Sustainable water management chance for mega cities in developing countries?

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ABSTRACT

In 1950 30% of the world's population lived in cities, in 2000 it was 47%. By 2007 more than half of the world's population will be living in cities. Mega cities are defined to have more than ten million inhabitants. Natural growth (the excess of births over deaths), migration from rural to urban areas, and redefinition of administrative boundaries incorporating rural surroundings support growth of cities to mega cities. Obviously developing countries presently go through the same processes and harmful activities, as developed countries did in the last century, only at an exponentially larger scale, due to the sheer size of their populations.

Mega cities need water in quantities, that severely impact local, regional and global water and matter cycles. Globalisation lets cities compete world-wide for new industries and further economic growth, which again is directly linked to the availability of water and the costs for its supply. The main water problems of mega cities are not restricted to water scarcity, but efficient distribution, production of waste water and resulting receiving water pollution, both of surface and groundwater, flooding and global change impacts.

Costs for large-scale technical water supply and disposal systems seem higher than the costs for smaller autarkic half centralized or decentralized systems. Operation of smaller units also is less vulnerable. Conventional structures of water authorities oppose changes in water concepts. For the environment it is important to make use of local resources such as rainwater, recycled grey water and reclaimed wastewater. For society it is important to check all option carefully. Sustainability indicators are suggested in this context. Apply these indicators to an urban development area it was found that the evaluation results depend on the choice of indicators, physical and time boundaries rather than on data uncertainties.

It was found, that sustainable water management solutions mainly can be influenced in the preplanning and planning phases, when precise data are not available. In consequence indicator based decision support and rather uncomplicated methods to evaluate sustainability are suggested. It is concluded, that sustainable water management may be the only chance for mega cities in developing countries to survive.

Key words: sustainability, water management, circular water management, decision support

1. INTRODUCTION

The need for sustainable water management gained recognition after the United Nations Conference on Environment and Development in Rio de Janeiro in 1992, known as "Earth summit". Ten years later, the World Summit for Sustainable Development held in Johannesburg 2002, re-iterated the need for sustainable development to relieve the pressures on natural resources.

1.1. Development of mega cities and limits of urban growth

Urbanisation ever since increased rapidly on a global scale, especially in developing countries. In 1900, less than 14 % of the world's population was urban, in 1950 30%, in 2000 47% and today 3.3 billion people, more than half of the world's population. There is a strong correlation between urbanisation and economic development. China leads in urban growth. "In urban terms, China is going where no other country has gone before in terms of the number, size, and sheer human scale of its experience" (Pannell, 2003 p. 480). There and in whole Southeast-Asia, Africa and South America a new phenomenon occurs, namely that cities grow together and form mega cities, i.e. in the Pearl River Delta between Hong Kong and Guangzhou, in the Jakarta-Surabaya-corridor and Japan's Tokaido corridor between Tokyo, Nagaya and Osaka (Geiger,2004). The term mega city conventionally applies to cities with over 10 million people. According to this definition in 1950 New York was the only mega city, while there were five in 1975, 17 in 2001 and today more than 21 (Table 1).

However, there is no standard criterion for defining mega cities´ boundaries. For example, Shanghai's city boundaries include a large population outside the city assets, such as land used for agricultural purposes. Other cities, such as Bangkok, Jakarta, Manila, and Taipei may be twice as large as the official, tightly drawn city boundaries and may omit peri-urban areas just outside the city.

Agenda 21 (1992, Chapter 17.3) noted that more than half of the world's population lived within 60 km of coasts. It was projected that by 2020 that proportion would rise to two thirds. Satellite images of the earth by night and recent computer generated images of population distribution (NSA http://www.earthobservatory.nasa.gov) clearly depict differences with major concentrations along the coasts of the Indian and Asian subcontinents. While economic growth and urbanisation are positively correlated, coastal resources are exploited at unsound rates. This is so for the Asia-Pacific region which controls almost two thirds of the globally important atmospheric and oceanic phenomena, such as the Asian Monsoon and the El-Nino Southern Oscillation phenomena (Harvey, 2006).

Migration is a key factor affecting population growth in mega cities. Indonesia and Vietnam are two typical examples of Asia's population shift. In Indonesia, 65 % of people live on the main island of Java, on just 7 % of country's land area. Similarly, in Vietnam coastal populations are growing 20 % faster than the rest of the country (Hinrichsen, 1998).

Table 1: Mega city development (according to United Nations, ….)

1950	
City	Population
New York	12.3

1975	
City	Population
Tokyo	19.8
New York	15.9
Shanghai	11.4
Mexico City	10.7
São Paulo	10.3
Total	68.1

2001	
City	Population
Tokyo	26.5
São Paulo	18.3
Mexico City	16.8
New York	16.5
Mumbai[1]	13.3
Los Angeles	13.3
Kalkata[2]	13.2
Dhaka	13.0
Delhi	12.8
Shanghai	11.8
Buenos Aires	12.1
Jakarta	11.4
Osaka	11.0
Beijing	10.8
Rio de Janeiro	10.8
Karachi	10.4
Metro Manila	10.1
Total	238.6

2005	
City	Population
Tokyo	27.2
Dhaka	22.8
Mumbai1	22.6
São Paulo	21.2
Delhi	20.9
Mexico City	20.4
New York	17.9
Jakarta	17.3
Kalkata2	16.7
Karachi	16.2
Lagos	16,0
Los Angeles	14.5
Shanghai	13.6
Buenos Aires	13.2
Metro Manila	12.6
Beijing	11.7
Rio de Janeiro	11.5
Cairo	11.5
Istanbul	11.4
Osaka	11
Tianjin	10.3
Total	340.5

Mega cities and emerging mega cities range from prosperous city states (i.e. Hong Kong or Singapore) to very-low income cities (i.e. Hanoi or Yangon). Some large urban corridors i.e. Tokyo-Osaka, Seoul-Pusan, and Taipei-Kaohsiung are linked by fast rail and road transport. Others have developed large urban agglomerations around their capital regions, i.e. Kuala Lumpur, Bangkok, and Jakarta (Harvey, 2006). In respect to water supply and drainage they all seem to reach limits of growth. Obviously their water problems cannot be solved with conventional central supply and disposal systems. The mega cities´ problems together with the pressing heritage of the 20th century, that is one billion people not sufficiently supplied with drinking water, two billion people not having adequate sanitation and four billion people polluting water resources, encumber the future.

1.2. Urban water problems in developing countries

Although increasing water demand seems of major concern, water problems of mega cities are not restricted to water scarcity, but embrace efficient distribution, production of waste water, surface and groundwater pollution and flooding, all of which again aggravate water scarcity. In China for instance, the number of cities since the 1980s increased from 180 to 666 (Harvey, 2006), because of industrial development and rapid urbanization. Developing countries go through same processes and harmful activities, as developed countries did in the past, only at an exponentially larger scale due to the sheer size of their populations. On top they face global climate changes affecting local hydrology. Besides, economic development changed water distribution among different users. In Shanghai for instance industrial water consumption in the past 50 years increased from 20% to 69.3% of the total water consumption requiring enormous capital investment, whereby there the most pressing water issue is not quantity, but quality. Groundwater overexploitation in coastal regions also leads to saltwater intrusion, i.e. along the Shandong coastline and in the Yangtze Delta summiting rising sea levels.

Another problem for water management in mega cities is, that data collection cannot keep pace with the fast growth and changes making appropriate forecasts difficult. Time and space resolutions needed for different planning purposes often are not available from standard data sources. Often data records are lost and new projects dealing with issues, that have already been addressed previously, have to start from zero. Reliable financial and social data are of equal importance but seldom were linked to water management in the past. The different dimensions and conventions in the different sectors make it difficult to use data of different sources in a correct manner (Geiger, 1995a). Further planning and management activities often are not adapted to site specific conditions. A common fault is the simple implementation of technology or procedures that are copied from somewhere else and may be inappropriate to the problem at hand.

