Int. J. Environ. Res., 7(2):343-358, Spring 2013
ISSN: 1735-6865

Land use and Water Quality in Guangzhou, China: A survey of ecological and Social Vulnerability in Four Urban Units of the Rapidly Developing Megacity

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Received 27 Feb. 2012; Revised 1 July 2012; Accepted 12 July 2012

ABSTRACT: This interdisciplinary paper aims at Guangzhou's development and its effects on surface and groundwater quality taking the new city axis as an example. Qualitative morphological analyses, field mappings, interviews and water sampling of standard in-situ and various hydrochemical parameters were conducted between 2007 and 2009 in order to examine the following research questions: Which types of land use can be found within the new city axis? Are there infrastructure differences of water supply and wastewater disposal? How does land use affect the quality of surface and groundwater? How do inhabitants perceive and appraise settlement structures, infrastructures and environmental quality and how do they cope with their individual situation? Within four small-scale research areas, so-called urban units, different stages and types of development and factors influencing the water resources as well as spatial variations of water quality could be identified. Deficits in city planning, water supply and sanitation lead, for example, to informal building expansion and groundwater use as well as to high concentrations of coliform bacteria in urban rivers. A wide range of ecological and social vulnerabilities became obvious.

Key words: Water quality, Land use,City pattern, Ecological, Social,Vulnerability, Guangzhou, China

INTRODUCTION

Mega-urbanization is not a new phenomenon. In the 1950s, the process of (mega) urbanization shifted from industrial to newly-industrialized and developing countries. There are, however, two differences within the urbanization process in these countries, which also affect the quality of water resources and its management: The gradual growth as realized in the industrial nations over about a century enabled a systematic planning of land use and water sector infrastructure. By contrast, the uncontrollable growth over a short period as in the newly-industrialized and developing countries caused massive land use changes and created informal living conditions e.g. due to insufficient living room and water supply capacities (Kraas & Sterly, 2009). Both situations imply major challenges for the management of urban water. For this reason, the sustainable use and development of land and water resources should be of vital importance – at least since the United Nations Conference on Environment and Development in Rio de Janeiro in 1992 and it being confirmed at the World Summit on Sustainable Development in Johannesburg in 2002 (UN, 2002; Weng & Yang, 2003). The links and interactions between land use and water resources however, have been underestimated in interdisciplinary studies a long time. Only the current ecological discussion increasingly focuses on these relationships and establishing integrated approaches (Tong & Chen, 2002; Hiwasaki & Arico, 2007).

Urbanization, in general, has four immediate repercussions on the hydrological cycle: These include flooding (e.g. as a result of increased soil sealing), water shortage (e.g. due to rising consumption), changes in the river and groundwater regimes as well as water pollution (Rogers, 1994). In addition, indirect effects such as variations in temperature can be identified (Weng, 2001). Changes in natural drainage as well as the emission of pollutants into groundwater and surface water put the urban water resources under extreme pressure in several cases. Surface run-off is increased by extensive soil sealing, reducing the natural groundwater recharge (Goudie, 1990). In contrast to the aforementioned groundwater reduction, the so-called urban

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groundwater recharge is increased by leaking water mains and sewerage canals (Lerner, 1990; Foster *et al.*, 1999; Welty, 2009). This, however, leads also to the leaching out of contaminants (Morris *et al.*, 1994; Klinger, 2007). The entry of pollutants into the urban water system rises by the interaction of ground, surface and wastewater systems – especially in cities having no adequate wastewater system (Strauch *et al.*, 2009; Putra & Baier, 2009).

Urbanization in *China* is taking the same course as the one associated with non-industrial nations. Since 1978, Chinese (mega) cities as well as small urban centers have been subject to far-reaching changes due to the economic reforms and opening. The urbanization level of the country rose continuously between 1978 and 1999 by 0.61 %/ a. from 17.92 % to 30.89 % and by 2008 to 45.68 % (Liu *et al.*, 2003; People's Daily OnlinePDO, 2009). In this context, the South-Chinese Pearl River Delta (PRD) became one of the most dynamic regions of China and one of the most densely populated areas worldwide. The consequences of these developments were fundamental land use changes mainly being substantiated by:

- a strong population growth especially due to migration,
- the regions' integration into global economic processes,
- the development of an urban middle class,
- excessive spatial expansion of metropolitan regions as a result of frequently lacking city planning and regulation mechanisms, different local legislations and political decision makers as well as
- power structures (cp. Kraas & Sterly, 2009).

