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URBAN WATER RESOURCES SUSTAINABLE DEVELOPMENT: A GLOBAL COMPARATIVE APPRAISAL*

M. VAZIRI** AND R. TOLOUEI

Dept. of Civil Engineering, Sharif University of Tech., P.O. Box 11155-9313, Azadi Avenue, Tehran, I. R. of Iran
Email: manouchehrvaziri@yahoo.com

Abstract– The challenges of water resources sustainable development are enormous. Around the globe, the increasing use of water coupled with 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 for the sustainable future of urban areas. The objective of this study was to assess water resources sustainable development for selected urban areas around the world. 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 350 cities around the globe, due to data inaccessibility, incompleteness and missing, 107 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 regions and countries. For the period of 1993 to 1998, elasticity of database variables were developed. Using elasticities, urban area rankings and addressing water resources sustainable development were suggested. The developed elasticity and rankings were used in taxonomy of the selected 107 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 consideration 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.

Keywords– Sustainable development, water resources, urban areas, global study, comparative analysis

1. INTRODUCTION

The last forty years of population, urbanization and economic growth have raised many concerns of undesirable socio-environmental impacts around the globe. The publication of "Our Common Future" known as The 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 [1]. The report emphasizes 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 the 21st century. Indeed, holistic perspectives addressing and appraising interrelationships and interfaces of environmental, social, and

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**Corresponding author

economic subsystems are needed. 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. Sustainable society favors conditions that benefit the environment, the economy and the society, without compromising the welfare of future generations. Consequently, a massive literature on sustainable development has grown up from the concerns about the relationships among economic activities, social aspects, and environmental considerations [2-6].

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 scarce resources over a long-time perspective. Issues concerning water resources sustainable development have been addressed at various times and geographic scopes, from local to global scales [7-10]. Around the globe the increasing use of water coupled with environmental deterioration calls for sustainable development of the limited water resources. Globally, some 1.1 billion people lack access to safe water. 2.6 billion lack access to safe sanitation and 1.7 million premature deaths are attributable to unsafe water, poor sanitation, and poor hygiene [11]. Since a growing share of the global population is urbanized, sustainability has increasingly become focused on urban areas. In developing countries, urban areas often have chronic deficiencies in the provision of the most basic services, while their environmental conditions are deteriorating. Urban water supply and demand should be efficaciously balanced and managed [12]. 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 [13-15].

The objective of the study reported herein was to comparatively assess water resources sustainable development for selected urban areas in the world 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, a set of urban areas with adequate information was identified 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 sustainable development challenges of the 21st century.

2. 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 international databanks [16-18]. The main problem encountered was the availability and accessibility to comparable water data on demand, supply, utilization and impacts at the urban level. The urban main centralized data source was found to be the Urban Indicator Database [17]. After evaluation of the centralized and accessible time-series databases and their completeness, the limited study resources confined the study scope to a preliminary selection of 363 urban areas and a time-series period of 1993 to 1998. The selected urban areas were from 141 countries around the globe. 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, 107 urban areas from 77 countries were selected for detailed analysis. 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 existed, zero or one
	24	CNGD	National GDP in constant 1995 US billion $
	25	CNIF	Inflation, GDP deflator

The Table 1 definitions are available in the original database and had been given to individual cities while the information was being completed. The study assigned variable names consisting of 4 digits. The first digit shows the category type, the second digit shows variable type, either urban or national, and the third and forth digits reflect variable description. There were 19 cardinal and 6 nominal variables. The nominal variables were EUPE, urban local environmental plans existed, EUPL, urban local environmental plans institutionalized, EUPI, urban local environmental plans implemented, CUDC, urban disaster building code existed, CUDM, urban hazard and disaster mapping existed, and CUDI, urban building disaster insurance existed, with the value of either zero or one. Only 26 urban areas had no missing data, namely, Amman of Jordan, Asuncion of Paraguay, Bangalore of India, Belgrade of Serbia, Brazzaville of Congo, Budapest of Hungary, Chennai of India, Colombo of Sri Lanka, Cotonou of Benin, Dhaka of Bangladesh, Jakarta of Indonesia, Kigali of Rwanda, Kostroma of Russia, Moscow of Russia, Nizhny-Novgorod of Russia, Porto-Novo of Benin, Quito of Ecuador, Recife of Brazil, Rio-de-Janeiro of Brazil, Santa-Cruz of Bolivia, Semarang of Indonesia, Sofia of Bulgaria, Stockholm of Sweden, Surabaya of Indonesia, Yaounde of Cameron and Yerevan of Armenia.

