %
Environmental	13	EUSR	Urban solid waste treated in %
	14	EUHE	Urban households with electric connection in %
	15	EUPE	Urban local environmental plans existed, zero or one
	16	EUPL	Urban local environmental plans institutionalized, zero or one
	17	EUPI	Urban local environmental plans implemented, zero or one
	18	ENEM	National annual CO2 emissions in metric tons per capita
Economical	19	CUCP	Urban city product in US $
	20	CUTC	Urban households with telephone connection in %
	21	CUDC	Urban disaster building code exited, zero or one
	22	CUDM	Urban hazard and disaster mapping exited, zero or one
	23	CUDI	Urban building disaster insurance exited, zero or one
	24	CNGD	National GDP in constant 1995 US $
	25	CNIF	Inflation, GDP deflator

The final study database consisted of 25 variables for 39 African urban areas for the period of 1993 to 1998. Due to inaccessibility to sufficient and relevant centralized data, 112 of originally selected 151 urban areas were dropped from detailed analysis. As Table 1 shows, there were 4 variable categories. The variable name is consisted of 4 digits, the first digit shows the category type, the second digit shows variable type, either urban or national, the third and forth digits reflect variable description. There were 19 cardinal and 6 nominal variables. The nominal variables were EUPE, EUPL, EUPI, CUDC, CUDM and CUDI, with the value of either zero or one.

The univariate statistical analysis of the database shed light on the database cross-sectional and time-series variability. The analysis covered computation of statistics such as minimum, maximum, mean, range, variance, standard deviation, coefficient of variation, kurtosis and skewness. Table 2 shows a summary of results of descriptive analysis.

Table 2. Descriptive analysis of the database variables

No.	Variable Name	Mean	Standard Deviation	Mean	Standard Deviation	Mean	Standard Deviation
		1993		1998		1993 to 1998	
1	WUHA	77.00%	19.73%	75.05%	23.22%	-4.50%	22.83%
2	WUHC	41.28%	24.14%	49.44%	24.18%	7.51%	17.34%
3	WUPR	$1.62	$3.55	$0.68	$0.75	-$1.13	$3.58
4	WUCO	58.99	35.40	54.61	48.11	-2.82	38.97
5	WUST	18%	33%	35.00%	34.12%	5.92%	18.31%
6	WUHS	18.46%	29.25%	36.52%	34.31%	8.44%	17.95%
7	SUPU	1169.75	1735.37	1259.47	2135.92	363.33	1352.62
8	SUPH	32.89%	18.42%	33.19%	17.25%	0.57%	20.21%
9	SUMF	10.62%	5.25%	13.99%	5.00%	4.08%	4.86%
10	SNPG	2.50	0.97	2.44	0.47	-0.05	0.94
11	SNPD	50.57	59.67	56.73	65.37	6.16	6.10
12	SNUP	31.28	14.79	34.52	15.76	3.24	1.46
13	EUSR	24.43%	36.94%	33.42%	36.12%	15.12%	34.58%
14	EUHE	48.15%	26.31%	57.18%	25.31%	6.46%	27.03%
15	EUPE	NA	NA	0.82	0.388776	NA	NA
16	EUPL	NA	NA	0.51	0.50637	NA	NA
17	EUPI	NA	NA	0.72	0.455881	NA	NA
18	ENEM	0.52	0.78	0.45	0.68	-0.06	0.21
19	CUCP	$949.75	$1,147.77	$632.49	$280.85	-$265.26	$934.34
20	CUTC	12.68%	9.67%	15.50%	13.54%	2.98%	10.00%
21	CUDC	NA	NA	0.59	0.49831	NA	NA
22	CUDM	NA	NA	0.49	0.50637	NA	NA
23	CUDI	NA	NA	0.56	0.502356	NA	NA
24	CNGD	5.30E+09	6.67E+09	6.37E+09	7.91E+09	1.07E+09	1.34E+09
25	CNIF	53.90	268.36	6.22	9.57	-47.68	266.87

For each of the 25 variables, the table shows the mean and standard deviation for 1993 and 1998, and the changes during the 5 years. Based on mean values, all cardinal variables showed growth during 1993 to 1998 except WUHA, WUPR, WUCO, SNPG, ENEM, CUCP and CNIF. The study database univariate analysis showed significant cross-sectional and time-series variations, as were reflected by means and standard deviations of Table 2. The time-series changes not supporting sustainability were related to variables WUHA, SUPH, SUMF and CUCP. Since for the nominal variables in environmental and economic categories, there was no information available for 1993, no statistics became available for their changes from 1993 to 1998, as shown by symbol "NA' in Table 2. Based on coefficient of variation, for both 1993 and 1998, for variable categories of water, social, environmental and economic, the highest variabilities were observed for WUPR, SNPD, ENEM and CNIF, respectively. For the changes from 1993 to 1998, for variable categories of water, social, environmental and economic, the highest variabilities were observed for WUCO, SUPH, EUHE and CNIF, respectively.

The mean and standard deviation of nominal variables reflect the significant concerns regarding environment and disaster mitigation by local governments since 1998. Urban environmental planning was implemented in 85% of the selected urban areas in 1998. Furthermore, local government disaster mitigation policies and activities exited for around 60% of the selected urban areas in 1998. These reflect significant attentions toward urban water resources sustainable development.