It becomes obvious that the processes, interactions and effects of the problem areas 'resource flows' and 'land use (modification)' are complex and dynamic as these factors overlap with one another – especially in megacities. The consequence might be a loss of ecological, social and economic governability and control. Against this background, this article focuses on the reciprocal influences between macro-scale development projects (the example of Guangzhou's new city axis) and micro-scale case study areas (so called 'urban units'). The interaction between urban dwellers and their environment with respect to their perceived and appraised social vulnerability in the context of land use and its impact on water resources are further focal points in this paper. The hypothesis is that ecological and social vulnerability (cp. Wehrhahn *et al.*, 2008) are increased by spatial changes and the state of water infrastructures.

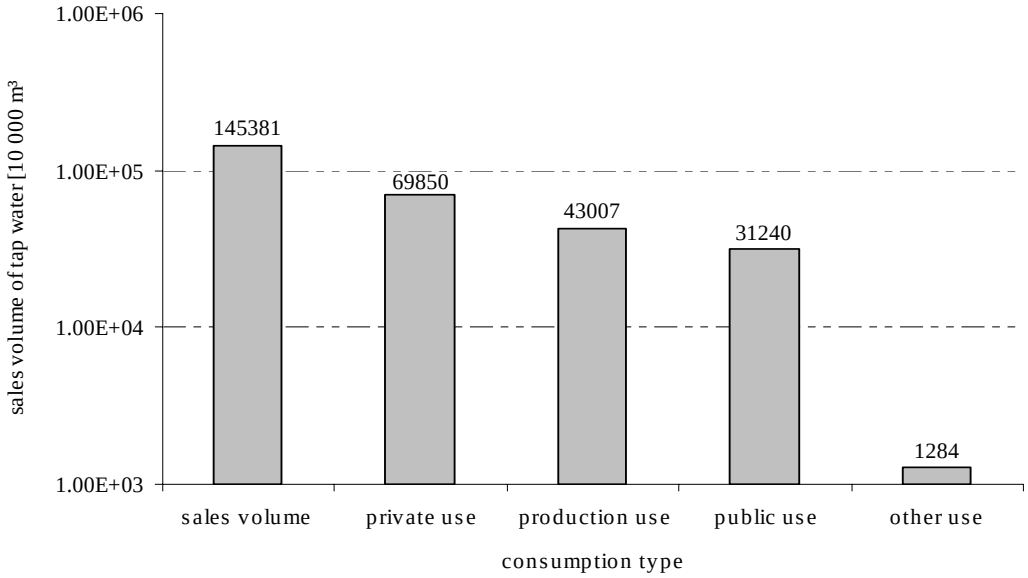
The research area *Guangzhou* is the capital and the economic, political, scientific and cultural center of Guangdong Province. The population figure varies between 12.7 and some 15 million people (Guangzhou International, 2010; Huang & Keyton, 2010) – depending on whether migrants are statistically in or excluded. In the last 20 years, Guangzhou's total built-up area has increased by about 1.8-fold and presently counts 7,434 km² (Zhao *et al.*, 2009). Especially the decrease of agricultural areas (309 km²), water areas (24.42 km²) as well as forests and green spaces (33 km) and the accompanying increase of densely populated residential areas (+369 km²) are indicators of Guangzhou's rapid urbanization from 1990 to 2005 (cp. Lu *et al.*, 2011). The city's average population density was 1,708 persons/ km² in 2010; it varies from 493 persons/ km² in the peri-urban district Nansha to 34,239 persons/ km² in the central district Yuexiu (Guangzhou International, 2010). Due to the Asian monsoon, the average precipitation amounts to 1,689-1,876 mm/ a. with maximum rainfall occurring from April to September. The city is located at the confluence of the Xijiang, Dongjiang, Beijiang and Liuxi River systems, which form one of the most complex deltas worldwide. Within the urban districts, the channel network consists of 231 (sub) surface rivers. Together they form a quantitatively sufficient water supply. In 2006, the production capacity of water was more than 6.4 million m³/ d., only 1,000 m³ of which were obtained from groundwater (GMSB, 2007). The latter is increasingly burdened by the intrusion of sea water particularly during the dry season which complicates its use (Liu *et al.*, 2010). Private use accounts for the largest proportion of total sales volume of tap water, followed by industrial, public and other use (Fig. 1). To meet the growing water demands, the municipality is planning a capacity increase of 2.3 billion m³/ a. of water withdrawals from the Beijiang (Xinhua News AgencyXAN, 2006). Further, four lakes are to be created which are to serve not only for floodwater storage in the rainy season and water supply of nearby creeks in the dry season, but also as drinking water (Zhu, 2009). Table 1 shows the expansion of the city's water infrastructure.

