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Sustainable Development of Urban Water Resources: An Appraisal for Asian Monsoon Region

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Abstract: The challenges of water resources sustainable development are enormous in the Asian monsoon region. Meteorological behaviour in this region is signified by its warm and moist winds, northwest monsoon, blowing from the sea to the land during summer and bringing heavy rains in India and South East Asia. On the contrary, the northeast monsoon occurs when cold and dry winter air flows out of the interior of Asia from the northeast and bring the cool and dry winter season. This unique cyclic behaviour often results in several months of drought followed by a period of flooding, demanding robust water resources management at regional as well as local scales. The objective of this study was to assess water resources sustainable development for selected urban areas in the Asian monsoon region 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 modelled. The study database consisted of information regarding urban water accessibility, consumption, price, wastewater treatment, and other pertinent social, environmental and economic indicators. Due to data inaccessibility, incompleteness and missing, less than 20 cities from Bangladesh, Brunei, China, India, Indonesia, Laos, Myanmar, Malaysia, The Philippines, Singapore, Sri Lanka, South Korea, Thailand and Vietnam 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 of Asian monsoon region. For the period of 1993 to 1998, elasticity of database indicators were developed. Using elasticities, a composite urban water resources sustainability index was suggested. The elasticities and index were used in taxonomy of the selected cities, and reflected considerable variations in urban water demand and supply development. The study confirmed the significance of urban areas water resources sustainability challenges of the 21^{st} century for the Asian monsoon region.

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 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 favours solutions that effectively integrate economic, environmental and community considerations, and is expected to be one of the major challenges of 21^{st} 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 scare 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 Asian monsoon region. Meteorological behaviour in this region is signified by its warm and moist winds, northwest monsoon, blowing from the sea to the land during summer and bringing heavy rains in India and South East Asia. On the contrary, the northeast monsoon occurs when cold and dry winter air flows out of the interior of Asia from the northeast and bring the cool and dry winter season. This unique cyclic behaviour often results in several months of drought followed by a period of flooding. Parallel to the unique meteorological behaviour, the region has recently experienced rapid changes in terms of population, urbanization, industrial and economic growth. For the monsoon region, water is not an issue with significant social and equity dimensions, affecting every person, especially the poor and disadvantaged, it is also an issue with key economic and environmental dimensions. The region's usage and development of water resources demand robust management at all levels, regional as well as local (Jalal and Rogers, 2002).

The objective of this study reported herein was to comparatively assess water resources sustainable development for selected urban areas in the Asian monsoon region 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 modelled. 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 16 urban areas were selected for detailed analysis. The subsequent analyses and modelling for the selected urban areas showed interesting results and relations in connection with water resources sustainable development of Asia monsoon region. The study confirmed the significance of urban areas water resources sustainability challenges of the 21st century for the Asian monsoon region.

Database

To address sustainable development of urban water resources in the monsoon region, 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 47 urban areas and time-series period of 1993 to 1998. The selected urban areas were from 15 countries namely, Bangladesh, Brunei, China, India, Indonesia, Laos, Myanmar, Malaysia, Nepal, The Philippines, Singapore, Sri Lanka, South Korea, Thailand and Vietnam. 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 16 urban areas were selected for detailed analysis for the period of 1993 to 1998. Table 1 shows the final study database structure and variable details.

The selected urban areas were Chittagong, Dhaka and Tangail from Bangladesh, Bangalore, Chennai, Delhi and Mysore from India, Bandung, Jakarta, Semarang and Surabaya from Indonesia, Vientiane from Laos, Pokhara from Nepal, Cebu from The Philippines, Colombo from Sri Lanka, and Hanoi from Vietnam. The final study database consisted of 25 variables for 16 monsoon region urban areas for the period of 1993 to 1998. Due to inaccessibility to sufficient and relevant centralized data, 31 of originally selected 47 urban areas were dropped from detailed analysis. As Table 1 shows, there were four variable categories. The variable name consisted of four alphabets, the first alphabet shows the category type, the second alphabet shows variable type, either urban or national, the third and fourth alphabets reflect variable description. There were 19 cardinal and six nominal variables. The nominal variables were EUPE, EUPL, EUPI, CUDC, CUDM and CUDI, with the value of either zero or one.