1.3 Socio-economic implications

Access to public services such as clean water and health services, is closely linked to wealth, whereby in mega cities due to the speed of growth the poor often are not reached by public services. However, access to water is one of the most crucial means to escape poverty. People also recognize water shortage and serious water pollution as technical failures, but rarely identify them as the results of mismanagement or as a social problem. Unfortunately in developing countries water management hardly ever is a holistic action of urban growth and economic development policy, associated water demand, supply and use and wastewater drainage involving administrative institutions, enterprises, public interest groups and general public, as it should be. So many problems simply are administrative.

Due to economic development and population increase in urban areas water needed and originally available for agriculture is now being used for the supply water of cities and industries usually having more political influence due to their economic strength (Geiger, 2005). This causes conflicts between cities and counties, production and living, not even considering environment needs. Action without clear and balanced goals leads to progressing dynamics of the problems. Social justices get lost and social solidarity decreases. It can be observed, that social conventions in rapidly developing countries like China and India are broken. An equal balance between economic, environmental and social needs almost never is achieved. Available techniques, i.e. for water saving often are considered to be too expensive, especially, when water prices charged to the users not meet the true cost of water.

Insufficient competence at various government levels and the artificial subdivision of reality into different sectors makes it difficult to cultivate interdisciplinary thinking. Maybe the biggest constraint is the shifting of responsibilities and duties, a phenomenon met in developing and developed countries alike (Geiger, 1995a). The question is not only, who is legally responsible, but also who is prepared to take it up. Finally political constraints and corruption often are much more significant than the technical and administrative ones. Answers to above problems may lay in highlighting local ownership and governance rather than central control and pricing policies Geiger, 1994).

2. SUSTAINABILITY AND WATER MANAGEMENT

Water in times of urban and economic growth usually is considered a commodity rather than part of development. This in history not always has been the case. The increasing water problems helped to understand, that sustainable water management not only forms development but also future life.

2.1 Ancient views on sustainability in water management

One may remember that Hesiod about 800 BC pointed out the elementary connection between water pollution and health of man. At that time it needed 300 years until sanitary measures were installed in Greek cities, although they existed in earlier cultures i.e. in Mesopotamia. It usually is forgotten, that some 2500 years ago Confucius (551 - 497 BC) urged people to use water sparingly to guarantee the continued existence of permanent water use. It also is delivered, that he said, :"If there were no sustainable rivers, where is the sustainable nation? If there were no sustainable waters, how can we have sustainable civilization? Water, has a long memory". Lao-tse , his respected teacher said: "Rivers, lakes, broad and deep sea, are the cradle of living things ".

Already ancient cities as Miletos practised integrated water management. This needed creativity to combine art and architecture with social needs using the knowledge on hydrology and technical innovations. This comprehensiveness attracted philosophers to deal with water. Thales of Miletos (624 to 545 BC) first established theories on the water cycle, which later were discussed by Platon (427 to 347 BC). Palissy (1510 to 1590) almost two thousand years later finally added scientific explanations. Descartes in his Rules for the Direction of the Mind 1629 stated "If anyone wishes to search out the truth of all things in earnest, he/she ought not to select one special science, for all the sciences are co joined and interdependent", which today may be considered a scientific insight for sustainability. However, the theory of a continuous water cycle and the obviously ever repeating rainfalls and never drying up springs and rivers left the opinion that water resources are unlimited, an opinion which still is reflected today by high water consumption in regions, where water is scarce. Water became a commodity which everyone uses and disposes without thinking of its origin and its destination.

Maybe for the first time the idea of sustainability was quantified by Carl von Carlowitz (1645 - 1714), a German forestry engineer (Sylvicultura Oeconomica, 1713). He defined the very simple balance which has to be fulfilled to reach a sustainable status for a given forest unit: "the amount of wood cut in one year should be equal or less the amount of wood growing up in one year". At last this is a clear definition of what is meant by the expression "carrying capacity of supporting ecosystem".

2.2 Remarks on today's understanding of sustainability

Today's sustainability discussion usually is linked to the World Commission on Environment and Development, which in 1987 defined sustainable development as a "development that meets the needs of the present generation without compromising the ability of future generations to meet their own needs" (Brundtland report). Before that in the 70ies of the last century United Nations (1994) and UNESCO (i.e. 1987 and 1996) through its International Hydrologic Programmes (IHP) strongly promoted integrative water management. Dimensions of sustainability then were agreed to be economic, environmental and social. There were, however, different opinions, which dimension should be dominant and if equal by which dimension equity is expressed (Geiger, 1995a).

Figure 1 illustrates different view of sustainability. The circles in Figure 1(a) identify the three dimensions environment, society and economy as being equally important. The Interactive system-environment model of Figure 1 (b) refers to the ideas of system theory. It describes that the human-social-system is a part or a sub-system of the ecosphere-system and again the economic-system is sub-system of the human-social-system. This is correct in a scientific view but does not reflect the typical priorities in practical decision making. There typically the environment is not the biggest and the dominating system but the weakest, as indicated by Figure 1(b). All of these presentations are not helpful, to evaluate sustainability, unless the circles would be given dimensions.

There are different opinions, which dimension should be dominant and if equal by which dimension equity is expressed. To express equity, a monetary currency certainly is not satisfactory. Environmentalists may have the opinion that the most sensitive dimension of sustainability is the environment being connected strongest to the potential of development for future generations. Thus the World Conservation Union, the United Nations Environment Program and the World Wildlife Fund for Nature defined sustainable development as a development that improves: “the quality of human life while living within the carrying capacity of supporting ecosystems” (IUCN,UNEP, WWF 1991 extracted from UNESCO n.d.).

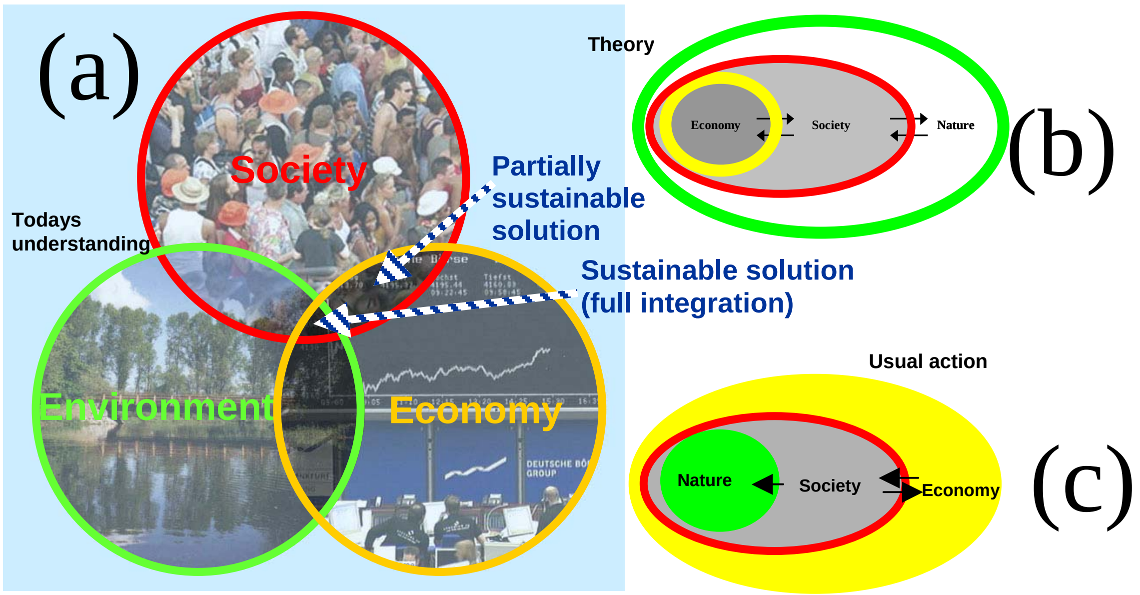


Figure 1 The three dimensions of sustainability (a) according to Munasinge 1993 (b) according to Kanatschnig 1992; extracted from Russ, 2000)

According to the Commission of the European Community, the characteristics [criteria] of sustainable development are to maintain the overall quality of life and the continuing access to natural resources as well as to avoid lasting environmental damages. Sustainable water management has to ensure, that today’s and future societies can live without compromising the natural hydrological cycle and ecosystem integrity (UNESCO, 1996). In short: “sustainability avoids future regret for decisions made today” (GEIGER, 2004). However, all of these definitions are too general an thus of limited use for decision making in water management.