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 the results of descriptive analysis. For each of the 25 variables, the table shows the mean, standard deviation and coefficient of variation for 1993 and 1998, and the changes during these 5 years. Based on mean values, all cardinal variables showed growth during 1993 to 1998 except WUHA, percent of urban households with access within 200 meters, WUHC, percent urban households with water connection, WUPR, urban water price in dollar per cubic meter, WUCO, urban daily consumption in liter per capita, SUPH, percent of urban households below poverty line, SNPG, national annual population growth, ENEM, national annual CO2 emissions in metric tons per capita, and CNIF, GDP Inflation deflator. The study database univariate analysis showed significant cross-sectional and time-series variations, as were reflected by standard deviation and coefficient of variation values of Table 2. The 1993 minimum, average and maximum coefficient of variation values were 0.21, 1.34 and 5.50, respectively. The 1998 minimum, average and maximum coefficient of variation values were 0.23, 0.97 and 3.03, respectively. The 1993-1998 minimum, average and maximum coefficient of variation of variable changes were 0.78, 50.15 and 709.01, respectively. The time-series changes not supporting sustainable development were related to variables WUHA, percent of urban households with access within 200 meters, WUHC, percent of urban households with water connection, and SUMF, percent of urban annual mortality rate for age 5 and below. 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 the symbol "NA" in Table 2. Based on 1993 coefficient of variations, for variable categories of water, social, environmental and economic, the highest variabilities were observed for WUPR, urban water price in dollars per cubic meter, SNPD, national population density in persons per square kilometer, ENEM, national annual CO2 emissions in metric tons per capita, and CNIF, GDP Inflation deflator, respectively. Based on 1998 coefficient of variations, for variable categories of water, social, environmental and economic, the highest variabilities were observed for WUPR, urban water price in dollar per cubic meter, SNPD, national population density in persons per square kilometer, ENEM, national annual CO2 emissions in metric tons per capita, and CNGD, national GDP in constant 1995 US billion dollars, respectively. For the changes from 1993 to 1998, for 4 variable categories of water, social, environmental and economic, the highest variabilities were observed for WUST, percent of urban water sewage treated, SNPG, national annual population growth, EUSR, percent of urban solid waste treated, and CUCP, urban city product in dollars, respectively. The mean and standard deviation of nominal variables reflect significant concerns regarding the environment and disaster mitigation by local governments in 1998. Urban environmental planning was implemented in 62% of the selected urban areas in 1998. Furthermore, local government disaster mitigation policies and activities existed for around half of the selected urban areas in 1998. These reflect some significant attention toward urban water resources sustainable development during the five year study period of 1993 to 1998.

Table 2. Descriptive analysis of the database variables.

No.	Variable name	Mean 1993	S. D. 1993	C.O.F. 1993	Mean 1998	S. D. 1998	C.O.F . 1998	Mean 93-98	S.D. 93-98	C.O.F . 93-98
1	WUHA	85.58	17.62	0.21	85.82	19.44	0.23	-0.77	18.49	24.01
2	WUHC	78.09	31.04	0.40	68.25	29.05	0.43	-0.20	17.02	85.10
3	WUPR	1.06	2.40	2.26	0.53	0.60	2.23	-0.62	2.29	3.63
4	WUCO	163.55	141.45	0.86	136.58	101.68	0.75	-22.97	87.69	3.82
5	WUST	40.42	41.60	1.03	45.49	38.72	0.85	0.04	28.36	709.01
6	WUHS	50.78	39.52	0.78	62.22	34.14	0.55	3.16	20.22	6.39
7	SUPU	1647.95	2367.76	1.44	1884.89	2552.87	1.35	363.40	1094.99	3.01
8	SUPH	28.82	21.09	0.73	25.04	17.85	0.72	-1.63	17.30	10.61
9	SUMF	6.14	5.56	0.91	6.70	6.33	0.94	0.7	4.5	6.43
10	SNPG	1.62	1.27	0.78	1.56	1.14	0.73	-0.06	0.74	12.33
11	SNPD	109.54	162.40	1.48	117.54	175.78	1.50	8.00	14.65	1.83
12	SNUP	47.39	23.24	0.49	49.60	22.75	0.46	2.21	1.73	0.78
13	EUSR	46.65	43.24	0.93	42.97	39.90	0.93	0.59	34.86	59.08
14	EUHE	74.95	28.91	0.39	80.94	25.92	0.32	3.78	20.93	5.54

Table 2 Continued.