Guangzhou's overall goal is to become a globalized eco-metropolis (Jin, 2007). In order to cope with the expected urban sprawl, the planning institutions specified the directions of development by creating zones that follow the principles "exploration in the South, optimization in the North, extension in the East, adjustment in the middle and coordination in the West" (Jin, 2007). Due to spatial limitations in the North (Baiyun Mountains) and East (City of Foshan), the main expansion takes place in southern and eastern directions. Within the wide range of reconstruction measures, the mega-project of the *new city axis* shows the city's intention to remain the province's center and

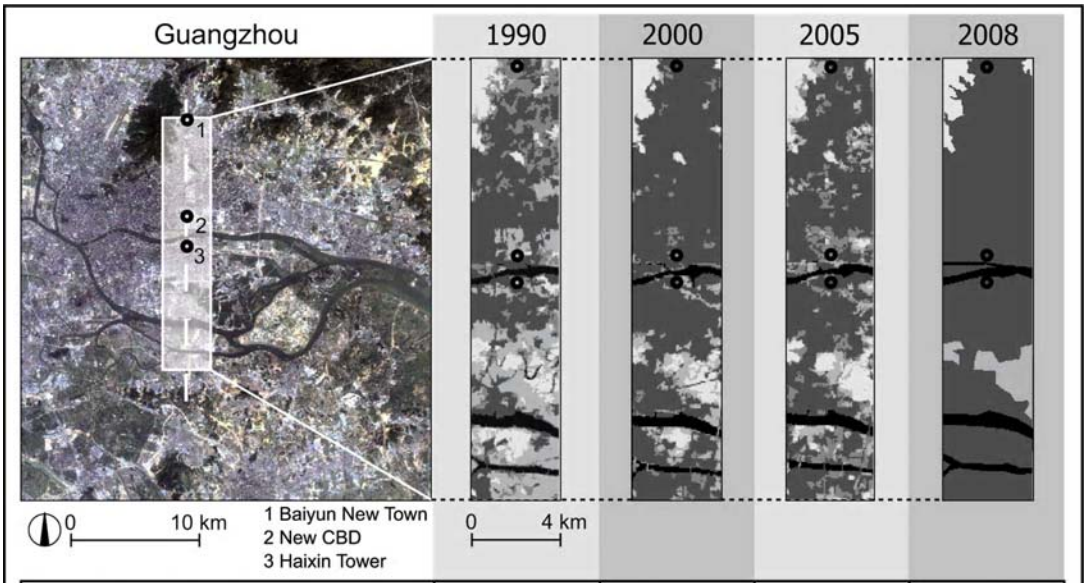
to uphold its market position next to Hong Kong. It represents a new urban center and is, however, the result of enormous transformation processes. The axis is about 12 km long and reaches from Guangzhou East Station to Baiyun New Town and further to the outer Pearl River harbor (Wu *et al*., 2007). Its entire planning surface covers some five million m². Fig. 2 shows the land use changes in this area between 1990 and 2008. In order to realize the project old buildings and remaining urban agricultural areas were replaced by a huge number of prestige projects such as symbolic high-rises resulting in a significant increase of build up area (+28.88 km²) and a decrease of agricultural area (12.98 km²). The realization of the axis is also linked to the development of traffic infrastructures such as Guangzhou South Railway Station as well as the creation of green belts and Haizhu Lake which is one of the above-named artificial lakes, having a water area of 0.53 km² (Strohschön, 2011). It was constructed on a former agricultural area, providing work and homes to about 50 migrant families living in dwellings without adequate water supply and sanitation (Fig. 3). Thus, parts of the axis can be seen as a modern example of a large inner-city project creating new urban green belts and water surfaces. Others are characterized by maximum urban expansion and an increasing density as old small-scale structures and agriculture are replaced with mega-structures with the highest possible density.

MATERIALS & METHODS

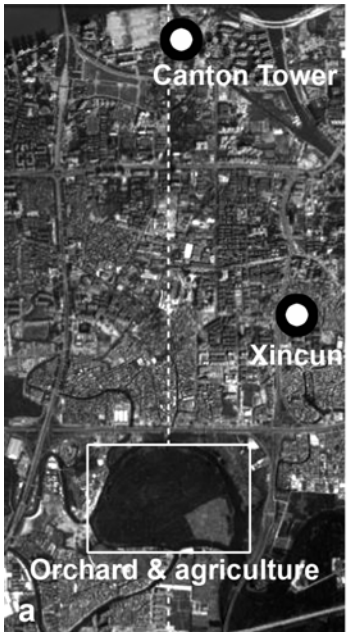
Within complex mega-urban areas, the different possible scales of observation represent a challenge: Examining the entire urban space would be very costly and would still not provide a detailed picture. On the other hand, the complexity of the urban system cannot be fully understood if only one level is looked at, e.g. at the scale of single buildings. Therefore, the approach is to divide large urban systems into small recurring and homogeneous sub-units which could, e.g. be a specific type of buildings and their outdoor spaces (‘*urban units*’). Using such blocks, it is possible to break down the complex structures of a megacity into their core components which play a significant and instructive role in the developmental analysis. In Guangzhou, those units can easily be identified on the basis of morphologically ‘closed’ settlement structures being relicts of the three main urbanization phases (cp.