2.3 View of sustainability in different development stages

The different components which make water management sustainable did not receive the same priorities at all times. At different stages of societal development, different objectives are considered more important. In the pre-industrial society, emphasis was placed on drinking water supply and irrigation. In the industrial society, generation of hydropower and waste disposal and transport are prioritized. Finally, in the post-industrial society, high emphasis is placed on aesthetics and ecology. Figure 2 sketches the interaction of industrialization and the environmental condition. While the existence of changing priorities must be recognized, still lower priority uses cannot be neglected over a long run of time, because of the interdependency of various uses.

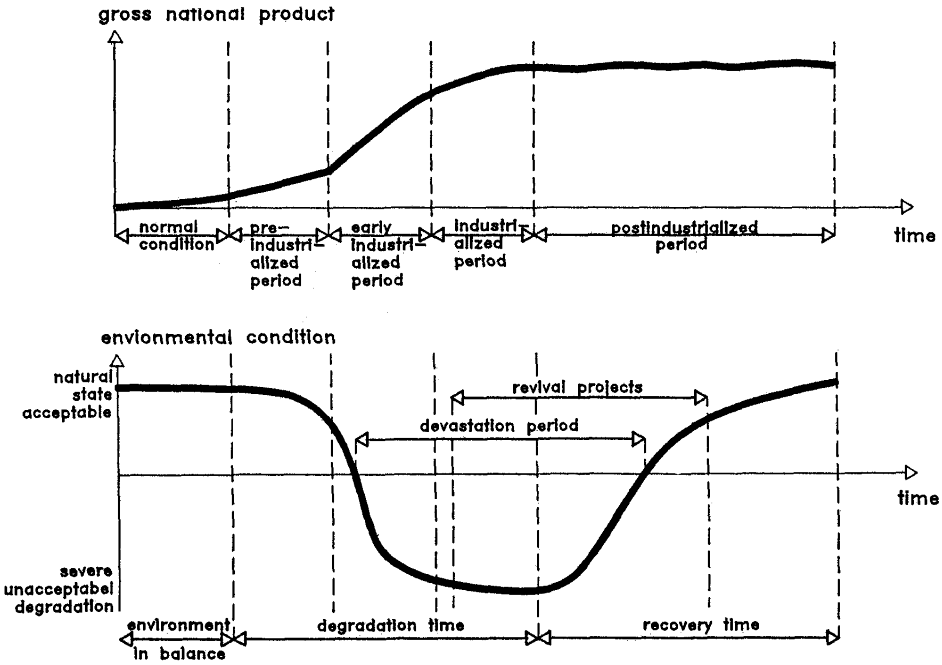


Figure 2 Interaction of industrialisation, economics and environmental condition (UNESCO, 1995)

3. SUSTAINABILITY ASSESSMENT AND OBJECTIVES

For the evaluation of sustainability there is a basic distinction between:

- Strong sustainability: preservation of natural capital cannot be substituted by any other form of capital and a balance must fulfilled for every case.
- Weak sustainability: depletion of natural capital can be substituted by man-made capital, as long as the sum of both is not decreasing.

This distinction is important for the definition of objectives for sustainability evaluation. Politics today still assumes that one only should met weak sustainability. The latter global warming discussion may change this attitude. To solve the severe water problems in mega cities, it is strongly recommended to only strive for strong sustainability.

3.1 Structure for sustainability evaluation

The first intermediate step for any evaluation is the classification of objectives. To achieve the objectives, criteria (sometimes called index) must be defined, which may comprise of one or several indicators. Figure 3 suggests a thinking structure for the sustainability evaluation. Essential is, to select indicators, that are not overlapping and calculable. Vital is, to merge these indicators in a way that evaluation for sustainability is not distorted. Finally the indicators are calculated for all alternatives and merged to one figures, that allows to rank the alternatives.

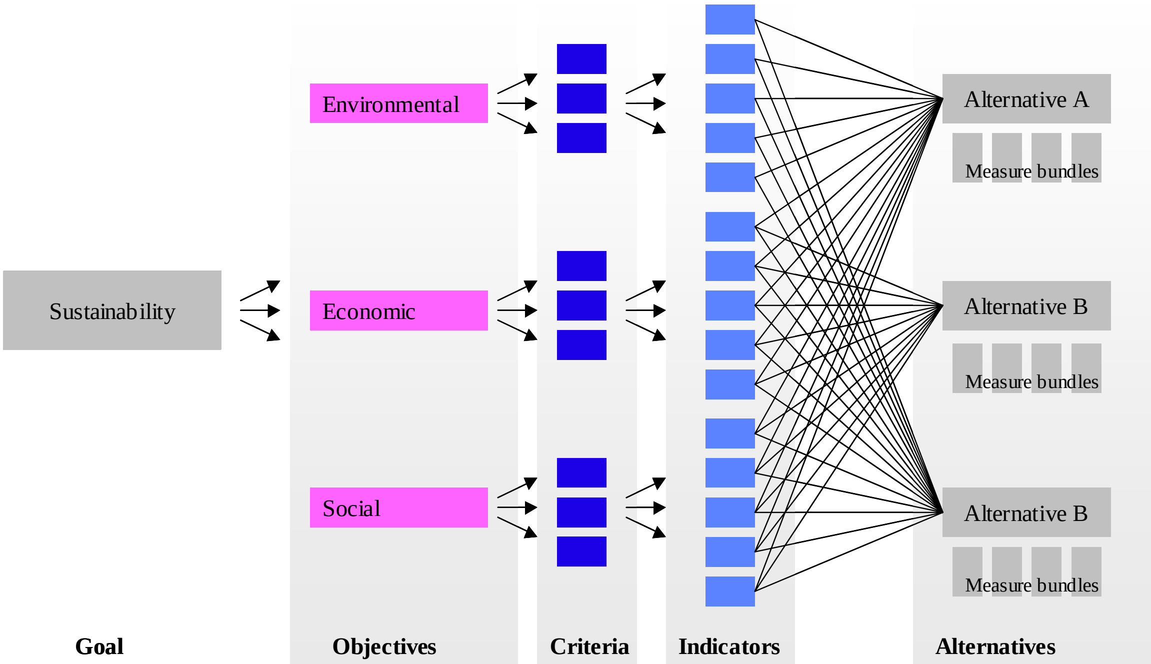


Figure 3 Structure for sustainability evaluation (Geiger et al., 2006)

3.2 Sustainability in different planning stages

Although water systems consist of quite similar sub-systems, i.e. freshwater extraction, treatment and distribution, greywater recycling, storm water drainage and wastewater reuse, collection and treatment, due to local hydrologic, geologic, but also socio-cultural and economic conditions in their composition each case should reflect an unique solution (Allon et al.,2004). To find the "best" option for a water concept is a difficult task, as planning horizons and data availability and accuracy in different planning stages vary significantly. Further the interaction of urban water systems with surrounding areas and river basin hydrology make it difficult to identify physical boundaries for evaluations. Even more significant is, in which planning phase the options at hand have to be evaluated. Table 1 relates assessment goals of different planning phases to possible evaluation criteria.