Correlation Analysis

To develop an understanding of the interrelationship among database variables, as a first, pair-wise correlation analysis for 1993, 1998 and the changes, was performed. The size of 75x75 correlation matrix prevented their display herein. Table 3 shows a summary of correlation analysis with respect to water variables.

Table 3. Correlation analysis of the database water variables

Variable	Correlated with variables	Variable	Correlated with variables	Variable	Correlated with variables
WUHA93	(+)EUHE93,EUHE98,ENEM93, ENEM98,CUCP93,CNGD93, CNGD98,CNGDΔ,WUHA98, WUHC93,WUHC98,WUCO93, WUCO98,WUST93,WUST98, WUHS93, WUHS98 (-)SUMF93	WUHA98	(+)EUHE98, CUCP93, WUHA93, WUHAΔ, WUHC93, WUHC98, WUPRΔ, WUST93, WUST98, WUHS93, WUHS98 (-)SUMF93, WUHCΔ, WUPR93, WUPR98	WUHAΔ	(+)SNPG93, EUHEΔ, CUDM98, WUHA98, WUPRΔ (-)SUPU93, SNPGΔ
WUHC93	(+)EUSR93, EUHE93, EUHE98, CUCP93, CUTC98, CNGD93, CNGD98, CNGDΔ, WUHA93, WUHA98, WUHC98, WUST93, WUST98, WUHS93, WUHS98 (-)SUMF93, SUMF98, SNPG98, EUHEΔ, ENEM93, ENEM98, WUHCΔ	WUHC98	(+)EUSR93, EUHE93, EUHE98, EUPI98, ENEM93, ENEM98, CUCP93, CUTC98, CUTCΔ, CNGD93, CNGD98, CNGDΔ, CINF98, WUHA93, WUHA98, WUHC93, WUCO98, WUST93, WUST98, WUHS93, WUHS98 (-)SUMF93, SUMF98, CUCPΔ	WUHCΔ	(+)EUHEΔ, CUTCΔ (-) EUHE93, WUHA98, WUST98
WUPR93	(+)WUPR98 (-)EUHE93, WUHA98, WUPRΔ	WUPR98	(+)SUMF93, WUPR93 (-)EUHE98, WUHA98	WUPRΔ	(+)SUPUΔ, WUHA98, WUHAΔ (-)SUMF93, WUPR93
WUCO93	(+) SUPH98, SUPHΔ, EUSR93, ENEM93, ENEM98, CUCP93, WUHA93, WUCO98,	WUCO98	(+)SUPHΔ, ENEM93, ENEM98, WUHA93,	WUCOΔ	(+)ENEM93, ENEM98, WUCO98 (-)EUSR93

	WUST93, WUST98, WUHS93 (-)CUDC98		WUHC98, WUCO93, WUCOΔ, WUST93, WUST98, WUHS93, WUHS98 (-)SUMF93, ENEMΔ		
WUST93	(+)EUSR93, EUHE98, ENEM93, ENEM98, CUCP93, CINF98, WUHA93, WUHA98, WUHC93, WUHC98, WUCO93, WUCO98, WUST98, WUHS93, WUHS98 (-)SUMF93, SUMF98, SNPG98	WUST98	(+)EUSR93 , EUHE93, ENEM93, ENEM98, CUCP93, WUHA93, WUHA98, WUHC93, WUHC98, WUCO93, WUCO98, WUST93, WUHS93, WUHS98 (-)SUMF93, SUMF98, SNPGΔ,	WUSTΔ	(+)CUCPΔ (-)SUPH93, CINF98
WUHS93	(+)EUSR93, EUHE93, EUHE98, ENEM93, ENEM98,, CUCP93, CNGD93, CNGD98, CNGDΔ, CINF98, WUHA93, WUHA98, WUHC93, WUHC98, WUCO93, WUCO98, WUST93, WUST98, WUHS98 (-)SUMF93, SUMF98, SNPG98, CUCPΔ, CINF93	WUHS98	(+)EUSR93 , EUHE93, ENEM93, ENEM98, CUCP93, CUTC98, CNGD98, CNGDΔ, CINF98, WUHA93, WUHA98, WUHC93, WUHC98, WUCO98, WUST93, WUST98, WUHS93 (-)SUPUΔ, SUMF93, CUCPΔ	WUHSΔ	

The correlation matrix revealed a number of interesting patterns and was found useful in subsequent analyses and modeling. Many pairs of variables were found correlated at a level of significance 0.05. Based on the 75x75 correlation matrix, on the average, a water variable was positively, 15.11%, and negatively, 4.18%, significantly correlated with the other variables. In Table 3 each variable is shown by an index reflecting the year or the changes. The water variables showed significant positive correlations with social variables, 0.55%, economic variables, 3.55%, water variables 8.01%, and environmental variables, 3%, respectively. They showed significant negative correlations with social variables, 2.18%, water variables, 0.91%, economic variables, 0.73%, and environmental variables, 0.36%, respectively

Elasticity Analysis

As a preliminary exploration into water resources sustainability, elasticity of water variables with respect to social, environmental and economic variables was developed. The elasticity E of a variable Y with respect to a variable X for the period t1-t2 reflects the percent variable Y changes with respect to one percent change of the variable X as is shown by Equation 1:

$$E_{Y/X,t1\text{-}t2} = [(Y_{t2} - Y_{t1})/(Y_{t2} + Y_{t1})] / [(X_{t2} - X_{t1})/(X_{t2} + X_{t1})] \quad (1)$$