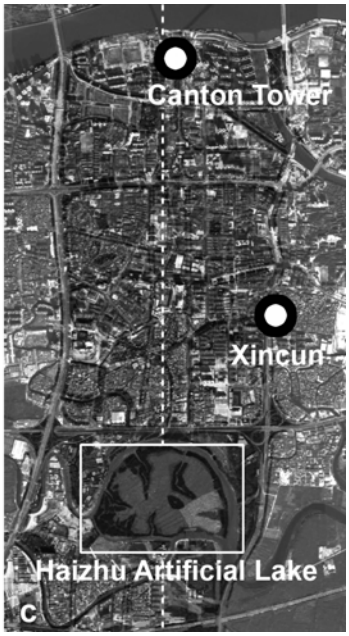


Item	1990	2000	2005	2006	2007
Total volume of water supply [10 000 m³]	86 136	124 958	170 969	172 997	178 809
Length of water supply lines [1 000 m]	2 947	5 169	11 532	12 495	13 750
Length of sewer pipelines [1 000 m]	1 217	1 952	4 827	5 157	5 548



land use type	area		area		area		area	
	km²	%	km²	%	km²	%	km²	%
water	4.55	6.00	4.59	6.00	4.45	5.82	5.40	7.01
urban area, high building density	34.76	45.47	57.04	74.61	49.60	64.88	63.64	83.24
urban area, low building density	11.65	15.24	1.85	2.42	7.45	9.74	0	0
agriculture	17.39	22.75	7.25	9.48	7.84	10.26	4.41	5.77
forest, green space	8.10	10.54	5.72	7.49	7.11	9.30	3.00	3.98
total	76.45	100	76.45	100	76.45	100	76.45	100