15	EUPE	NA	NA	NA	0.68	0.47	0.69	NA	NA	NA
16	EUPL	NA	NA	NA	0.49	0.50	1.03	NA	NA	NA
17	EUPI	NA	NA	NA	0.62	0.49	0.79	NA	NA	NA
18	ENEM	3.43	5.12	1.49	3.27	4.92	1.51	-0.16	0.65	4.06
19	CUCP	4528.57	8483.34	1.87	4933.24	9351.03	1.90	752.74	4480.80	5.95
20	CUTC	35.87	30.71	0.86	43.01	33.52	0.78	10.08	22.61	2.24
21	CUDC	NA	NA	NA	0.67	0.47	0.70	NA	NA	NA
22	CUDM	NA	NA	NA	0.57	0.50	0.88	NA	NA	NA
23	CUDI	NA	NA	NA	0.55	0.50	0.91	NA	NA	NA
24	CNGD	521.22	1541.34	2.96	604.24	1832.18	3.03	89.3	310.28	3.47
25	CNIF	330.63	1818.03	5.50	11.34	18.44	1.63	-319.20	1818.39	5.69
Average		NA	NA	1.34	NA	NA	0.97	NA	NA	50.15

3. 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 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	(+)SNUP93,SNUP98,EUSR93, EUSR98,EUHE93,EUHE98, ENEM93,ENEM98,CUCP93, CUTC93,CUTC98,CNGD93, CNGD98,CNGDΔ,WUHA98, WUHC93,WUHC98,WUCO93, WUCO98,WUST93,WUST98, WUHS93,WUHS98 (-)SUPH98,SUMF93,SUMF98, SNPG93,SNPG98,SNPDΔ, WUHAΔ,WUPR98	WUHA98	(+)SNPD93,SNPD98,SNUP93, SNUP98,EUSR93,EUSR93, EUHE93,EUHE93,EUHE98, ENEM93,ENEM98,CUCP93, CUTC93,CUTC98,CUTCΔ,CNGD93 ,CNGD98,WUHA93,WUHAΔ, WUHC93,WUHC98,WUPRΔ, WUCO93,WUCO98,WUST93, WUST98,WUHS93,WUHS98 (-)SUPH98,SUMF93,SUMF98, SNPG93,SNPG98,SNUPΔ, WUHCΔ,WUPR93,WUPR98	WUHAΔ	(+)SNPD93,SNPD98 ,SNPDΔ,CUDC98, WUHA98,WUPRΔ, (-)SUMF98,SNPGΔ, WUHA93,WUPR93
WUHC93	(+)SNUP93,SNUP98,EUSR93, EUSR98,EUHE93,EUHE98, ENEM93,ENEM98,CUCP93, CUCP98,CUTC93,CUTC98, CNGD93,CNGD98,CNGDΔ, WUHA93,WUHA98,WUHC98, WUCO93,WUCO98,WUST93, WUST98,WUHS93,WUHS98 (-)SUMF93,SUMF98,SUMFΔ, SNPG93,SNPG98,SNUPΔ, EUSRΔ,EUHEΔ,EUPE98, ENEMΔ,WUHCΔ,WUPR93, WUHSΔ	WUHC98	(+)SNUP93,SNUP98,EUSR93, EUSR98,EUHE93,EUHE98, ENEM93,ENEM98,CUCP93, CUCP98,CUTC93,CUTC98, CUTCΔ,CNGD93,CNGD98, CNGDΔ,CINF93,WUHA93, WUHA98,WUHC93,WUCO93 ,WUCO98,WUST93,WUST98, WUHS93,WUHS98 (-) SUPH98,SUMF93,SUMF98, SUMFΔ,SNPG93,SNPG98, SNPDΔ,SNUPΔ,EUSRΔ, EUPE98,ENEMΔ,CINFΔ	WUHCΔ	(+)SUMF98,SNPG93 ,EUHEΔ,WUPR93, WUSTΔ,WUHSΔ (-) SNPGΔ,SNPD93, SNPD98,SNPDΔ, EUHE93,WUHA98, WUHC93,WUHS93
WUPR93	(+)EUSRΔ,WUHCΔ,WUPR98 (-) EUHE93,EUHE98,CUDC98, CUDM98,CUDI98,WUHA98, WUHAΔ,WUHC93,WUPRΔ,	WUPR98	(+)SUMF93,CUCP93,CUCP98 ,CUCPΔ,WUPR93 (-) EUHE93,EUHE98,WUHA93, WUHA98,WUCO98	WUPRΔ	(+)EUHE93,EUHE98, CUDC98,WUHA98, WUHAΔ (-) SUMF93,EUSRΔ, WUPR93

Table 3 Continued.