Table 1: Description and Structure of the Study Database Variables

Category	*No.*	*Name*	*Description*
Water	1	WUHA	Urban households with access within 200 metre in %
	2	WUHC	Urban households with connection in %
	3	WUPR	Urban water price in $ per cubic metre
	4	WUCO	Urban daily consumption in litre 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 kilometre
	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 CO_2 emissions in metric tonnes per capita
Economical	19	CUCP	Urban city product in US $
	20	CUTC	Urban households with telephone connection in %
	21	CUDC	Urban disaster building code existed, zero or one
	22	CUDM	Urban hazard and disaster mapping existed, zero or one
	23	CUDI	Urban building disaster insurance existed, zero or one
	24	CNGD	National GDP in constant 1995 US $
	25	CNPI	National price index, 100 for base-year 1995

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.

For each of the 25 variables, the table shows the mean and standard deviation for 1993 and 1998, and the changes during the five years. Based on mean values, all cardinal variables showed growth during 1993 to 1998 except WUHC, WUCO, WUST, SUPH, SUMF, SNPG and EUSR. 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 WUHC, WUST, EUSR, ENEM and CNPI. 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, SUPU, EUSR and CUCP, 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, EUSR and CUCP, 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 75% 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 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 75 × 75 correlation matrix prevented their display herein. Table 3 shows a summary of correlation analysis with respect to water variables.

The correlation matrix revealed a number of interesting patterns and was found useful in subsequent analyses and modelling. Many pairs of variables were found

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	81.67	15.24	91.49	8.05	10.44	18.55
2	WUHC	53.75	26.43	46.3	19.80	-9.17	25.65
3	WUPR	0.18	0.27	0.32	0.34	0.20	0.35
4	WUCO	129.22	50.79	129.61	40.71	-3.68	37.73
5	WUST	24.29	28.14	21.66	29.55	-3.60	22.18
6	WUHS	30.46	23.10	53.95	21.02	15.8	23.38
7	SUPU	3488.35	3640.82	4177.58	4133.76	689.22	806.75
8	SUPH	24.57	22.18	17.55	14.23	-2.67	16.01
9	SUMF	5.94	5.21	5.13	2.74	-1.12	3.56
10	SNPG	1.84	0.31	1.76	0.30	-0.08	0.15
11	SNPD	322.57	296.16	351.86	322.84	29.29	26.80
12	SNUP	26.62	9.51	29.56	10.75	2.94	1.57
13	EUSR	10.87	11.16	7.4	11.94	-3.2	14.33
14	EUHE	81.56	16.18	87.85	12.04	6.31	19.43
15	EUPE	Na	na	0.88	0.34	na	na
16	EUPL	Na	na	0.44	0.51	na	na
17	EUPI	Na	na	0.75	0.45	na	na
18	ENEM	0.62	0.41	0.73	0.45	0.11	0.07
19	CUCP	636.20	686.81	1258.78	1260.56	502.13	1210.31
20	CUTC	21.80	14.25	39.72	26.76	16.89	31.15
21	CUDC	Na	na	0.68	0.48	na	na
22	CUDM	Na	na	0.56	0.51	na	na
23	CUDI	Na	na	0.31	0.48	na	na
24	CNGD	527.12	308.73	601.75	304.68	74.62	31.50
25	CNPI	84.24	2.51	149.60	41.86	67.54	44.10

correlated at a level of significance 0.05. Based on the 75 × 75 correlation matrix, on the average, a variable was 12.9% significantly correlated with the other variables. On an average, a water variable was positively, 5.8%, and negatively, 4.7%, 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, 2.6%, economic variables, 1.3%, water variables, 1.3%, and environmental variables, 0.6%, respectively. They showed significant negative correlations with social variables, 1.9%, water variables, 1.9%, economic variables, 0.5%, and environmental variables, 0.4%, 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 $E_{Y/X,t1-t2}$ is the arc elasticity of variable *Y* with respect to variable *X* during the period t1 to t2. When the difference between *t*1 and *t*2 gets very small, the arc elasticity converges to point elasticity. For each of the 16 urban areas, based on non-missing values, a maximum of 6 × 19=114 elasticities for the period of 1993 to 1998 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 elasticities showed several interesting results. After their careful evaluations and consideration of missing values and correlation matrix, eighteen elasticities were selected for further analysis. For the