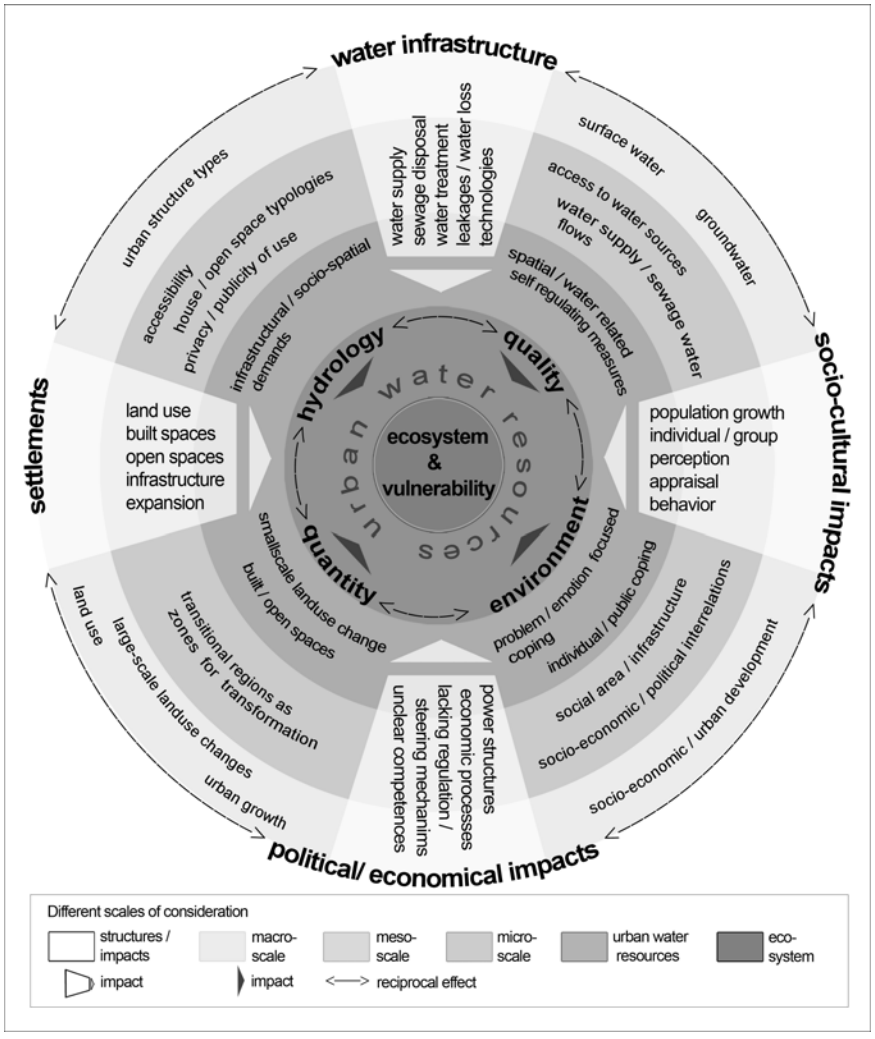




e.g. Gaubatz, 1999; Liu *et al.*, 2003): I. Traditional Chinese City (till 1949), II. Maoist City (1949-1978) and III. The Emerging Chinese City (1978 till present), which is today in the stage of saturation as more and more qualitative instead of quantitative restructuring processes take place. Based on today's urban landscape and seen from a morphological perspective, various stages of development of originally similar and self-contained units are apparent. In the course of urbanization, lot's of those areas expanded and merged into larger units.

To study the impacts of urbanization on Guangzhou's water resources and the reciprocal effects between settlements, humans and the environment, a trinomial approach considering macro , meso and micro-scales was conceptualized (Fig. 4). To integrate the disciplinary works thematically and methodologically, a descriptive approach was chosen and substantiated by specific figures where available. First, it was necessary to determine internal and external transformation variables. It was investigated whether the identified changes follow standards and which kinds of structural patterns can be differentiated. Studies about the extent of macro-scale transformation processes, possibly recurring on the micro-scale, followed. Based hereon, conclusions could be drawn about the social and ecological vulnerability of Guangzhou.

Considering the PRD's morphogenesis since 1978, 67 small-scale investigation areas were roughly analyzed by site-inspections. Due to their different phases of development four characteristic *urban units* could be chosen within the sphere of the city axis. The examples of Liedecun (herein after referred to as Liede), Xincun, Yuangangcun and Shibi represent these patterns best (Fig. 5):



Liede was an *urban village* located in Tianhe district. It consisted of small groceries and residential houses with 4-6 storeys providing homes to some 7,000 locals and 10,000 migrants (Wehrhahn & Bercht, 2008). As it was situated in the center of the new city axis, and thus in the city's prime location for developing the new CBD, 'Liede renovation project' was started in 2009. Being Guangzhou's first urban village to be removed completely, all houses are demolished by now. In conjunction with this planning process, a modernization of the banks of the nearby Liede creek was implemented in 2011.

Xincun is an *urbanized village* in the center of Haizhu district and is thus situated at the southern core of the axis. Hence, it is envisaged by the real estate market looking for areas that are suitable for constructing high standard housing and commercial infrastructure (Wehrhahn *et al.*, 2008). It has undergone multiple transformation phases since 1990 and developed from a traditional village to an area, which is more and more affected by the current urbanization processes. A creek, several ponds and agricultural land were backfilled to provide settlement area in 2008.

The *village* Yuangangcun, located in the semi-urban Panyu district, became part of Nansha Development Zone in 1992. The incorporation led to spatial transformations and created a *mixed land use* containing remaining agricultural areas and increasing residential, industrial and trade areas with points for collecting plastic, harbor engineering and packaging spots. Since 2008, small trade buildings have been demolished. A high-rise complex and subsequent traffic infrastructures are being built in the village's northern part, indicating the ongoing rapid urbanization progress in a southern direction. Meanwhile, two out of every 6,000 inhabitants are migrants.

The still *rural shaped village* Shibi is located 17 km south of the city center in Panyu district. In 2008, some 10,000 permanent residents and about 10,000 intra-Chinese migrants mainly working in the secondary sector lived there. Shibi has a less dense settlement structure and is dominated by 1-2 storey houses, which are mainly arranged along a courtyard and adjacent to agricultural areas. The development suggests that the village will develop into an urbanized village with increasing urban land use. As a result of the construction and opening of Guangzhou South Railway Station in 2010, 35 km² of rural landscape were transformed into zones for transportation purposes (Fig. 6).

The approach of the urban units helps to reveal formal and informal characteristics and puts emphasis on the development of built and open space as well as on spatial density and population density. Thus, the following indicators of urbanization were analyzed between 2007 and 2009:

- the micro-scale land use (change) and structural pattern,
- the density based on built and open surfaces and spatial proportions,
- water infrastructures,
- the functionality of the existing area based on perception and utilization, and
- the peoples' coping strategies regarding spatial demands and deficient infrastructures.