Where $E_{Y/X,t1\text{-}t2}$ is the arc elasticity of variable Y with respect to variable X during the period t1 to t2. When the difference between t1 and t2 gets very small, the arc elasticity converges to point elasticity. For each of the 39 urban areas, based on non-missing values, a maximum of 6x19=114 elasticities for the period of 1993 to1998 were computed. For Equation 1, Y's were water variables, and X's were the cardinal social, environmental and economic variables. The nominal variables of EUPE, EUPL, EUPI, CUDC, CUDM and CUDI were excluded from elasticity development. The descriptive analysis of the 114 elasticity's showed several interesting results. After their careful evaluations and consideration of missing values and correlation matrix, 36 elasticity's were selected for further analysis. For the selected elasticity's, Y's were variables WUHA, WUHC, WUPR, WUCO, WUST and WUHS, and X's were variables SUPU, SUPH, EUSR, ENEM, CUCP and CNGD. The results of descriptive analysis for the 36 elasticity's are summarized in Table 4.

The elasticity's showed significant variations reflected by observed means and standard deviations. The highest variation in each of the tripartite categories of social, environmental and economic, based on coefficient of variations, were observed for $E_{WUPR/SUPH}$, $E_{WUHA/ENEM}$ and $E_{WUCO/CNGD}$, respectively. Each of the developed elasticity's represented a unique facet hinting on urban water resources sustainable development. They were found acceptable indicators for sustainability appraisal addressing specific subjects pertinent to the involved pairs of variables. They offer a profile for each urban area that could be used in monitoring and control of sustainable development. To support sustainability, increase of WUHA, WUHC, WUST and WUHS elasticity's was found more desirable.

Development of elasticity's provided a base to further develop individual and composite sustainability rankings. As social, environmental and economical are the major tripartite dimensions of sustainability, for urban areas in each group individual rankings and a composite ranking was developed for comparative analysis. Several classifications were developed, using different combinations of water variables and cardinal variables of the triple groups.

Table 4. Descriptive analysis of selected elasticity's

Elasticity	Mean	Standard deviation	Elasticity	Mean	Standard deviation	Elasticity	Mean	Standard deviation
$E_{WUHA/SUPU}$	0.12	1.43	$E_{WUHA/EUSR}$	-0.48	2.05	$E_{WUHA/CUCP}$	-0.85	2.42
$E_{WUHC/SUPU}$	1.49	3.18	$E_{WUHC/ EUSR}$	-0.35	1.80	$E_{WUHC/CUCP}$	0.07	1.27
$E_{WUPR/SUPU}$	-2.39	4.29	$E_{WUPR/ EUSR}$	-0.60	5.24	$E_{WUPR/CUCP}$	-2.37	7.62
$E_{WUCO/SUPU}$	-2.25	10.84	$E_{WUCO/ EUSR}$	-1.19	5.73	$E_{WUCO/CUCP}$	1.13	2.33
$E_{WUST/SUPU}$	-19.02	68.74	$E_{WUST/ EUSR}$	0.12	1.25	$E_{WUST/CUCP}$	-0.16	0.51
$E_{WUHS/SUPU}$	1.73	5.78	$E_{WUHS/ EUSR}$	0.05	0.86	$E_{WUHS/CUCP}$	2.82	1.95
$E_{WUHA/SUPH}$	0.10	1.32	$E_{WUHA/ENEM}$	-0.14	14.46	$E_{WUHA/CNGD}$	-1.13	3.01
$E_{WUHC/SUPH}$	0.09	1.98	$E_{WUHC/ENEM}$	-10.68	35.51	$E_{WUHC/CNGD}$	0.95	2.50
$E_{WUPR/SUPH}$	-0.03	3.74	$E_{WUPR/ENEM}$	-13.97	30.45	$E_{WUPR/CNGD}$	-2.80	6.96
$E_{WUCO/SUPH}$	0.29	2.03	$E_{WUCO/ENEM}$	-4.35	17.09	$E_{WUCO/CNGD}$	0.21	4.66
$E_{WUST/SUPH}$	4.94	9.75	$E_{WUST/ENEM}$	10.63	98.45	$E_{WUST/ CNGD}$	1.85	6.48
$E_{WUHS/SUPH}$	0.49	3.50	$E_{WUHS/ENEM}$	4.73	18.68	$E_{WUHS/CNGD}$	-1.67	9.57

The individual ranking of urban area for specific Y and X variables, $R_{Y/X}$, is developed by comparing the rate of changes in water variables with respect to rate of changes in social, environmental and economic variables, after due consideration of desirable sign for sustainability. For instance, in developing $R_{WUHA/SUPH}$, the urban areas for which relevant data is available are divided into four subgroups based on sign of changes in WUHA and SUPH variables. Subgroup 1 includes urban areas with positive sign in rate of changes in WUHA and negative sign in rate of changes in SUPH which form the most desirable subgroup in respect to sustainability, Subgroup 2 includes urban areas with positive sign in rate of changes in both WUHA and SUPH variables, Subgroup 3 includes urban areas with negative sign in rate of changes in both WUHA and SUPH variables and Subgroup 4 includes urban areas with negative sign in rate of changes in WUHA and positive sign in rate of changes in SUPH which form the most undesirable subgroup in respect to sustainability. Then the urban areas in each subgroup are ranked based on desirable percent changes in WUHA and SUPH variables to develop individual rankings. For better understanding of concept of individual rankings, a percentile ranking for each urban area which is a relative performance comparison to other urban areas, was developed using the following equation:

$$PR_{Y/X} = R_{Y/X} / (N+1) \quad (2)$$

Where $PR_{Y/X}$ is the percentile ranking of urban area for specific Y and X variables and N is the number urban areas for which relevant data is available. The lower the percentile ranking, the better the performance. For example, an African urban area with a percentile ranking of 10 performed better than 90 percent of its peer urban areas. Tables 5, 6, and 7 reflect individual rankings and percentile rankings for selected social, environmental and economic category variables, respectively. Unfortunately, lack of data for many urban areas prevented them from having individual rankings which are replaced by symbol "NA" in the tables.

Table 5. Individual rankings for selected social category variables

No.	Urban Area	WUHA/SUPH		WUHC/SUPH		WUST/SUPH		WUHS/SUPH	
		Ranking	Percentile Ranking	Ranking	Percentile Ranking	Ranking	Percentile Ranking	Ranking	Percentile Ranking
1	Accra	NA	NA	NA	NA	NA	NA	NA	NA
2	Addis Ababa	NA	NA	NA	NA	NA	NA	NA	NA
3	Antananarivo	19	86%	12	63%	NA	NA	6	46%
4	Bamako	2	9%	3	16%	NA	NA	10	77%
5	Bangui	17	77%	8	42%	4	40%	NA	NA
6	Banjul	10	45%	18	95%	NA	NA	9	69%
7	Bobo-Dioulasso	16	73%	10	53%	NA	NA	NA	NA
8	Brazzaville	12	55%	13	68%	NA	NA	8	62%
9	Bujumbura	11	50%	17	89%	5	50%	5	38%
10	Bulawayo	NA	NA	NA	NA	NA	NA	NA	NA
11	Conakry	3	14%	14	74%	NA	NA	3	23%
12	Cotonou	8	36%	9	47%	6	60%	2	15%
13	Dakar	18	82%	6	32%	2	20%	7	54%
14	Douala	5	23%	5	26%	9	90%	11	85%
15	Gaborone	20	91%	NA	NA	1	10%	NA	NA
16	Harare	NA	NA	NA	NA	NA	NA	NA	NA
17	Jinja	NA	NA	NA	NA	NA	NA	NA	NA
18	Kigali	7	32%	16	84%	3	30%	NA	NA
19	Kinshasa	1	5%	1	5%	NA	NA	NA	NA
20	Kisumu	NA	NA	NA	NA	NA	NA	NA	NA
21	Koudougou	NA	NA	NA	NA	NA	NA	NA	NA
22	Kumasi	6	27%	2	11%	NA	NA	NA	NA
23	Lagos	13	59%	NA	NA	NA	NA	NA	NA
24	Libreville	NA	NA	NA	NA	NA	NA	NA	NA
25	Lilongwe	NA	NA	NA	NA	NA	NA	NA	NA
26	Lome	NA	NA	NA	NA	NA	NA	1	8%
27	Maputo	NA	NA	NA	NA	NA	NA	NA	NA
28	Maseru	NA	NA	NA	NA	NA	NA	NA	NA
29	Mombasa	NA	NA	NA	NA	NA	NA	NA	NA
30	Monrovia	NA	NA	NA	NA	NA	NA	NA	NA
31	N'Djamena	NA	NA	NA	NA	NA	NA	NA	NA
32	Niamey	NA	NA	NA	NA	NA	NA	NA	NA
33	Nouakchott	21	95%	NA	NA	NA	NA	NA	NA
34	Ouagadougou	9	41%	15	79%	8	80%	NA	NA
35	Porto-Novo	4	18%	4	21%	NA	NA	NA	NA
36	Rabat	15	68%	11	58%	NA	NA	4	31%
37	Tunis	NA	NA	NA	NA	NA	NA	NA	NA
38	Windhoek	NA	NA	NA	NA	NA	NA	NA	NA
39	Yaounde	14	64%	7	37%	7	70%	12	92%