Table 1 Goals of sustainability evaluation in different planning phases

planning phase	**assessment goals**	**evaluation criteria**	**comments**
feasibility study	to decide on general requirements i.e. for water supply, storm drainage, waste water reuse, collection and treatment, protection of receiving waters and flood control.	strongly depend on natural and local conditions, interests of stakeholders and political priorities	at this stage most money can be saved, environment can be protected best and socio-economic concerns considered most.
pre planning	to decide on systems, i.e. for water supply, drainage, waste water treatment, surface or groundwater protection, etc.	strongly depend on natural and local conditions, interests of stakeholders and political priorities.	at this stage still money can be saved, environment can be protected and socio-economic concerns considered largely.
planning	system or protection	may address i.e. cost	economic advances

	level largely are firm, only technical layout in more detail can be evaluated.	efficiency, society´s acceptance, etc.	and environmental upgrading maybe marginal.
design	only material choice, etc. may be decided.	criteria may address costs, durability etc.	saving potential is already quite small.
implementation	different construction processes may be sequenced.	construction options be judged for costs and environmental impacts	Improvements in all respects are marginal
operation	different operational schemes may be compared	cost and financial burden for the users	improving potentials again are significant, but much less as in feasibility/preplanning

4. CALCULABLE INDICATORS AND THEIR EVALUATION

There are maybe two basic different approaches to provide decision support for selecting most sustainable water management options. The one is, to simulate the (dynamic) processes leading to social, economic and environmental impacts or consequences as a result of different planning, design or operational options. The second is, to make a (static) assessment of system situations in form of water and mass balances or other environmental indicators, social and economic indices based on characteristic system conditions. While dynamic simulations of any kind require detailed and precise data, static assessments simply can be based on lumped data. Referring to Table 1 sustainability can be influenced most in the initial planning phases, where detailed data usually not exist, while during design stages more detailed data are available, but sustainability can be influenced to the smallest amount. Further it should be noted, that the risk of imprecise evaluation results is high, when lumped data are too vague, but even higher, when process modelling is mainly done on the basis of assumptions and literature values. Most reliable answers may be obtained in the pre-planning or planning phase if possible involving hydrologic type of modelling approaches. In consequence this chapter elaborates on indicator based decision support tools. To formulate calculable criteria, which allow for unbiased evaluation of sustainability and functional evaluation methods, however, is a most difficult task.

4.1 Suggestion of reliable indicators

Many indicators have been suggested to achieve environmental, social and economic objectives. To achieve strong sustainability, that is the preservation of natural capital without allowing for substitution by any other form of capital for every case the following three criteria are suggested:

(1) the indicator/index of financial burden (social)
(2) the indicators for sustainable groundwater and surface water use (environmental)
(3) the indicator/index of "Actual Cash Value" (economic)

The indicator formula and their objective values are listed in table 2.

Objectives and criteria, which make water management sustainable did not receive the same priorities at all times. At different stages of societal development, different objectives are considered more important. Pre-industrial societies usually emphasize drinking water supply and irrigation. In societies undergoing rapid economic development and industrial societies, generation of electric power, water supply for industry and population, safe drainage and waste disposal, usually after a minimum of treatment are given priorities. In post-industrial societies, as they exist in most European countries high emphasis is placed on aesthetics in urban planning, extensive protection of water resources and ecology.

Table 2 Indicator formula and their objective values

indicator/index	**formula**	**objective value**
financial burden (social)	$I_{FB} = \frac{CO_{DW} \cdot C_{wm^2} / 1000 \cdot 365}{I_{average}}$ CO_{DW} Water consumption per day per capita [l/d] C_{wm^2} Unit costs for water [RMB/m³] $I_{average}$ Annual av. income [RMB/year], i.e. 30000 RMB/year	If people would be ready to spend about 10% of their income, the objective value is SFB = 0.1. Up to the portion of 10% the costs for water are considered sustainable, whereby a higher portion means an unsustainable financial burden.
ground and surface water use (environmental)	$I_{GW/SW} = \frac{CO_{GW/SW}}{RG_{GW/SW}}$ I_{GW} Indicator for groundwater use I_{SW} Indicator for surface water use CO_{GW} Consumption of groundwater CO_{SW} Consumption of surface water RG_{GW} Regeneration of groundwater RG_{SW} Regeneration of surface water	When the consumption of groundwater is equal to the regeneration of groundwater, extraction and recharge are in balance. This situation may be considered sustainable. Therefore, the objective value for groundwater use is SGW = 1.0. Similarly, the objective value for surface water use is SSW = 1.0.
"Actual Cash Value" (economic)	$ACV_{OC} = NV_{OC} \cdot (1 + RPI) \cdot \frac{(1+IR)^n - (1+RPI)^n}{(1+IR)^n \cdot (IR - RPI)}$ $ACV = ACV_{IC} + ACV_{OC}$ ACV_{OC} Actual Cash Value of operational costs ACV_{IC} (Actual Cash Value of investment costs)= NV_{IC} (only valid if hole investment made in base year)	The smaller the costs the better

4.2 Overview on Multi-criteria decision making

An applicable approach for integrative evaluation of water systems is the Multi-criteria decision making (MCDM), which allows for multiple objectives and value judgments whereby subject is wanted. These methods differ from others, as they account for multidimensional objectives and criteria, conflicting, and intangibles. MCDM approaches encompass multi-objective decision making (MODM) methods and multi-attribute decision making (MADM) methods. Figure 4 provides an overview of common multi-criteria decision making processes.

MODM and MADM support decision making in case of multiple and conflicting objectives, intangibles evaluation criteria and various points of view. They aim for a clear presentation of potential impacts of different choices assumes that criteria can be partially traded off against each other. MODM methods deal with decision problems where a most promising decision alternative has to be identified from an infinite set of options. MADM methods constitute a methodological framework for ranking a predetermined set of alternatives. The approach to rank a predetermined set of various alternatives is equivalent to the approach to evaluate sustainability for the Olympic project.

Thus, MADM methods play an interesting role to evaluate sustainability for the water management concepts.

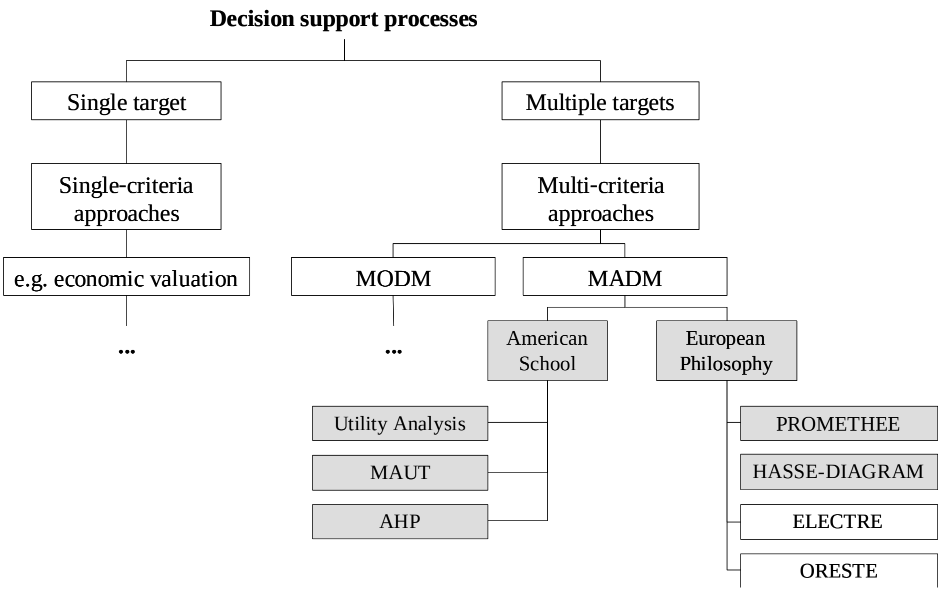


Figure 4 Overview of common multi-criteria decision making processes (Geiger et al., 2006)

MADM methods can be divided into two categories. Methods using single criterion synthesizing approaches assume that decision makers have a clear idea of the utility of criteria values and related preference weights. They can be referred to as approaches of the 'American School'. Outranking methods are approaches of the 'European Philosophy', which are based on the assumption that decision makers do not have a clear idea about their preferences and that therefore consequences of different preference weights have to be demonstrated. They consider incomparability of alternatives rather than providing a set of ideal solutions (Geldermann, 2002)

4.2 Suggestion for practicable evaluation of different alternatives/scenarios

For evaluation of different alternatives/scenarios two methods are explained and referenced in some detail, namely the Analytic Hierarchy Process (AHP) and the short bucket theory (SBT).