Water sector structures were surveyed on-site to link land use and its effects on water resources and to gain knowledge on a micro-scale embedded in the mega-urban context. It also made it possible to identify potential sources for surface and groundwater contamination. In addition, a total of 22 single samples were taken in autumn 2007 and 2008. The 13 measuring

sites of surface water were chosen, where possible, at the river's inflow and outflow of the urban unit to recognize water quality changes between upper reaches and lower sections or at striking places. The 9 sampled wells were located in central parts of each unit. The water was collected in rinsed 0.55 L and 1.5 L plastic bottles and brought to the laboratory as promptly as possible where the samples were kept refrigerated and unfiltered. They were examined for Cd, Cr, Cu, Pb, Zn, NH_4^+, NH_3^- and total coliform bacteria. As most of the heavy metals' measuring results were below Chinese and international guideline values (cf. Wiethoff *et al*., 2011), this article focuses on coliform bacteria. The latter were analyzed in accordance with the examination method GB/ T 5750.12-2006, which was implemented by the Ministry of Environmental Protection of the People's Republic of China (MEP) in 2006. Immediately after sampling, measurements of pH, electrical conductivity [µS/ cm], oxygen content [mg/ L], oxygen saturation [%] and redox potential [mV] were conducted in a mobile laboratory.

Within 20 random test interviews in Yuangangcun as well as several informal talks in Xincun and Liede conducted in 2008, information were e.g. gathered concerning individually perceived transformations within the settlement unit, changes in water quality and environmental problems in Guangzhou. The effects of the environmental situation on human performance and the mediating social-psychological processes, that explain why appraisals and behavior are interfaced with the environment in the way they are, were examined in 51 extensive semi-structured face-to-face interviews with residents of Shibi in 2009 (cp. Bercht & Wehrhahn, 2010). The human-centered research, for practical reasons mainly conducted in Shibi, was applied in order to facilitate an in-depth understanding of social aspects such as peoples' cognitive and behavioral response to rapid urban transformation and ecological vulnerability.

RESULTS & DISCUSSION

Coherence can be postulated between the spatial situation, current development pressure and the changing units' morphology; negative outcomes on the local ground and surface water could be identified. The location of the areas entails that their morphology today is directly and substantially influenced by Guangzhou's urbanization. They exhibit a particularly high degree of growing spatial density and surface sealing. With regards to the structures, they seem to follow similar rules during the transformation phases. Structural transformations on the macro-scale from rural or peri-urban to urban structures enforce various vulnerabilities on inhabitants and the environment also on the micro-scale. Comparing the different urban units, a downward gradient, which directly correlates with the distance to the axis, is clearly recognizable: The closer the position in relation to the axis,

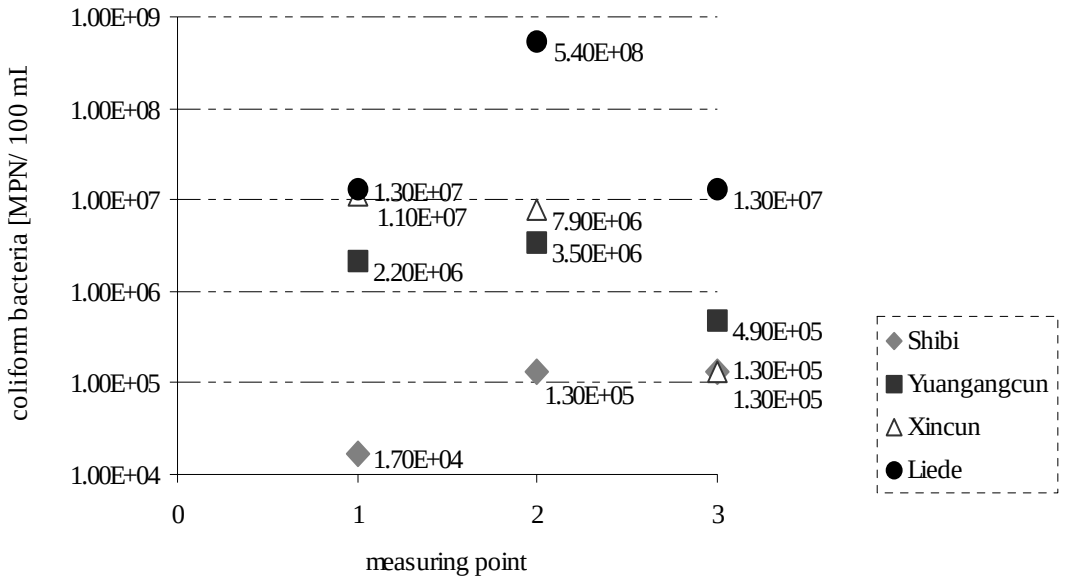
- the larger the development pressure,
- the larger the pressure on inhabitants,
- the stronger and more urgent the demand for living space,
- the poorer the quality of the open space due to enormous surface sealing and densification,
- the higher the degree of informal design and use of the existing space, and
- the stronger the deterioration of surface water quality with coliform bacteria,

but not the stronger the pollution of groundwater with coliform bacteria as a higher concentration was measured in the area of the old city center.