WUCO93	(+)SNUP93,SNUP98,EUSR93 ,EUSR98,EUHE93,EUHE98, ENEM93,ENEM98,CUCP93, CUTC93,CUTC98,CUDM98, CNGD93,CNGD98,CNGDΔ, CINF93,WUHA93,WUHA98, WUHC93,WUHC98,WUCO98, WUST93,WUHS93,WUHS98 (-) SUMF93,SUMF98,SUMFΔ, SNPG93,SNPG98,SNUPΔ, EUSRΔ,ENEMΔ,CINFΔ,WUCOΔ	WUCO98	(+)SNUP93,SNUP98,EUSR93 EUHE93,EUHE98,ENEM93, ENEM98,CUCP93,CUCP98, CUTC93,CUTC98,CNGD93, CNGD98,CNGDΔ,WUHA93, WUHA98,WUHC93,WUHC98, WUCO93,WUST93,WUST98, WUHS93,WUHS98 (-) SUMF93,SUMF98,SUMFΔ, SNPG93,SNPG98,SNUPΔ, EUSRΔ,WUPR98	WUCOΔ	(+)SUMF98,SNPG93, SNPG98,SNUPΔ, ENEMΔ (-) SNUP93,ENEM93, ENEM98,CUTC93, CUTC98,WUCO93, WUHS93,WUHS98
WUST93	(+)SNUP93,SNUP98,EUSR93 ,EUHE93,EUHE98,ENEM93, ENEM98,CUCP93,CUCP98, CUTC93,CUTC98,CNGD93, CNGD98,CNGDΔ,WUHA93, WUHA98,WUHC93,WUHC98, WUCO93,WUCO98,WUST98, WUHS93,WUHS98, (-) SUMF93,SUMF98,SNPG93, SNPG98,SNUPΔ,ENEMΔ, WUSTΔ	WUST98	(+)SUPUΔ,SNUP93,SNUP98, EUSR93,EUHE93,EUHE98, ENEM93,ENEM98,CUCP93, CUTC93,CUTC98,CUTCΔ, CNGD93,CNGD98,WUHA93,WUHA98,WUHC93,WUHC98,WUCO98, WUST93,WUSTΔ, WUHS93,WUHS98 (-) SUMF93,SUMF98,SNPG93, SNPG98,SNPGΔ,SNPDΔ, SNUPΔ,EUHEΔ,ENEMΔ, CUDM98	WUSTΔ	(+)CINFΔ,WUHCΔ, WUST98 (-) SUPH93,SNPGΔ, SNPD93,SNPD98, SNPDΔ,CINF93, WUST93
WUHS93	(+)SNUP93,SNUP98,EUSR93, EUHE93,EUHE98,ENEM93, ENEM98,CUCP93,CUCP98, CUTC93,CUTC98,CNGD93, CNGD98,CNGDΔ,WUHA93, WUHA98,WUHC93,WUHC98, WUCO93,WUCO98,WUST93, WUST98,WUHS98 (-) SUMF93,SUMF98,SNPG93, SNPG98,SNUPΔ,EUSRΔ,EUPE98, ENEMΔ,WUHCΔ,WUCOΔ,WUHSΔ, WUHCΔ,WUHSΔ, CUTCΔ	WUHS98	(+)SNUP93,SNUP98,EUSR93, EUSR98,EUHE93,EUHE98, ENEM93,ENEM98,CUCP93, CUCP98,CUTC93,CUTC98, CUTCΔ,CNGD93,CNGD98, CNGDΔ,WUHA93,WUHA98, WUHC93,WUHC98,WUCO93, WUCO98,WUST93,WUST98, WUHS93 (-) SUMF93,SUMF98,SNPG93, SNPG98,SNPDΔ,SNUPΔ,EUSRΔ, ENEMΔ,WUCOΔ	WUHSΔ	(+)SNUPΔ,CINF98, WUHCΔ (-)WUHC93,WUHS93

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 average, a water variable was positively 26.7%, and negatively 12.2%, significantly correlating 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, 3.3%, economic variables, 7.4%, water variables, 10.1%, and environmental variables, 5.9%, respectively. They showed significant negative correlations with social variables, 6.1%, economic variables, 0.9%, water variables, 2.8%, and environmental variables, 2.4%, respectively.

In 1993, for WUHA, percent of urban households with water access within 200 meters, cross sectional positive correlations were found with SNUP, EUSR, EUHE, ENEM, CUCP, CUTC, CNGD, WUHC, WUCO, WUST and WUHS. Cross sectional negative correlations were found with SUMF and