Table 3: Correlation Analysis of the Database Water Variables

Variable	*Correlated with variables*	*Variable*	*Correlated with variables*	*Variable*	*Correlated with variables*
WUHA93	(+)CUTC93, SUPH98; (-)SNPG98, SNPD93, SNPD98, SNPDΔ, WUHAΔ	WUHA98	(+)EUHE98, SUPH93, CUCPΔ, SUMF98, SUMF93, EUPL98, WUHAΔ, WUCOΔ, (-)WUPR93, WUHCΔ	WUHCΔ	(+)WUCO93, (-)WUHC93, WUHS93, WUHA98, EUPL98, EUHEΔ
WUHC93	(+)SUPH93, SUMF93, EUPL98 (-)WUCO93, WUHCΔ, WUHSΔ	WUHC98	(+)CNPIΔ, (-)SUMFΔ	WUPRΔ	(+)WUPR98, CUCP98, CUCP93, SNUPΔ (-)SNPG98
WUPR93	(+)WUST98, SUPU93, SUPU98 (-)WUHA98	WUPR98	(+)SNUPΔ, WUPRΔ (-)SNPGΔ, SUPHΔ	WUCOΔ	(+)SNPD93, SNPD98, WUHS93, WUHA98, SUPH93, SUMF98, SNPDΔ (-)WUCO93
WUCO93	(+)WUHCΔ (-)WUHC93, WUHS93, CUTC93, WUCOΔ	WUCO98	(+)CNGP93, CNGP98, SNUP93, SNUP98, CUDI98	WUSTΔ	(-)SNPD93, SNPD98, SUPH98, SNPDΔ
WUST93	(+)WUST98	WUST98	(+)WUPR93, WUST93, ENEMΔ	WUHSΔ	(+)CNGD93, CNGD98, SNUP93, SNUP98, CNPI98, CUCP93, SNUPΔ, CNPIΔ (-)SNPD93, SNPD98, WUHC93, WUHS93, SUPH98, SNPDΔ
WUHS93	(+)SNPD93, SNPD98, SNPDΔ, SNGDΔ, EUHEΔ, WUCOΔ (-)SNGD93, SNGD98 SNUP93, SNUP98, CNPI98, EUHE93, CUTC98, WUCO93, SNUPΔ, CNPIΔ, WUHCΔ, WUHSΔ, CUTCΔ	WUHS98	(-)CUDM98		
		WUHAΔ	(+)SNPD93, SNPD98, SNPDΔ, WUHA98, SUPH98, SUMF98, CUDC98, EUPL98, EUHEΔ (-)ENEM93, ENEM98, WUHA93		

selected elasticities, *Y*'s were variables WUHA, WUHC, WUPR, WUCO, WUST and WUHS, and *X*'s were variables SUPU, ENEM and CUCP. The results of descriptive analysis for the 18 elasticities are summarized in Table 4.

The elasticities 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 $E_{WUCO/SUPU}$, $E_{WUHC/ENEM}$ and $E_{WUHS/SUPU}$, 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

Table 4: Descriptive Analysis of Selected Elasticities

Elasticity	*Mean*	*Standard deviation*	*Elasticity*	*Mean*	*Standard deviation*	*Elasticity*	*Mean*	*Standard deviation*
$E_{WUHA/SUPU}$	1.06	2.34	$E_{WUHA/ENEM}$	0.56	1.42	$E_{WUHA/CUCP}$	0.21	0.35
$E_{WUHC/SUPU}$	-0.69	5.06	$E_{WUHC/ENEM}$	0.04	4.78	$E_{WUHC/CUCP}$	-0.91	2.05
$E_{WUPR/SUPU}$	9.19	9.29	$E_{WUPR/ENEM}$	5.94	8.52	$E_{WUPR/CUCP}$	5.70	7.63
$E_{WUCO/SUPU}$	0.39	3.02	$E_{WUCO/ENEM}$	0.03	1.91	$E_{WUCO/CUCP}$	-0.43	1.15
$E_{WUST/SUPU}$	-5.06	11.72	$E_{WUST/ENEM}$	-3.23	13.55	$E_{WUST/CUCP}$	-9.17	14.45
$E_{WUHS/SUPU}$	5.52	8.59	$E_{WUHS/ENEM}$	5.68	10.46	$E_{WUHS/CUCP}$	1.72	7.53

could be used in monitoring and control of sustainable development. To support sustainability, increase of WUHA, WUHC, WUST and WUHS elasticities were found more desirable.