The city area is increasingly becoming a place for migrants to move to due to the close proximity to potential jobs. In general, this leads to a higher degree of surface sealing and reduced infiltration areas due to the need for horizontal construction, increasing density as a result of vertical development, rising water consumption and sewage production as consequences of population growth and enhanced living conditions. While structural changes in the areas next to the town center, as in Xincun and the former Liede village, nearly exceed the spatial capacities and necessary expansions fall back on the narrow transition areas, the periphery of Yuangangcun and Shibi still has sufficient space to expand. In Liede, already in the 1990s, the percentage of sealed surfaces has been up to 40 % of the total area and increased to more than 60 % in 2008. The intensity of construction activities can be compared with Xincun in 2008 where nearly 60 % of the area was sealed. Surveys in 2012 showed, that today nearly 70 % of the area is densely built; wide parts of the former agricultural land are now occupied by skyscrapers. Xincun is also characterized by an already high and constantly growing *spatial density* and has a population density exceeding more than 20 times the average rate of Guangzhou. The number of migrants living in Xincun rose from 50 % in 1993/ 94 to 83 % in 2008, while the predominant part of the local inhabitants moved away (Wehrhahn *et al.*, 2008). In the already urbanized units next to the center, this intra-cellular re-densification is nearly ten times higher than in the peri-urban areas. The settlement structure of Xincun and Liede built in the 1990s was strict: Buildings with 5-8 storeys were constructed with 0.5-1 m distance between them, resulting in very bad lightning and ventilation conditions. However, this building typology can also increasingly be found in Shibi and Yuangangcun – here as an indication of social ascent. In Shibi and Yuangangcun, each have

an average building density of 60 %, the growth and structural density rates are less. In Shibi, the percentage of sealed surfaces nearly doubled from roughly 25 % in the 1990s till about 40 % in 2008. The development of Yuangangcun is comparable: The increase of the unit's area used for construction purposes from 30 % to about 40 % between 1990 and 2008 shows the rising space demands resulting from urbanization and economic growth. Old structures in the settlement core are kept, while buildings of a higher standard (e.g. equipped with public water supply or having more living space to install household appliances like washing machines) are constructed at the unit's outskirts. Thus, the settlement structure becomes fragmented, consisting of traditional buildings, abandoned surfaces, waste and agriculture land as well as new housing estates. Hence, qualitative disparities between insufficient and adequate water infrastructures as well as environmental and living conditions are an obvious consequence. Based on the analysis of the urban units' perimeters, characteristics can be gathered about the spatio-structural changes of the entire urban unit: In comparison with the neighboring areas, Xincun can be described as an urban system with a relatively high degree of permeability and reciprocal effects between 'inside' (the unit) and 'outside' (its surroundings). In contrast to this, a closed settlement system can be found in Shibi and Yuangangcun. Here, the transition areas between agricultural and settlement areas do not develop rigorously. With a higher demand for space, the agglomeration can expand over the original settlement perimeters towards the agricultural areas. In Xincun, as in other urban or urbanized structures of this kind, the quality of the building structures as well as their durability differs from the fringes to more central parts of the unit. Old or informal dwellings are mainly inhabited by disadvantaged groups who have found temporary shelter. These housing structures have typical poor living conditions such as deficient sanitation facilities and open sewers. Here, the necessity of adjusting the surrounding to one's need became obvious: Similar characteristics of design and use could be identified as, for example, the establishment of subsistence farming gardens or the outsourcing of commonly internal functions such as kitchen, sanitary facilities like washbasins or storage spaces. There is a high risk that these are the first buildings forced to give way to new development projects.