Table 6. Individual rankings for selected environmental category variables

No.	Urban Area	WUHA/EUSR		WUHC/EUSR		WUST/EUSR		WUHS/EUSR	
		Ranking	Percentile Ranking	Ranking	Percentile Ranking	Ranking	Percentile Ranking	Ranking	Percentile Ranking
1	Accra	NA	NA	NA	NA	9	56%	8	44%
2	Addis Ababa	18	62%	19	79%	NA	NA	16	89%
3	Antananarivo	NA	NA	NA	NA	NA	NA	NA	NA
4	Bamako	12	41%	10	42%	NA	NA	NA	NA
5	Bangui	24	83%	11	46%	8	50%	NA	NA
6	Banjul	7	24%	23	96%	NA	NA	17	94%
7	Bobo-Dioulasso	26	90%	8	33%	NA	NA	NA	NA
8	Brazzaville	23	79%	20	83%	NA	NA	5	28%
9	Bujumbura	6	21%	21	88%	6	38%	3	17%
10	Bulawayo	11	38%	13	54%	15	94%	11	61%
11	Conakry	2	7%	17	71%	NA	NA	1	6%
12	Cotonou	9	31%	9	38%	10	63%	9	50%
13	Dakar	28	97%	14	58%	14	88%	10	56%
14	Douala	3	10%	3	13%	12	75%	13	72%
15	Gaborone	NA	NA	NA	NA	NA	NA	NA	NA
16	Harare	NA	NA	NA	NA	NA	NA	NA	NA
17	Jinja	20	69%	5	21%	13	81%	2	11%
18	Kigali	14	48%	NA	NA	NA	NA	NA	NA
19	Kinshasa	10	34%	16	67%	NA	NA	NA	NA
20	Kisumu	NA	NA	NA	NA	NA	NA	NA	NA
21	Koudougou	NA	NA	NA	NA	NA	NA	NA	NA
22	Kumasi	1	3%	NA	NA	NA	NA	NA	NA
23	Lagos	NA	NA	NA	NA	NA	NA	NA	NA
24	Libreville	16	55%	2	8%	1	6%	NA	NA
25	Lilongwe	NA	NA	NA	NA	NA	NA	NA	NA
26	Lome	NA	NA	15	63%	NA	NA	12	67%
27	Maputo	22	76%	NA	NA	NA	NA	7	39%
28	Maseru	NA	NA	NA	NA	NA	NA	NA	NA
29	Mombasa	15	52%	NA	NA	11	69%	NA	NA
30	Monrovia	13	45%	NA	NA	NA	NA	NA	NA
31	N'Djamena	17	59%	1	4%	2	13%	NA	NA
32	Niamey	NA	NA	NA	NA	NA	NA	NA	NA
33	Nouakchott	21	72%	NA	NA	NA	NA	NA	NA
34	Ouagadougou	5	17%	22	92%	5	31%	NA	NA
35	Porto-Novo	8	28%	12	50%	NA	NA	NA	NA
36	Rabat	25	86%	7	29%	NA	NA	6	33%
37	Tunis	4	14%	18	75%	4	25%	15	83%
38	Windhoek	27	93%	6	25%	7	44%	4	22%
39	Yaounde	19	66%	4	17%	3	19%	14	78%

Table 7. Individual rankings for selected economical category variables

No	Urban Area	WUHA/CUCP		WUHC/CUCP		WUST/CUCP		WUHS/CUCP	
		Ranking	Percentile Ranking	Ranking	Percentile Ranking	Ranking	Percentile Ranking	Ranking	Percentile Ranking
1	Accra	NA	NA	NA	NA	NA	NA	NA	NA
2	Addis Ababa	NA	NA	NA	NA	NA	NA	NA	NA
3	Antananarivo	NA	NA	NA	NA	NA	NA	NA	NA
4	Bamako	NA	NA	NA	NA	NA	NA	NA	NA
5	Bangui	NA	NA	NA	NA	NA	NA	NA	NA
6	Banjul	NA	NA	NA	NA	NA	NA	NA	NA
7	Bobo-Dioulasso	NA	NA	NA	NA	NA	NA	NA	NA
8	Brazzaville	5	71%	6	86%	NA	NA	2	40%
9	Bujumbura	NA	NA	NA	NA	NA	NA	NA	NA
10	Bulawayo	4	57%	5	71%	4	80%	3	60%
11	Conakry	NA	NA	NA	NA	NA	NA	NA	NA
12	Cotonou	1	14%	1	14%	1	20%	1	20%
13	Dakar	NA	NA	NA	NA	NA	NA	NA	NA
14	Douala	NA	NA	NA	NA	NA	NA	NA	NA
15	Gaborone	NA	NA	NA	NA	NA	NA	NA	NA
16	Harare	NA	NA	NA	NA	NA	NA	NA	NA
17	Jinja	NA	NA	NA	NA	NA	NA	NA	NA
18	Kigali	3	43%	3	43%	2	40%	NA	NA
19	Kinshasa	NA	NA	NA	NA	NA	NA	NA	NA
20	Kisumu	NA	NA	NA	NA	NA	NA	NA	NA
21	Koudougou	NA	NA	NA	NA	NA	NA	NA	NA
22	Kumasi	NA	NA	NA	NA	NA	NA	NA	NA
23	Lagos	NA	NA	NA	NA	NA	NA	NA	NA
24	Libreville	NA	NA	NA	NA	NA	NA	NA	NA
25	Lilongwe	NA	NA	NA	NA	NA	NA	NA	NA
26	Lome	NA	NA	NA	NA	NA	NA	NA	NA
27	Maputo	NA	NA	NA	NA	NA	NA	NA	NA
28	Maseru	NA	NA	NA	NA	NA	NA	NA	NA
29	Mombasa	NA	NA	NA	NA	NA	NA	NA	NA
30	Monrovia	NA	NA	NA	NA	NA	NA	NA	NA
31	N'Djamena	NA	NA	NA	NA	NA	NA	NA	NA
32	Niamey	NA	NA	NA	NA	NA	NA	NA	NA
33	Nouakchott	NA	NA	NA	NA	NA	NA	NA	NA
34	Ouagadougou	NA	NA	NA	NA	NA	NA	NA	NA
35	Porto-Novo	2	29%	2	29%	NA	NA	NA	NA
36	Rabat	NA	NA	NA	NA	NA	NA	NA	NA
37	Tunis	NA	NA	NA	NA	NA	NA	NA	NA
38	Windhoek	NA	NA	NA	NA	NA	NA	NA	NA
39	Yaounde	6	86%	4	57%	3	60%	4	80%