Development of elasticities provided a base to further develop composite sustainability indices. There are many suggestions to combine different sustainability indicators to develop a single measure to present the approximate overall status [Malkine-Pykh and Pykh, 2001, Morse et al., 2001; OECD, 1998; UN, 2000]. As social, environmental and economical are the major tripartite dimensions of sustainability, for each group an aggregate measure was developed. To make elasticities comparable, *Z* scores were computed by the following equation:

$$ZE_{Y/X} = [E_{Y/X} - M(E_{Y/X})]/S(E_{Y/X}) \quad (2)$$

where $ZE_{Y/X}$ is the *Z* score of the $E_{Y/X}$ as computed by Equation 1, and *M* and *S* are functions that provide the mean and the standard deviation of their arguments, respectively.

The composite index *CI* for each of the social, environmental and economical groups, was computed using the *Z* scores:

$$CI_G = (\Sigma\, \alpha_Y\, ZE_{Y/G})/\Sigma\, |\alpha_Y| \quad (3)$$

where CI_G is the composite index of group *G*, either social S or environmental *E* or economical *C*, as variable *X*, α_Y's are coefficients that are +1 for elasticities with desirable positive sign and –1 for those with desirable negative sign, when *Y* variable is WUHA, WUHC, WUST and WUHS, and $|\alpha_Y|$ is the absolute value of α_Y. Since monotonic increase of WUPR and WUCO could not always be related to sustainable development, their elasticities were excluded from *CI* development. The results of composite indices development are reflected in Figures 1 to 3.

As Figure 1 shows, the sustainability social index, CIS, had a range of –1.59 to 2.36 for the period of 1993 to 1998 for the 16 selected urban areas.

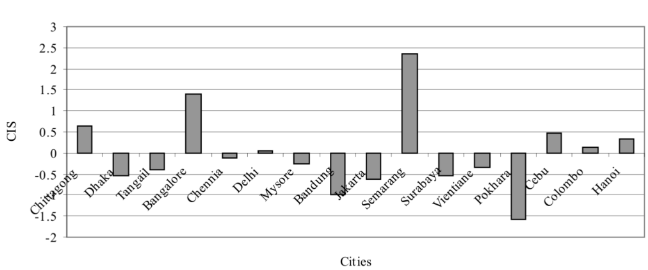

Figure 1: Urban areas sustainability social composite index, CIS.

As is shown in Figure 2, the economic sustainability index, CIC, had a range of –1.83 to 0.99 for the period of 1993 to 1998 for the 16 selected urban areas. For urban areas of Chittagong, Chennai, Mysore, Surabaya, Vientiane, Colombo and Hanoi, no CIC was computed due to database missing values.

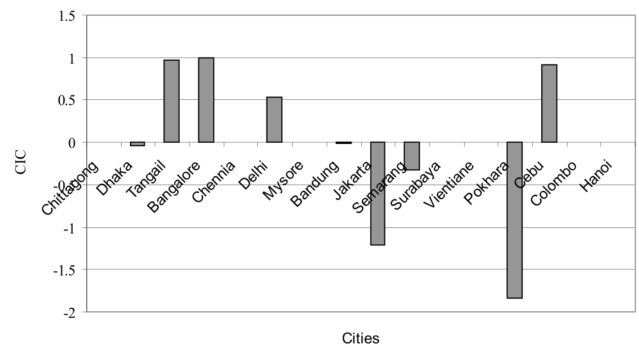

Figure 2: Urban areas sustainability economic composite index, CIC.

As Figure 3 shows, the environmental sustainability index, CIE, had a range of –1.83 to 0.99 for the period of 1993 to 1998 for the 16 selected urban areas. The composite indices reflected the sustainability status of each urban area in connection with the tripartite dimensions of social, economical and environmental. Not always the status of an urban area remained similar with respect to all dimensions.

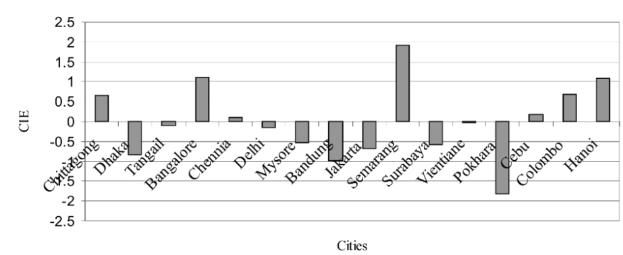

Figure 3: Urban areas sustainability environmental composite index, CIE.