The **Analytic Hierarchy Process (AHP)** was developed by Thomas L. Saaty in the early 1970's for decision structuring and analysis by using matrices and linear algebra for the formalisation of a decision process (Merz and Buck 1999: p.46). It allows to structure complex decision problem in a hierarchical order, thus exhibiting the relationship between the decision alternatives, objectives and evaluation criteria. Thus AHP facilitates analysis by transforming a complex evaluation into a hierarchy of smaller more manageable sub-evaluations. A complex dataset is thus decomposed into smaller constituent elements between which pair wise comparison is elicited. AHP is a compensatory decision methodology as alternatives that are deficient with respect to certain objectives can compensate by their performance with respect to other objectives (Merz and Buck, 1999).

To rank the decision alternatives the complex decision situation is structured hierarchically. The top element of the hierarchy represents the overall goal of the decision. The hierarchy decomposes to more specific evaluation attributes such as objectives and manageable decision criteria (sub-objectives) until a level of measurable indicators is met. The final level is constituted by the different alternatives. This hierarchy can consists of as many levels as possible, with each level influencing the paramount level and being influenced by the subordinate level (Merz and Buck, 1999). Thus AHP is applicable method to evaluate sustainability of different water management systems.

The **Short bucket (SBT)** also can be used to calculate the sustainability of different scenarios (Lu Zhibo, 2006). Therefore it is especially useful in EIA. According to SBT, the capacity of a wood bucket hoop by wood pieces does not depend on the longest piece or the average piece, but on the shortest piece. If one wants to increase the capacity of the bucket, one must improve the length of the shortest piece. This theory also fits sustainability evaluation. Sustainability of a urban water system is like the wood bucket. It is decided by the shortest indicator value (similar to the wood piece), which constraints sustainable development or which defines the sustainability of a system. This approach for evaluation of sustainability pays more attention to the most deficient factor.

The principles of SBT can be followed in figure 5. In the process of calculation, one must distinguish positive and negative indicators, because different equations should be adopted according to their attributes. If there is only one indicator in one index, then the equivalent radius is the standardized value of the indicator itself. If there are two indicators in one index, the equivalent radius is equal to the smaller standardized value of the indicator.

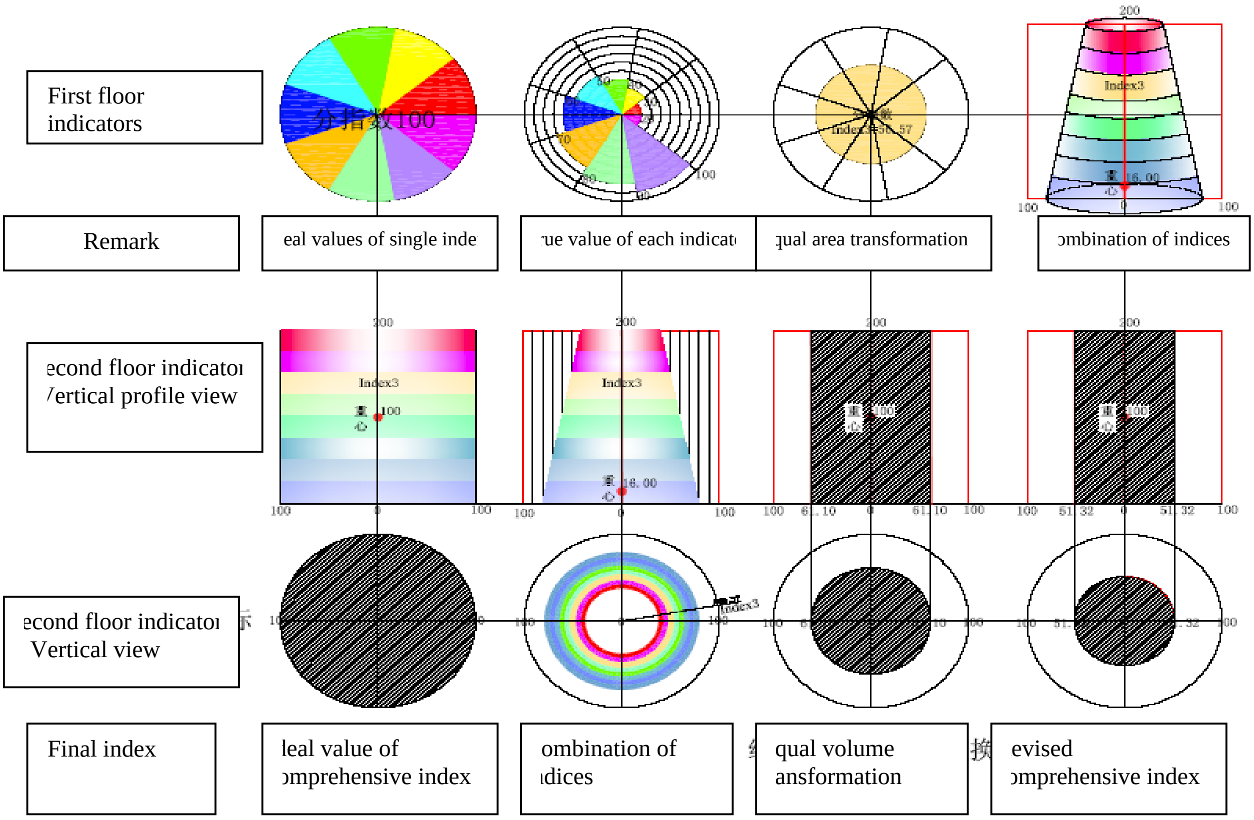


Figure 5 Principles of short bucket theory (Lu Zhibo, 2006)

5. EXAMPLES FOR OLD/NEW DIMENSIONS IN URBAN WATER MANGEMENT

A small selection of examples of integrated urban water management, which aim for sustainability are presented. On purpose the oldest example, known to the author, namely the water supply, matter recycling and storm runoff infiltration system of ancient Mohenjo Daro approx. 2500 BC.

5.1 Mohenio Daro – an ancient sustainable solution

The early Harappan civilization developed on the arid plains of the Indus Valley of Pakistan and northwestern India in the middle of the 3rd millennium BC and lasted for about five centuries. The ancient urban dwelling of Mohenjo Daro was a major urban centre of the Harappa Culture. Access to water resources and their maintenance was of vital importance the existence.

Water supply and sewage disposal at Mohenjo-Daro has been extensively studied by M. Jansen (1999). The quality and amount of the Mohenjo-Daro data allowed to investigate, why some houses at Mohenjo-Daro had wells and others did not and quantifying which wells within buildings can be interpreted as public and which as private. Even more Mohenio Daro seemed to have a water concept comprising of rainwater harvesting, waste water reuse and storm and wastewater infiltration after sedimentation. Figure 6 gives some insight into this integrated water concept.