SNPG. In 1993, for WUHC the percent of urban households with water connection, cross sectional positive correlations were found with SNUP, EUSR, EUHE, ENEM, CUCP, CUTC, CNGD, WUHA, WUCO, WUST and WUHS. Cross sectional negative correlations were found with SUMF, SNPG and WUPR. In 1993, for WUPR, urban water price in dollars per cubic meter, no cross sectional positive correlation was found, but negative correlations were found with EUHE and WUHC. In 1993, for WUCO, urban daily consumption in liter per capita were found with SNUP, EUSR, EUHE, ENEM, CUCP, CUTC, CNGD, CINF, WUHA, WUHC, WUST and WUHS. Cross sectional negative correlations were found with SUMF and SNPG. In 1993, for WUST, percent of urban water sewage treated were found with SNUP, EUSR, EUHE, ENEM, CUCP, CUTC, CNGD, WUHA, WUHC, WUCO and WUHS. Cross sectional negative correlations were found with SUMF and SNPG. In 1993, for WUHS, percent of urban households with sewage connection, cross sectional positive correlations were found with SNUP, EUSR, EUHE, ENEM, CUCP, CUTC, CNGD, WUHA, WUHC, WUCO and WUST. Cross sectional negative correlations were found with SUMF and SNPG.

In 1998, for WUHA, percent of urban households with water access within 200 meters, cross sectional positive correlations were found with SNPD, SNUP, EUHE, ENEM, CUTC, CNGD, WUHC, WUCO, WUST and WUHS. Cross sectional negative correlations were found with SUPH, SUMF, SNPG and WUPR. In 1998, for WUHC, percent of urban households with water connection, cross sectional positive correlations were found with SNUP, EUSR, EUHE, ENEM, CUCP, CUTC, CNGD, WUHA, WUCO, WUST and WUHS. Cross sectional negative correlations were found with SUPH, SUMF, SNPG and EUPE. In 1998, for WUPR, urban water price in dollars per cubic meter, cross sectional positive correlation were found with CUCP. Cross sectional negative correlations were found with EUHE, WUHA and WUCO. In 1998, for WUCO, urban daily consumption in liter per capita were found with SNUP, EUHE, ENEM, CUCP, CUTC, CNGD, WUHA, WUHC, WUST and WUHS. Cross sectional negative correlations were found with SUMF, SNPG and WUPR. In 1998, for WUST, percent of urban water sewage treated, cross sectional positive correlations were found with SNUP, EUHE, ENEM, CUTC, CNGD, WUHA, WUHC, WUCO and WUHS. Cross sectional negative correlations were found with SUMF, SNPG and CUDM. In 1998, for WUHS, percent of urban households with sewage connection, cross sectional positive correlations were found with SNUP, EUSR, EUHE, ENEM, CUCP, CUTC, CNGD, WUHA, WUHC, WUCO and WUST. Cross sectional negative correlations were found with SUMF and SNPG.

During the period 1993 to 1998, changes for WUHA, the percent of urban households with water access within 200 meters, positive correlations were found with 1993 SNPD. Negative correlations were found with 1993 WUHA and WUPR. During the period 1993 to 1998, changes for WUHC, in percent of urban households with water connection, positive correlations were found with 1993 SNPG and WUPR. Negative correlations were found with 1993 SNPD, EUHE, WUHC and WUHS. During the period 1993 to 1998, changes for WUPR, urban water price in dollars per cubic meter, positive correlation was found with 1993 EUHE. Negative correlations were found with 1993 SUMF and WUPR. During the period 1993 to 1998, changes for WUCO, urban daily consumption in liter per capita, positive correlation was found with 1993 SNPG. Negative correlations were found with 1993 SNUP, ENEM, CUTC, WUCO and WUHS. During the period 1993 to 1998, changes for WUST, percent of urban water sewage treated, no positive correlation was found with any 1993 variable. Negative correlations were found with 1993 SUPH, SNPD, CINF and WUST. During the period 1993 to 1998, changes for WUHS, percent of urban households with sewage connection, no positive correlation was found with any 1993 variable. Negative correlations were found with 1993 WUHC and WUHS.

As many pairs of variables were found significantly correlated, the results of correlation analysis could have been used as inputs to cross sectional and time series empirical model development. Nevertheless, to address sustainable development, the study focused more on time series analysis, and specifically elasticity analysis.

4. ELASTICITY ANALYSIS

As a preliminary exploration into water resources sustainable development, elasticity of water variables with respect to social, environmental and economic variables was developed [19-20]. The arc elasticity E of a variable Y with respect to a variable X for the period t1-t2 reflects the average percent variable Y changes with respect to a one percent change of the variable X, during t1 to t2, as is shown by Eq. (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 becomes very small, the arc elasticity converges to point elasticity. For each of the 107 urban areas, based on non-missing values, a maximum of 6x19=114 elasticities for the period of 1993 to1998 were computed. For Eq. (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 elasticities showed several interesting results. After careful evaluation and consideration of missing values and correlation matrix, 36 elasticities were selected for further analysis. For the selected elasticities, 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 elasticities are summarized in Table 4.