Determining individual rankings, the composite ranking CR for each of the social, environmental and economical groups, was computed using the following equation:

$$CR_G = (\Sigma\ PR_{Y/X})\ /\ n \qquad (3)$$

Where CR_G is the composite ranking of group G, either social S or environmental E or economical C, and $PR_{Y/X}$ is the individual percentile ranking of urban area for specific Y and X variables, and n is the number of individual rankings based on the number of Y and X variables. In this analysis, the Y's were WUHA, WUHC, WUST and WUHS, and X's were SUPH, EUSR, and CUCP. Since monotonic increase of WUPR and WUCO could not always be related to sustainable development, they were excluded from CR development of equation 3. The composite ranking CR for each urban area is a ranking from 0-100 with zero reflecting the best ranking score and one hundred the worst ranking score. Figures 1 to 3 reflect the result of composite rankings for the three groups for the selected urban areas.

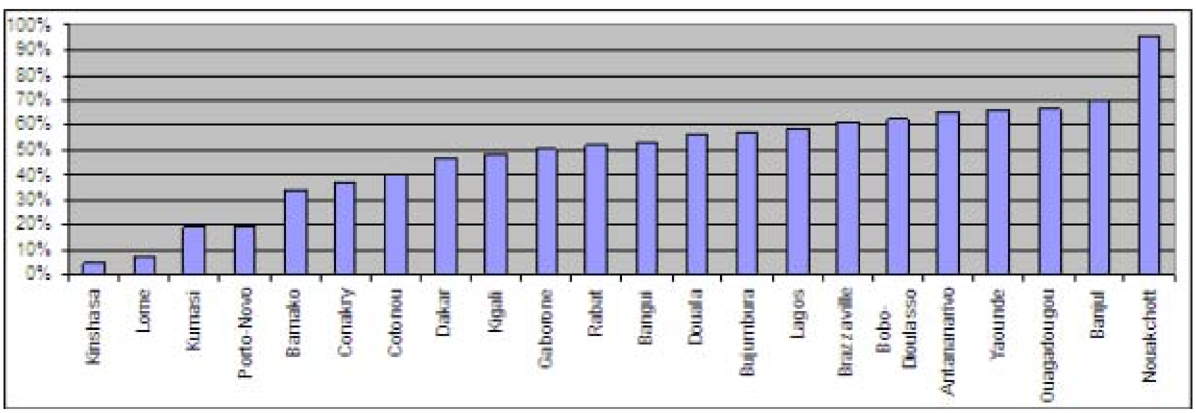

Figure 1. Composite ranking for social category, CR_S

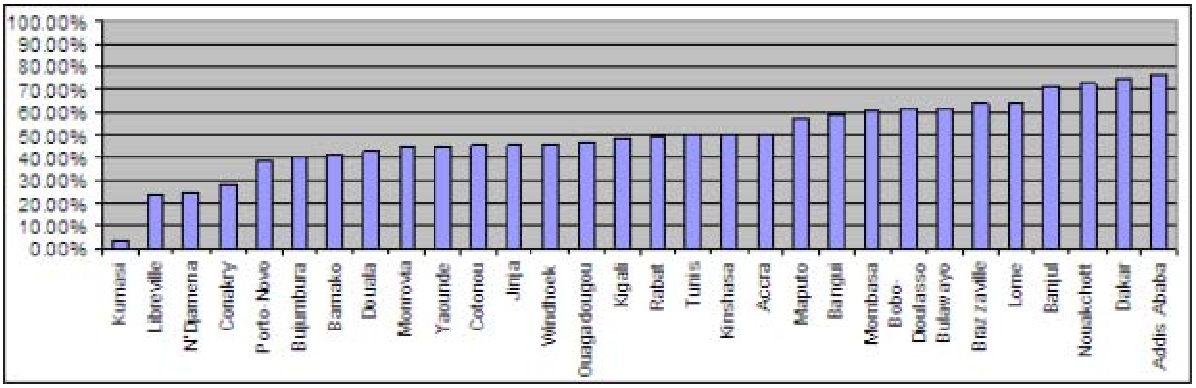

Figure 2. Composite ranking for environmental category, CR_E

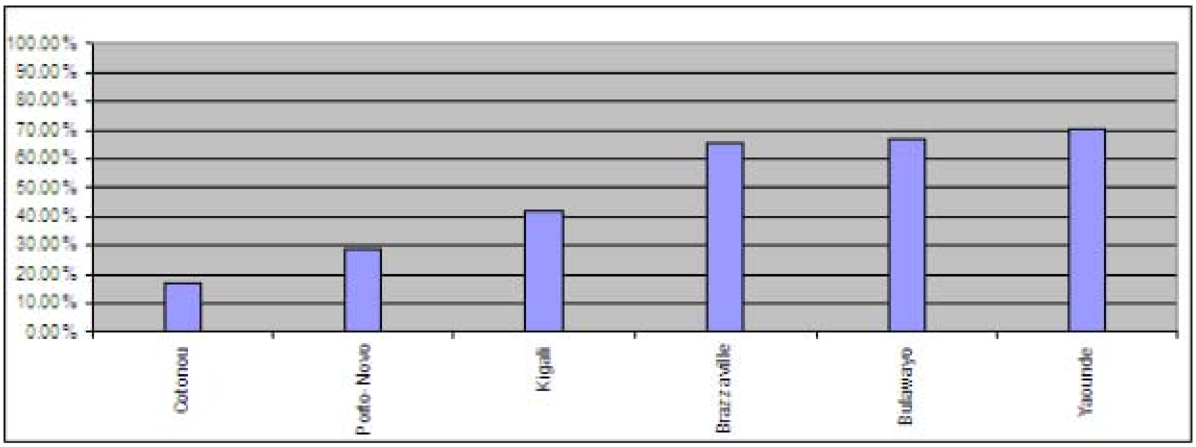

Figure 3. Composite ranking for economic category, CR_C

To develop an overall sustainability ranking, social, environmental and economic composite rankings were again aggregated as weighted combination:

$$OSR = (\beta_S CR_S + \beta_E CR_E + \beta_C CR_C) / (\beta_S + \beta_E + \beta_C) \quad (3)$$