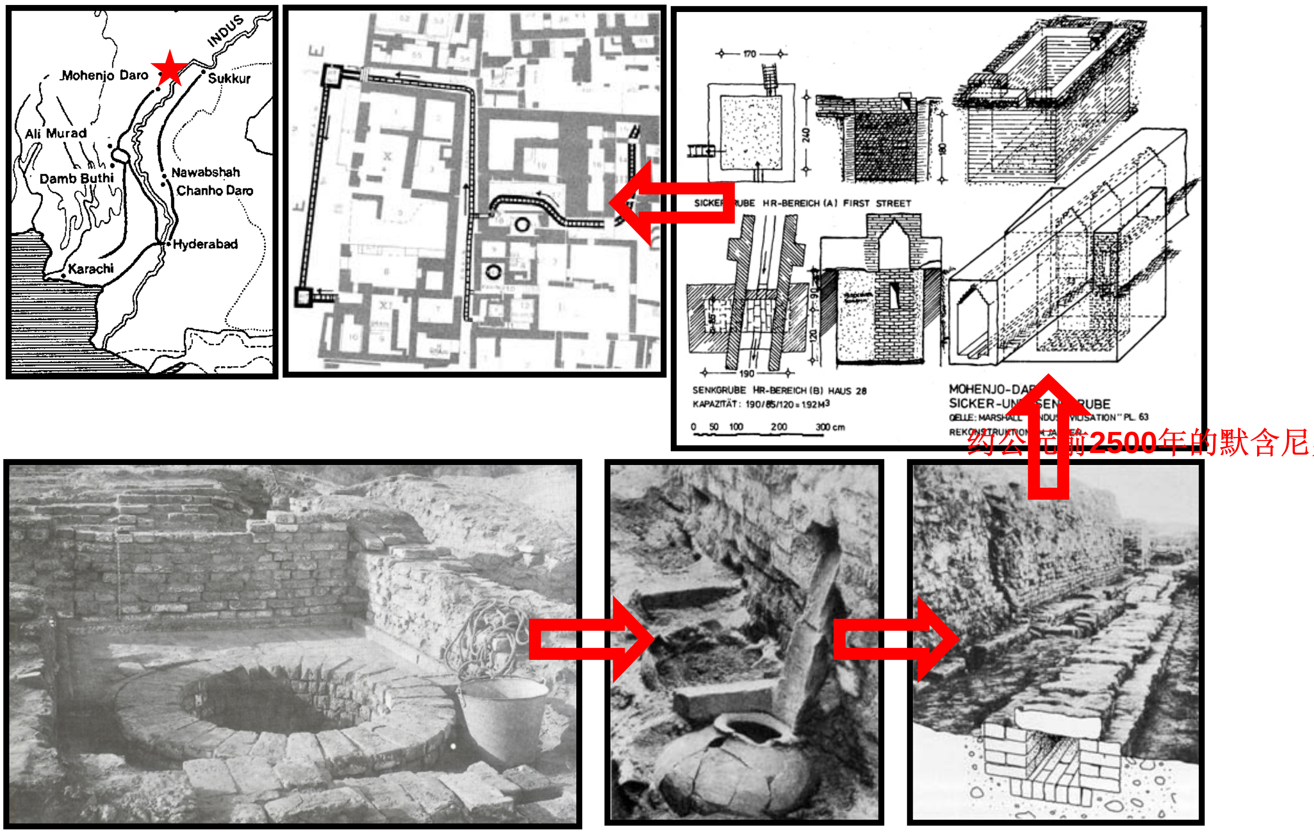


Figure 6 Water supply and drainage concept of Mohenio Daro, approx. 2500 BC

5.2 Flood control and groundwater recharge - Pilot study Beijing

Beijing is listed among the world top ten cities suffering from a lack of water resources. The total amount of annual rainfall differs significantly, i.e. from 242 mm in 1869 to 1406 mm in 1959. Unevenly distributed rainfalls, where 80 % of the average annual rainfall of 640 mm appears within three months and urbanization with a high rate of sealed surfaces cause local flooding and reduce groundwater recharge. This in the past decreased groundwater levels in West-Beijing by about 23 meters between 1958 and 1986.

The semi-arid conditions call for integrative storm water management. The technical challenge is that a high degree of flood protection is guaranteed and at the same time groundwater recharge is maximised, which again enhances local water resources. These goals are contradictory, because of the high dynamics of storm runoff and flow limitation necessary for treatment and infiltration to the underground.

In 2000 a four-year joint Chinese-German pilot project with substantial support by The German BMBF and the Chinese MOST was launched to find technical solutions to bridge scarcity and surplus of water as well as demand and availability. The Beijing Water Bureau, mainly through the Beijing Hydraulic Research Institute together with five companies (Dorsch Consult Ingenieurgesellschaft mbH, Munich; GEP Umwelttechnik GmbH, Eitorf; UFT, Bad Mergentheim; WASY GmbH, Berlin; ibb Ingenieurbüro für Bauwesen Professor Burkhardt GmbH & Co, Munich) and two German Universities (Dep. of Urban Water Management, University of Essen and Dep. of Water Quality Control, Technical University Berlin) developed various solutions and outlined different conceptual approaches (Geiger, 2003).

Cities like Beijing have a variety of different types of urban development and solutions largely depend on the type of development. It was not an easy task to choose project areas that represent the overall situation in Beijing. Table 2 summarizes the characteristics of the selected demonstration areas.

Table 2 Characteristics of the selected demonstration areas

Project area	**Precondition**	**Type of change**	**Future land use**	**Area in ha**
Beijing Institute of Geological Engineering	dense institute and residential	none	residential/commercial	3
Tianxiu Garden	agricultural	new development	residential	11
Hydraulic Engineering Foundation Works	institute	densification	commercial/residential	7
Haidian Park	partly agricultural	new development	recreation	38
Beijing Technical School of Water Resources and Hydropower	school/residential	none	residential/school	4
Shuangziyuan	residential	modification	residential	2

On the grounds of the **Beijing Institute of Geological Engineering** in Bali Zhuang as drainage concept detention of surface runoff, followed by different stages of mechanical treatment prior to infiltration into the underground through recharge wells was chosen. It should be noted that for general applications, this concept not necessarily is economical. The purpose was to demonstrate that even under severe space constraints the goal of storm water retention and infiltration may be achieved.

The drainage concept suggested for **Tianxiu Garden** residential area focused on the collection and storage of roof runoff for recharge of evaporation losses in the artificial lake within the area and infiltration of surplus water into the underground. The overflow of this system led into an existing storm sewer, which detained and finally drained street runoff to Qing river. The system was designed for a five-year rainstorm condition.

The drainage concept in the residential area of Beijing **Hydraulic Engineering Foundation Work** (EFW) includes reuse for treated greywater and filtrated rainwater. Greywater from one building is collected in a sump and treated, stored (service water) and reused for toilet flushing. Rainwater from the roofs of two buildings is collected, filtered, stored and additionally used for toilet flushing in another building.

The buildings of the **Beijing Water Conservancy School** accommodate classrooms and laboratories, residential units for the students, administrative and operational units. The school has a long tradition in educating technicians in the fields of water supply, wastewater treatment and drainage systems. Therefore it was decided to install a large variety of water-saving, rainwater harvesting, storm water treatment and groundwater recharge facilities useful also for the practical education and training of students. Roofs were partially connected to a storage tank for rainwater reuse, partially directly connected to a groundwater recharge well in a sandy layer close to surface, partially directly drained to a lawn for aerial infiltration. A playground was covered with pervious asphalt and pervious concrete paving. While surplus water from playgrounds and service streets was collected and treated for groundwater recharge, the water infiltrated and stored in an underground layer was extracted for toilet flushing in times when the rainwater collection storage tank was empty. On the institute grounds also different test facilities were installed in order to compare the infiltration capacities of different pervious pavement types and to test different layouts of first flush devices. The facilities were monitored by students.

In **Haidian Park** the intention was, to demonstrate, how within the park area ponding during severe rainstorms can be avoided. It was feared that due to ponding landscaping and grass would suffer. Furthermore, for safety reasons, a storm runoff treatment structure similar to that of the institute grounds of Geological Engineering Bali Zhuang was used for treatment of the collected surface runoff from streets and parking lots, whereby the parking spaces were covered with concrete lawn turf stones. After treatment this runoff entirely infiltrated to the ground for groundwater recharge.

The water concept in the **Shuangziyuan** residential area included storage and treatment of roof runoff for later use for irrigation. Furthermore, the wastewater from the four apartment blocks and other auxiliary buildings was treated in septic tanks using anaerobic digestion. After treatment, the wastewater is transported into a cistern and used for greenbelt irrigation and car washing.

5.3 Sustainability evaluation of planning alternatives for Olympic Green 2008

Beijing and the Olympic Committee emphasises “Green Olympic Games and Human Olympic Games”. One of the key issues is to ensure sustainable ecologically sound development. For this water plays a significant role. Quality problems and sinking groundwater tables are key issues in Beijing. In a joint effort, funded by the German BMBF and the Chinese MOST, six German and three Chinese partners cooperate in this project.