Table 4. Descriptive analysis of selected elasticities

Elasticity	Mean	Standard deviation	Elasticity	Mean	Standard deviation	Elasticity	Mean	Standard deviation
$E_{WUHA/SUPU}$	-0.16	7.47	$E_{WUHA/EUSR}$	-0.74	4.42	$E_{WUHA/CUCP}$	-0.21	1.40
$E_{WUHC/SUPU}$	6.67	29.84	$E_{WUHC/ EUSR}$	0.47	3.19	$E_{WUHC/CUCP}$	0.10	1.83
$E_{WUPR/SUPU}$	3.22	24.52	$E_{WUPR/ EUSR}$	-1.19	9.44	$E_{WUPR/CUCP}$	-3.86	13.02
$E_{WUCO/SUPU}$	21.71	130.84	$E_{WUCO/ EUSR}$	0.27	5.20	$E_{WUCO/CUCP}$	1.16	3.48
$E_{WUST/SUPU}$	-2.57	50.44	$E_{WUST/ EUSR}$	1.15	4.75	$E_{WUST/CUCP}$	-1.25	8.04
$E_{WUHS/SUPU}$	7.37	35.71	$E_{WUHS/ EUSR}$	1.95	9.55	$E_{WUHS/CUCP}$	0.98	3.57
$E_{WUHA/SUPH}$	0.16	1.08	$E_{WUHA/ENEM}$	-0.02	8.66	$E_{WUHA/CNGD}$	-0.33	2.08
$E_{WUHC/SUPH}$	-0.10	1.47	$E_{WUHC/ENEM}$	-3.03	20.50	$E_{WUHC/CNGD}$	0.32	2.30
$E_{WUPR/SUPH}$	-0.57	6.49	$E_{WUPR/ENEM}$	11.91	96.49	$E_{WUPR/CNGD}$	-2.48	9.11
$E_{WUCO/SUPH}$	-0.02	3.16	$E_{WUCO/ENEM}$	-2.59	25.55	$E_{WUCO/CNGD}$	0.16	4.31
$E_{WUST/SUPH}$	1.45	6.18	$E_{WUST/ENEM}$	1.58	50.50	$E_{WUST/ CNGD}$	0.31	6.59
$E_{WUHS/SUPH}$	-0.06	2.26	$E_{WUHS/ENEM}$	2.78	10.75	$E_{WUHS/CNGD}$	-0.04	6.07

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

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

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 the rate of changes in social, environmental and economic variables, after due consideration of a desirable sign for sustainable development. For instance, in developing $R_{WUHA/SUPH}$, the urban areas for which relevant data are available are divided into four subgroups based on sign of changes in WUHA and SUPH variables. Subgroup 1 includes urban areas with a positive sign in the rate of changes in WUHA and negative sign in the rate of changes in SUPH. They form the most desirable subgroup with respect to sustainable development. Subgroup 2 includes urban areas with a positive sign in the rate of changes in both WUHA and SUPH variables. Subgroup 3 includes urban areas with a negative sign in the rate of changes in both WUHA and SUPH variables. Subgroup 4 includes urban areas with a negative sign in the rate of changes in WUHA and a positive sign in the rate of changes in SUPH. They form the most undesirable subgroup with respect to sustainable development. Subsequently, the urban areas in each subgroup are ranked based on desirable percent changes in WUHA and SUPH variables to develop individual rankings. For comparative assessment of individual rankings, a percentile ranking for each urban area was developed. Percentile ranking shows the relative performance with respect to other urban areas, and was developed using the following equation:

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

Where $PR_{Y/X}$ is the percentile ranking of urban area for specific Y and X variables and N is the number of urban areas for which relevant data is available. The lower the percentile ranking the better the performance. For example, an urban area with a percentile ranking of 10% performed better than 90 percent of other urban areas.

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

$$CR_G = (\Sigma\, PR_{Y/X}) \;/\; n \tag{3}$$

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 SUPU, SUPH, EUSR, ENEM, CUCP and CNGD. 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 tripartite dimensions for the selected urban areas.