Where OSR is the overall water resources urban sustainability ranking, β_S, β_E and β_C are the weighting factors of social, environmental and economical dimensions, respectively. Figure 4 shows the results of the above-mentioned computations, using equal weighting factors, $\beta_S = \beta_E = \beta_C$. The values for overall sustainability ranking should be interpreted in the context of comparative assessment.

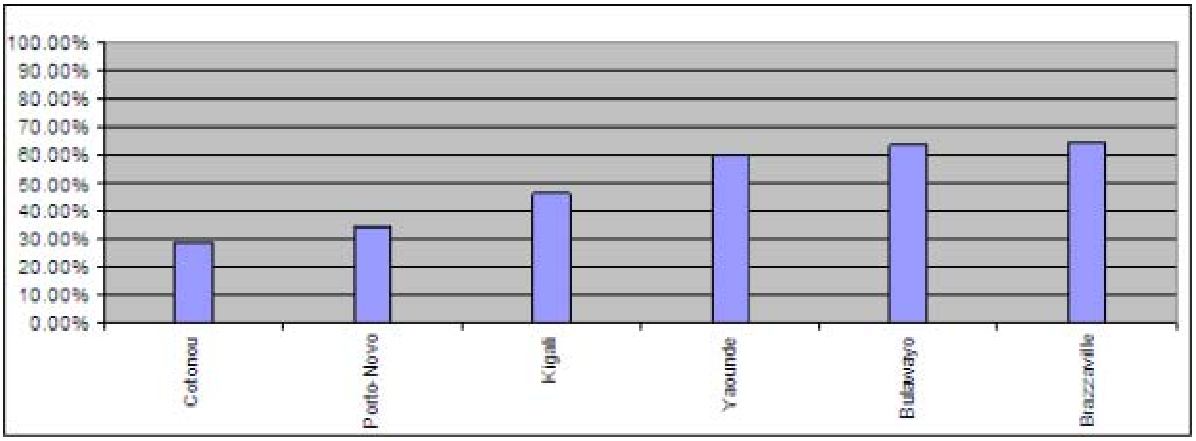

Figure 4. Overall sustainability ranking, OSR

Figure 1 to 4 summarize the composite and overall sustainability rankings of the selected urban areas. Due to missing values, among 39 urban areas, the number of ranked urban areas in social, environmental and economic groups were 22, 30 and 6, respectively. And as a consequence, only 6 overall sustainability ranking was developed and reflected in figure 4. The lowest and best $CR_{S,}$ CR_E and CR_C were for Kinshasa, Kumasi and Cotonou, respectively. Among the 6 ranked urban area, Cotonou, Porto-Novo and Kigali had the best three overall sustainability rankings. These urban areas can be used as show cases for learned lessons and good practices. Having the values of composite rankings in major tripartite dimensions of sustainability, urban water resources sustainability pyramids for each urban area can be developed. Water resources sustainability pyramids for the cities of Cotonou and Brazzaville, as examples, are shown in figure 5 and 6, with the zero value reflecting the best ranking in each dimension.