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

$$OSI = (\beta_S\, CI_S + \beta_E\, CI_E + \beta_C\, CI_C) / (\beta_S + \beta_E + \beta_C) \quad (4)$$

where OSI is the overall water resources urban sustainability index, 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, $\beta_S = \beta_E = \beta_C$. When a composite index for category G is missing, β_G is assumed to be zero. Based on Z score computation and usages, as reflected by Equation 2, the values for overall sustainability index should be interpreted in the context of comparative assessment. Figure 4 shows the overall sustainability index of the selected urban areas. As Figure 4 shows, the overall sustainability index, OSI, had a range of −1.97 to 1.53 for the period of 1993 to 1998 for the 16 selected urban areas.

The highest OSI, CI_S and CI_E values were for Semarang and Bangalore, respectively. The highest CI_C were for Bangalore and Tangail, respectively. From Figures 1 to 4 urban area groups were distinguishable. There were urban areas with OSI and CI's positive values and significantly above average. These urban areas can be used as show cases for learning lessons and good practices. There were urban areas of second and third groups with OSI and CI's negative and around average values that can be learned from the abovementioned first group.

Individual urban areas, to monitor their water resources sustainable development through time, can also use the original 18 elasticities, three developed composite indices or the overall sustainability index, without looking to other urban areas for any comparative assessment. To check whether their developments are sustainable, they should monitor and control the index trend through time, as enhancement would be desirable to achieve.

As each urban area is unique in many historical, geographical, political, racial, cultural, social, environmental and economic aspects, their comparative appraisal with respect to sustainable development needs due considerations of these local factors and issues. Consequently, the developed elasticities and indices should be used as complimentary indicators, with other types of indicators and assessments, to enhance sustainable urban water resources. Nevertheless, monitoring of similar indices would facilitate sustainable development.

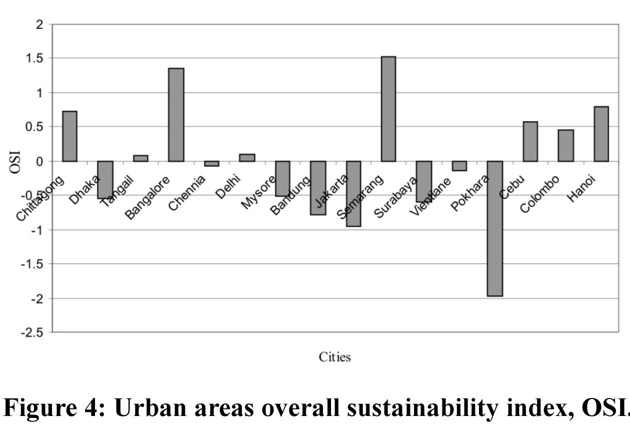

Figure 4: Urban areas overall sustainability index, OSI.

Conclusions

This paper describes an attempt to address urban water resources sustainability for Asian monsoon region through a macroscopic comparative analysis. The study database consisted of 25 variables for 16 countries. The variables were six for water, and 19 for three other categories of social, economic, and environmental. The selected variables and the period of 1993 to 1998 were suitable in the context of 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 type of assessment to enhance urban policies in support of sustainable urban water resources development.

For the 16 selected urban areas in Asian monsoon region, the database univariate analysis showed significant cross-sectional and time-series variations. The observed trends however were not always in favour of sustainable development. Based on mean values, the 1993 to 1998 time-series changes not supporting sustainability were related to variables WUHC, WUST, EUSR, ENEM and CNPI. 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 variable was 12.9% of times significantly correlated with other variables. On an average, a water variable was positively, 5.8%, and negatively, 4.7%, 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. Based on elasticities, composite indices for the tripartite dimensions of social, environmental and economic were developed. Utilizing tripartite composite indices, for comparative sustainability assessment with a single index, an overall sustainability index was also developed. The developed elasticities and indices can be used in monitoring and controlling urban water resources sustainable development. They are suggested as sustainable development indicators for comparative appraisal. The overall sustainability index was used to identify three urban area groups with different sustainability status. The urban areas with significant above average overall sustainability index values can be used as show cases and examples of good practices by other urban areas.

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, especially for the Asian monsoon.

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