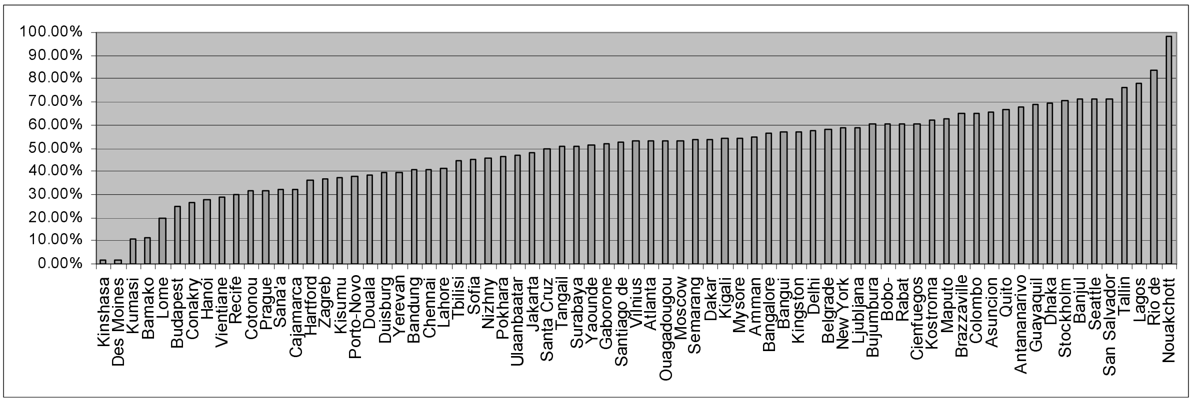

Fig. 1. Composite ranking for social category, CR_S

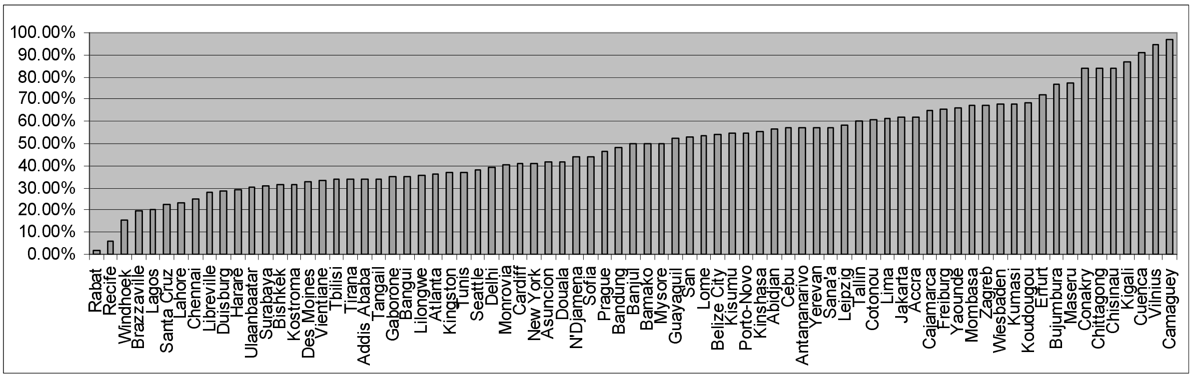

Fig. 2. Composite ranking for environmental category, CR_E

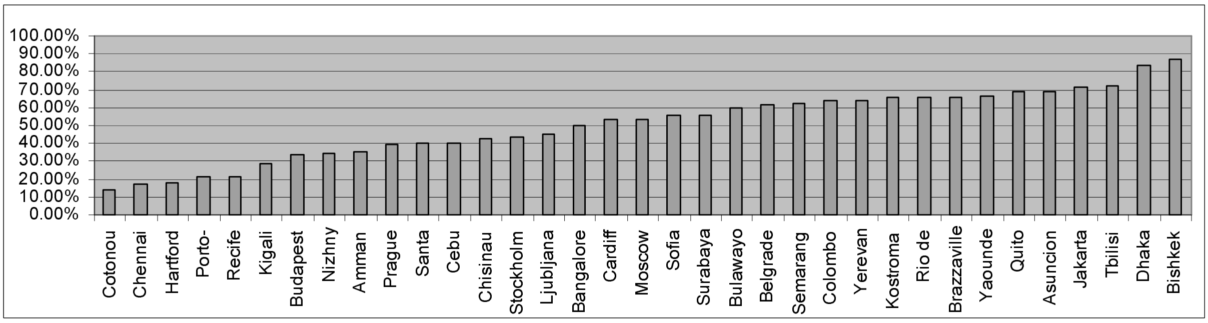

Fig. 3. Composite ranking for economic category, CR_C

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

$$OSR= (\beta_S CR_S + \beta_E CR_E + \beta_C CR_C) / (\beta_S + \beta_E + \beta_C) \quad (4)$$

Where OSR is the overall urban water resources sustainable development 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, $\beta_S = \beta_E = \beta_C$. This assumption was based on considering equal importance for the composite rankings of the three groups. Obviously, other weight factor values can be selected that would reflect other relative weights. The values for overall sustainable development ranking should be interpreted in the context of comparative assessment.