Within the project “Integrated Water Management” a practicable method for the evaluation of water management options for their sustainability was applied to assist the best choice of the water concepts for the Olympic Grounds in Beijing. Three alternative concepts to supply and drain Olympic village were investigated, whereby one concept conventionally connected Olympic village to central water supply and treatment systems, the second involved storm water detention and infiltration and the third in addition greywater recycling. It became evident, that the evaluation results depend on the choice of indicators, the choice of physical boundaries and the choice of time boundaries. Therefore for each sustainability evaluation it is recommended to establish a matrix explaining objectives, indicators and boundaries. The calculation of the sustainability indicators and the evaluation procedure was realized in context with a GIS-based database and monitoring system. Other projects elaborated on flood protection, water saving technologies, utilization of greywater and water quality in the Olympic lake.

6. FUTURE NEED FOR ACTION AND RESEARCH

For sustainable water management in mega cities need for action and research is seen for

- quantifying the effects of human activities on environment and society, to forecast consequences of policy options
- linking the time scales of up to ten years for assessing existing conditions by monitoring and modelling processes in river catchments and of short times available for fixing individual measures (sometimes within one year).
- defining calculable indicators for different planning phases, which must be applied whatever the case may be and which could be applied optionally in addition
- developing criteria for the independence of indicators from each other.
- identifying compulsory data accuracies for each indicator in every planning phase

- deriving an unbiased common and non-monetary currency for merging indicators of different sustainability categories
- categorizing available evaluation procedures for their subjectivity and applicability in different planning phases
- establishing practical standards for sustainability assessment and evaluation categorized into minimum and advanced requirements

In the following some related research underway within the UNESCO chair in Sustainable Water Management program is introduced.

6.1 Uncertainties of data and their effects on evaluation results

When calculating the value of indicators, the precision depends mainly on the input information of the parameters which are contained in the formula of calculation. The question is, how the uncertainty of input parameter values affect the output indicator results. This presently is investigated for a case using the indicators financial burden, groundwater and surface water use (see table 2). The parameter variables used for the calculation and the distribution type of their values are listed in table 3.

Table 3 Parameter name and distribution type of parameter values used in the case study

Parameter Name	**Statistical Distribution**
Parameters for financial burden	
apartments	one value
person per apartment	Classification
consumption water person per day	Gauss
water costs	Classification
water demand toilet	Gauss
water demand laundry	Gauss
water demand bath_shower_tap	Gauss
water demand cleaning	Gauss
water demand kitchen	Gauss
Parameters for groundwater use	
portion of groundwater used for public supply	negative skewness*
runoff coefficient [] street	Gauss
runoff coefficient [] Greenland	Gauss
runoff coefficient [] roof	one value
initial loss [mm] street	Gauss
initial loss [mm] greenland	Gauss
initial loss [mm] roof	one value
percentage of area with infiltration	Gauss
overflow height [m]	negative skewness*
Infiltration capacity [m/s]	Gauss
portion of infiltrated non interflow water which drains to the groundwater layer, which can be used for drinking water [%]	Gauss

* For the “negative skewness” distribution type the relevant distribution functions are difficult to decide. Then it is converted into “classification” distribution in the calculation procedure.

There are four different types of probability distribution of the parameter values: “Gauss Distribution” (so-called “Normal Distribution”), “Negative Skewness”, “Classification Distribution”, and “One Value”. “One Value” means that the parameter value is a fixed number, which is easiest to deal with. Given the distribution functions and characteristic values, the possible ranges of parameter value can be simulated. Because the relevant distribution functions for “negative skewness” are difficult to choose, parameter distribution for this type is converted into “classification”.

The indicator calculation procedure is demonstrated in figure 5. The parameter values (x_1,x_2,x_3…) together with different types of variations are put in the calculation model (f(x)) and the indicator results (y_1,y_2…) and their variations are put out. If the indicators are ranked and incorporated into one value, the total calculation result can be displayed in a figure with a variation area (see the bottom of Figure 5). In this way the uncertainty of the model calculation is found.

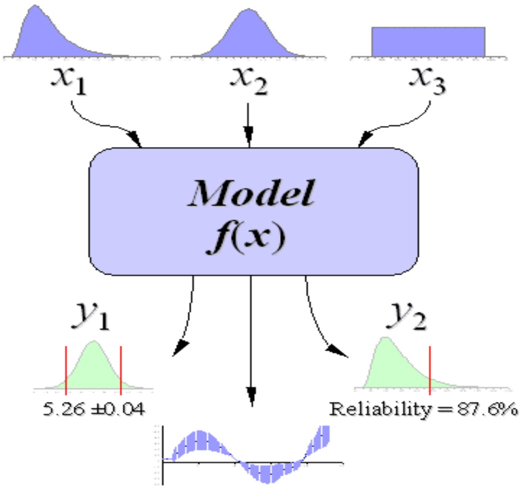
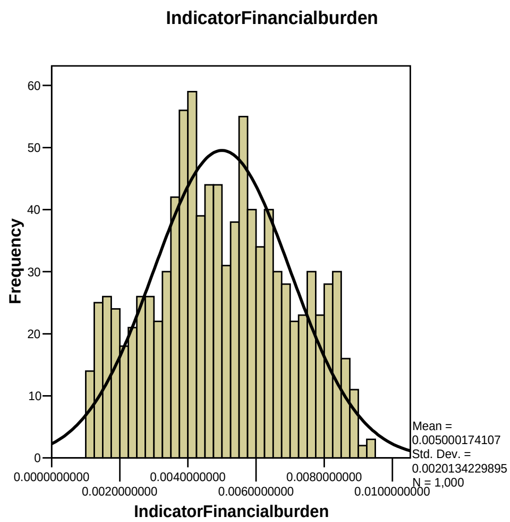


Figure 5 The working procedure of uncertainty analysis of indicator calculation model (Wittwer, J.W. 2004)

Monte Carlo method may be chosen to simulate parameter values so that indicators can be computed. Running Monte Carlo 1000 times and the number of parameter variables in the indicator calculation model being 20 for a test area the calculation results for the indicator of financial burden are shown in figures 6 and 7.



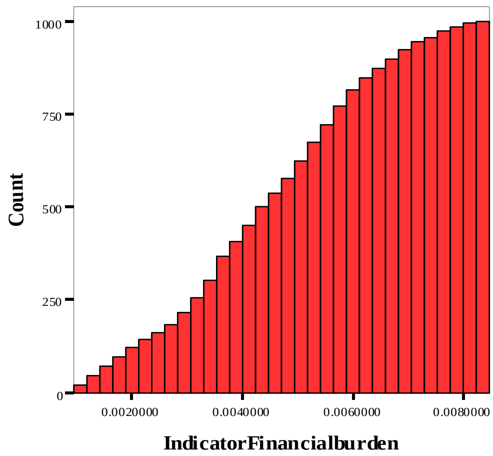


Figure 6 Probability distribution for indicator values of financial burden (Huo Li, 2007)

Figure 7 Cumulative probability for indicator values of financial burden (Huo Li, 2007)

The probability distribution in figure 6 for the indicator values of financial burden looks like “Normal Distribution” except some extreme values. The mean value is 0.005; the maximum value is 0.009; the minimum value is 0.001; the Standard Deviation is 0.002; the Skewness is 0.031; the Kurtosis is -0.823. The standard deviation of financial burden indicator is small. The most possible value range takes up approximately 30% of the total range. Still under investigation is, inasmuch probability distributions of different indicators may influence the ranking of alternative scenarios.

6.2 Theory and structure for the Hierarchical Decision Support Concept

For different levels of criteria a two stage decision support system is under development. The two stages are selection/combination criteria and advanced criteria. For stage one it is suggested to establish measure catalogues, from which according to pre-designed selection/combination criteria independent from the user scenarios are established and ranked. Prior to selection/combination, the measures must be checked for their hydrologic, geologic and socio-cultural applicability to the area under consideration. This step is added to the conventional approach to water management as a basic pre-condition. Only a small number of alternatives then is investigated in more detail to define the final strategy. This is called decision support level two. Figure 8 provides a sketch of the Hierarchical Decision Support Concept for Sustainable Water Management.