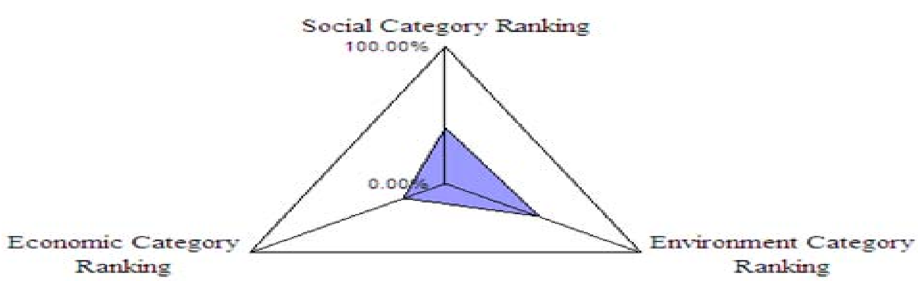

Figure 5 Urban water resources sustainability pyramid for Cotonou

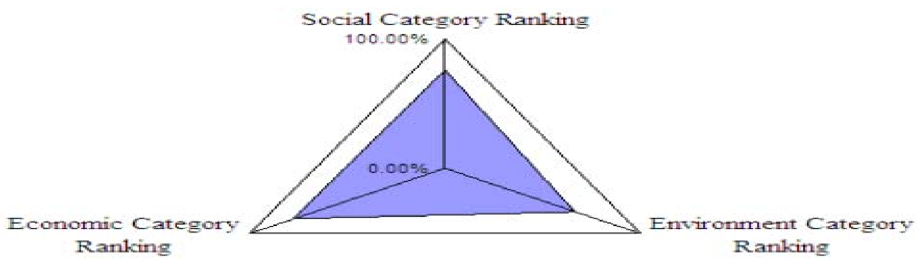

Figure 6 Urban water resources sustainability pyramid for Brazzaville

Conclusions

This paper describes an attempt to address urban water resources sustainability for selected African urban areas through a macroscopic comparative analysis. The study database was consisted of 25 variables for 32 countries and 39 urban areas. The variables were 6 for water, and 19 for 3 other categories of social, economic, and environmental. The selected variables and the period of 1993 to 1998 were suitable in the context information availability, reliability and completeness. The variables were neither unique nor standard, and far from ideal. Availability of more relevant comparative urban data on water demand, supply and utilization, and their more direct economic, social and environmental impact could have greatly enhanced the study results. As a consequence, the study results would be of more methodological interest, and their direct policy implications render great caution. Furthermore, each urban area is unique in many historical, geographical, cultural, social, environmental and economic aspects that any comparative appraisal needs due considerations of these local factors and issues. Nevertheless, the applied comparative assessment methodology could be used as a compliment to any other types of assessment to enhance urban policies in support of sustainable urban water resources development.

For the 39 selected urban areas, the database univariate analysis showed significant cross-sectional and time-series variations. The observed trends however were not always in favor of sustainable development. Based on mean values, the 1993 to 1998 time-series changes not supporting sustainability were related to variables WUHA, SUPH, SUMF and CUCP. Nevertheless, the mean and standard deviation of nominal variables reflected the significant concerns regarding environment and disaster mitigation by local governments since 1998. The pair-wise correlation analysis showed that for 1993, 1998 and changes from 1993 to 1998, on the average, a water variable was positively, 15.11%, and negatively, 4.18%, significantly correlated with the other variables. As a preliminary exploration into urban water resources sustainability, for each urban area, elasticity of water variables with respect to social, environmental and economic variables was developed. Composite rankings for the tripartite dimensions of social, environmental and economic were developed. Utilizing tripartite composite rankings, for comparative sustainability assessment with a single ranking, an overall sustainability ranking was also developed. The developed elasticities and rankings can be used in monitoring and controlling urban water resources sustainable development. They are suggested as sustainable development indicators for comparative appraisal.

Urban water resources sustainability should be pursued through robust management, integrated policy making, efficient resource allocation and utilization, and efficacious information collection and dissemination. Enhancement of relevant and centralized water resources databases is a key element of sustainable development monitoring and control. In this study, the elasticity of water variables with respect to tripartite dimensions of social, environmental and economic was suggested as a base for development of indicators. The study findings were based on selected variables and indicators that were neither unique nor universal and consequently, the study is of more methodological value than quantitative results. Based on the limited data, nevertheless, the study confirmed the significance of urban water resources sustainable development challenges.

Acknowledgement

The authors wish to thank the Sharif University of Technology for providing partial funding for this study.

References

Bossel, H. (1999). Indicators for Sustainable Development: Theory, Method and Application, International Institute for Sustainable Development, Canada.

Elliot, J. A. (2001). *An Introduction to Sustainable Development, 2nd Edition,* Routledge, London, UK.

Hardi, P., and Zdan, T. (1997). *Measuring Sustainable Development: Review of Current Practice,* International Institute for Sustainable Development, Canada.

Lundin, M., Molander, S., and Morrison, G. M. (1999). A set of indicators for the assessment of Temporal variation in the sustainability of sanitary systems, *Water Science and Technology,* Volume 39, No. 5, pp. 235-242.

Moffatt, I., Hanley, N., and M. D. Wilson (2001). *Measuring and Modeling Sustainable Development,* Parthenon Publishing Group, London.

Morrison, G., Faloke, O. S., Zinn, E., and Jacobson, D. (2001). Sustainable development indicators for urban water systems: A case study evaluation of King William's Town, South Africa, and the applied indicators, *Water SA,* Volume 27, No.2, pp. 219-232.

Rosegrant, M. W., and Perez, N. D. (1997). *Water Resources Development in Africa: A Review and Synthesis of Issues, Potentials, and Strategies for the Future*, Environment and Production Technology Division, International Food Policy Research Institute, Washington D.C.

Vaziri, M., and A. A. Rassafi (2001). An appraisal of forest sustainability in the Asia and Pacific Region, proceedings of *3rd International Conference on Ecosystem and Sustainable Development,* Wessex, UK, pp. 616-621.

Vaziri, M., and A. A. Rassafi (2003). Globalization and sustainable development: European experience. Proceedings of *7th International Conference on Global Business and Economic Development,* Bangkok, Thailand, pp. 36-42.

World Commission on Environment and Development (1987). *Our Common Future,* Oxford University Press, Oxford.

United Nations (2001). *Statistical Yearbook, 46th Edition*. United Nations, New York.

United Nations-Habitat (2004). *Global Urban Observatory and Statistics,* http://www.unhabitat.org

World Bank (2002). *The World Development Indicators 2002 CD-ROM,* World Bank, Wash. D.C.