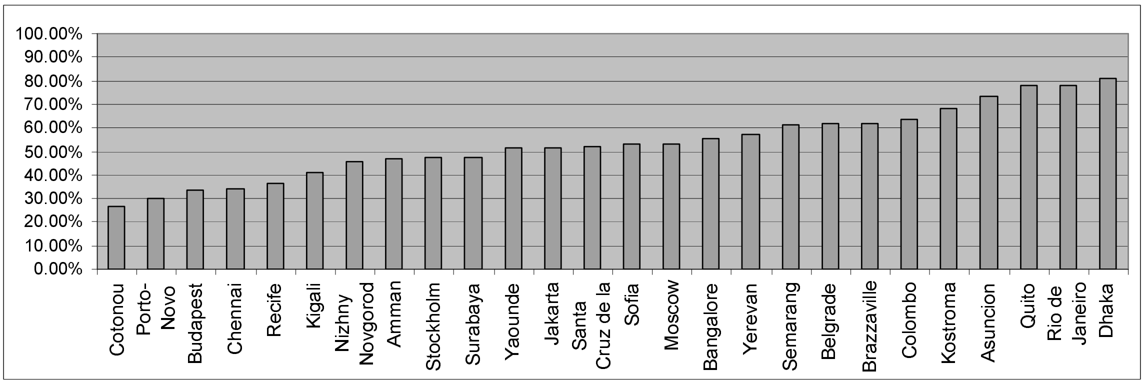

Fig. 4. Overall sustainable development ranking, OSR

Figures 1 to 4 summarize the three composite rankings of social, environmental and economic categories, and the overall sustainable development rankings of the selected urban areas. Due to missing values, among 107 urban areas, the ranked urban areas in social, environmental and economic groups were 73, 77 and 35, respectively. And, as a consequence, for 26 urban areas overall sustainable development ranking was developed, as reflected in Figure 4. The best $CR_{S,}$ CR_E and CR_C were for Kinshasa, Rabat and Cotonou, respectively. Among the 26 ranked urban areas, Cotonou, Porto-Novo and Budapest showed better overall sustainable development rankings. These urban areas can be used as showcases for learned lessons and good practices. Having the values of composite rankings in major tripartite dimensions of sustainable development, urban water resources sustainable development pyramids for each urban area can be developed. For example, water resources sustainable development pyramids for Amman and Belgrade are shown in Figures 5 and 6. The zero value in these figures reflects the best ranking in each of the tripartite dimensions.

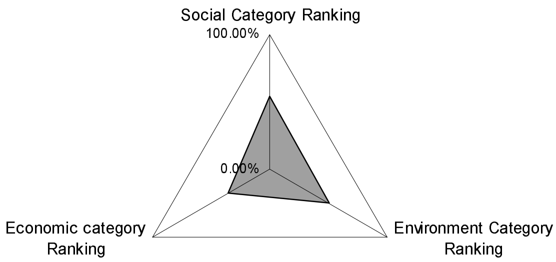

Fig. 5. Urban water resources sustainable development pyramid for Amman

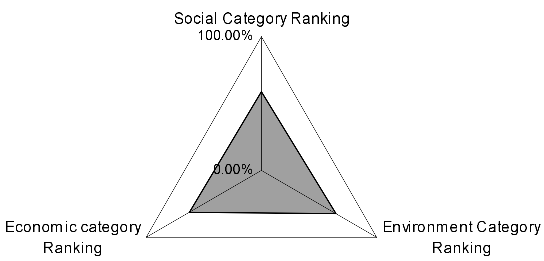

Fig. 6. Urban water resources sustainable development pyramid for Belgrade

5. CONCLUSION

This paper describes an attempt to address urban water resources sustainable development for urban areas around the world through a macroscopic comparative analysis. The study database consisted of 25 variables for 107 urban areas from 77 countries. The variables were 6 for water, and 19 for 3 other categories of social, economic, and environmental. The variables were neither unique nor standard, and far from ideal. The selected variables and the period of 1993 to 1998 were suitable in the context of information availability, reliability and completeness. 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 consideration of these local factors and issues. Nevertheless, the applied comparative assessment methodology could be used as a compliment to any other type of assessment to enhance urban policies in support of sustainable urban water resources development.

For the 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 sustainable development were more related to 3 variables, namely percent of households with water access, WUHA, percent of households with water connection, WUHC, and urban mortality rate, SUMF. 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 average, a water variable was positively, 26.71%, and negatively, 12.2%, significantly correlated with the other variables. As a preliminary exploration into urban water resources sustainable development, 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 sustainable development assessment with a single dimension, an overall sustainable development ranking was also developed. The developed elasticities and rankings can be used in urban water resources sustainable development management. They are suggested as sustainable development indicators for comparative appraisal. Although the study database did not have any information regarding urban areas in Iran, the data can be developed domestically, and can consequently be used for future comparative appraisals.

Urban water resources sustainable development 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 the development of indicators. The study findings were based on selected variables 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.

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