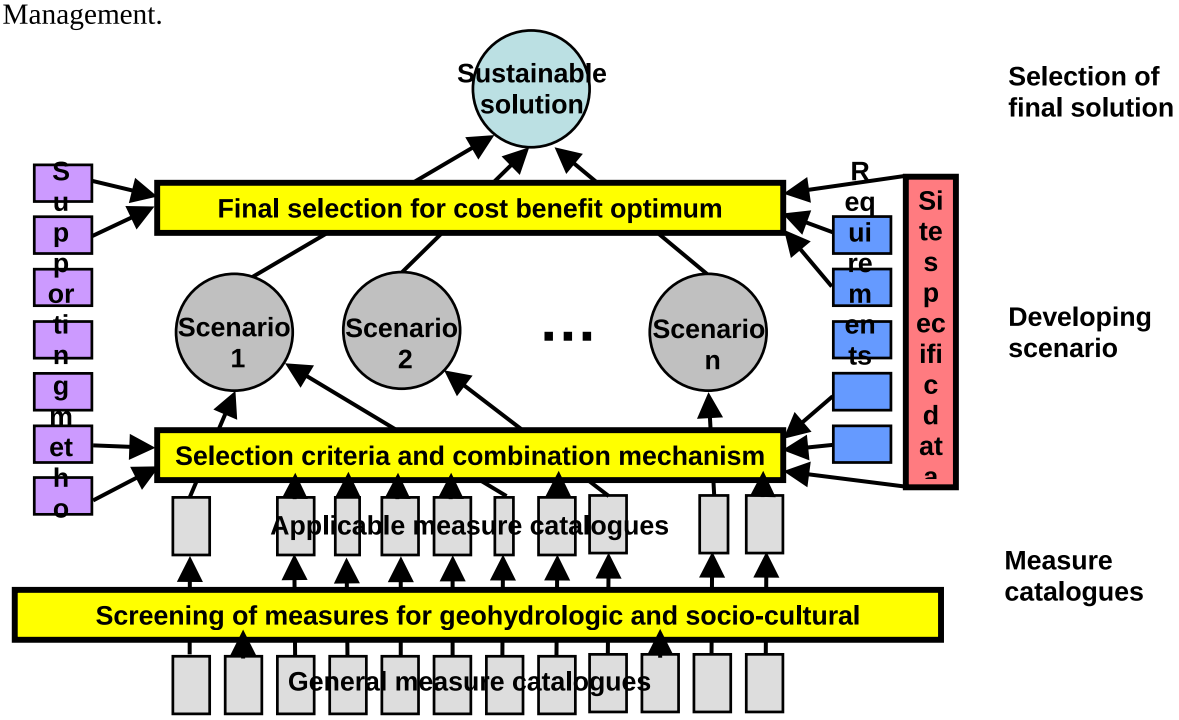


Figure 8: Hierarchical Decision Support Concept for Sustainable Water Management

For decision support level two it is suggested to establish a GIS based detailed data base which dependent on the objective also can be updated by satellite images or field surveys. Starting from this database data for the planning horizon are extrapolated. Then suitable modelling techniques according to data availability, planning goal, time availability and available finances are applied. As a next step pre-selected scenarios are optimized and checked if they can be implemented establishing stage plans and detailed cost estimates. The final selection of the most cost-efficient solution again similar to decision support level one must be then on the basis of environmental and resource effects checking it again for its social acceptance and financing possibilities.

The advantage of the system is that it can be followed by decision makers. This is not the case with most of the decision support systems which exist so far, where the decision makers have to trust that complex modelling schemes are true. Even more, with the suggested system the input data used for calculations are laid open to the decision maker and he himself can judge on the validity of inputs.

6.3 Definition of catchments' boundaries for sustainability evaluations

Already the definition of the catchments' boundary is not an easy task, as it depends on the study objectives. To reduce ammonia toxicity or oxygen depletion downstream of an urban area for instance it may be sufficient to limit emitted pollutant concentrations and thus to assess the situation within the urban area only. If the problem is nutrification or sedimentation in far distant water bodies agricultural inputs as well as urban discharges have to be assessed within the whole contributing area. Later planning of abatement measures can be restricted in the first case to the emission sources within an urban area while in the second case all possible interactions with different land-uses must be included and the most cost-effective measures in the whole system should be taken (Nafo and Geiger, 2004).

While effects within urban areas can be identified in detail by models reflecting the rainfall-runoff and pollutant processes, for assessment in distant water bodies mainly empirical methods are necessary which have a lower requirement on data compared to physically based methods. Figure 9 links the spatial extent of the catchments, the time span to be considered and the technique applied to establish water and matter balances. Storm water discharges from urban catchments have special influence to receiving water bodies.

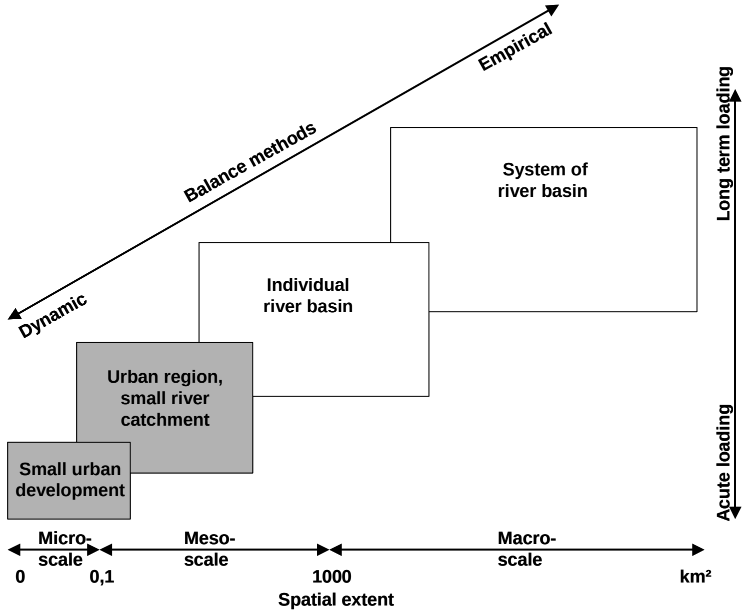


Figure 1: System limits and time horizons for water management (Nafo, 2004)

7. CONCLUSION

Urban water systems have to consider social and economic aspects, as already recognized in 1970 by Professor Mc Pherson, one of the first urban hydrologists. Sustainability in water affairs affects society as a whole including its institutions and administration. It is a learning process which begins in schools and continues throughout every ones life, whereby renewal of thinking about water must come from inside, from the user itself. Only today it is understood, that water management is most important to improve poverty and thus social stability. Present management practices cannot meet future water needs in for mega cities.

To minimize failures demonstration projects to test new ideas and approaches must be encouraged endorsing systems analysis and rigorous evaluation of such projects. Pricing incentives must be given that acknowledge full environmental impacts of proposed systems. Pricing policies for drinking and recycled water must be found, that ensure efficient use of these valuable resources, whereby environmental externalities, i.e. the cost of disposal of storm water and treated effluents as well as research funding requirements should be factored into the water price or penalties.

Better integrated planning and water management in urban areas through institutional reforms involving local government, water boards and utilities, and state (government) agencies should be forced, considering self-regulating bodies. Continuing research and education will lead to progressive improvement in costs and efficiency of advanced water concepts. Change of water infrastructures and institutions take time. The key is to invest in small scale infrastructures, especially to solve problems on local scales, but using available technologies to estimate their effects, if applied in general.

It was found, that sustainable water management solutions mainly can be influenced in the preplanning and planning phases, when precise data are not available. In consequence indicator based decision support and rather uncomplicated methods to evaluate sustainability are suggested. It is concluded, that sustainable water management may be the only chance for mega cities in developing countries to survive.

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