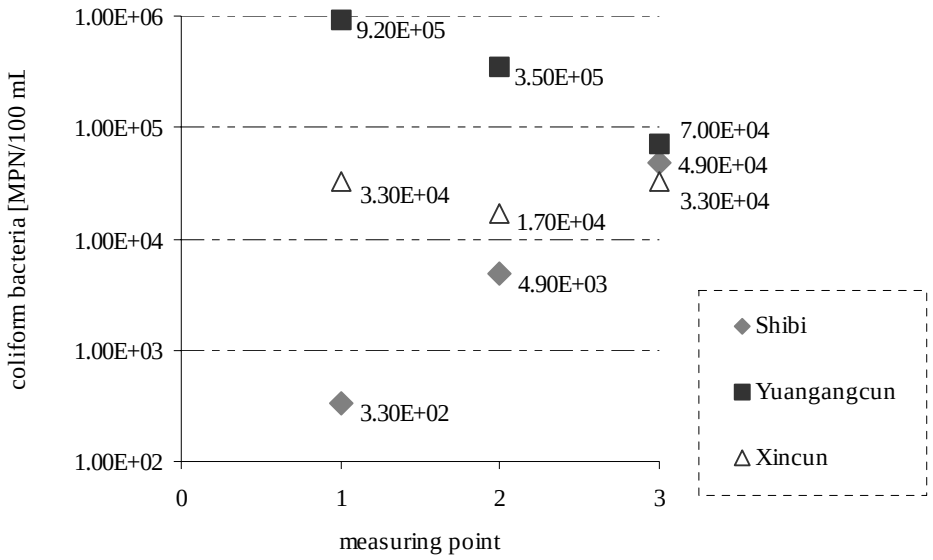
With regard to *water infrastructure* and *surface water quality* several signs of vulnerability such as deficient access to public sewage disposal, poor drainage in open sewers or informal and thus insecure dumps of various sizes filled with mixed waste could be found in all units. The dumps are located either in alcoves or between houses, adjacent to creeks or ponds that are used for cultivating fish or on agricultural areas traversed by feeders as in Shibi and Yuangangcun. Agricultural activities in Shibi and Yuangangcun, animal husbandry in Shibi and untreated domestic sewage discharges in all units are leading to surface water contamination by microorganisms and organic pollutants. The measuring results of in-situ parameters of the surface water showed pH values between 7.06 and 7.64, electrical conductivity ranging from 424 (Shibi) to 1789 µS/ cm (Xincun), oxygen content of 2.3 (Liede) to 6.56 mg/ L (Xincun), oxygen saturation of 28 (Liede) to 76.4 % (Shibi) and a redox potential between -214 (Liede) and 345 mV (Yuangangcun). The concentration of coliform bacteria was $1.7*10^4$ MPN/ 100 mL in Shibi, ascending to $1.3*10^7$ MPN/ 100 mL in Liede. Taking the measuring point's spatial position to the axis into account revealed that the maximum concentration of coliform bacteria was found in Liede, which is within the axis' center (cp. Fig. 7). This high concentration is not surprising as the measuring point was chosen at the end of Liede Creek, which accumulates domestic waste water as it flows through the northern urban area. According to the quality standards for surface water GB 3838-2002 issued by the MEP in 2002, the highest water quality class V allows a maximum concentration of coliform bacteria of 40 000 MPN/ L. Thus, the critical value of this water quality standard was seriously exceeded at all testing points. The measured microbiological pollution by animal and/ or human waste of the tested surface water might cause gastro-intestinal infections or diseases as the water is/ was used for irrigating purposes in three of the four units (Shibi, Yuangangcun and Xincun). Other potential surface water contamination and health-risks might arise depending on whether limited technological filtering or treatment resources are available. In addition, it depends on how or if liquid fertilizer are used on a large-scale in the agricultural areas as informal talks in Shibi revealed. Several residents believe the consumption of *groundwater* tainted by fertilizer-polluted run-off is a major cause of stomach cancer. Due to the fact that local-scale statistical data concerning cancer mortality rates are not accessible to the public, the correlation between mortality rate and polluted water as mentioned above could not be verified. It is, however, known that in the 1980s alone, the use of chemical fertilizer in the PRD increased by 40 % (Hugentobler & Lütolf, 2006). Besides, studies from the World Resources Institute (1998) indicate 1. that China's water resources are increasingly polluted by toxic contaminants such as synthetic nitrogen fertilizers, 2. that the stomach cancer's rate is 3-7 times higher in polluted rural areas



than in less contaminated ones, and 3. that the cases of stomach cancer are at least partly caused by water pollution. These results could be transferred to Shibi and thereby support the residents' statements.

The interactions between land use, humans and groundwater become visible in three of the four units if one looks at how people use groundwater as part of their daily diet from privately and publicly available wells. Due to the "good taste" of groundwater that to be better than that of tap water, several residents of Xincun, Yuangangcun and Shibi consume the water regularly without previously boiling it. Some of them store the water for a few days to let the solids in the water settle; others know about the potential pollution or dislike the taste and use the water only for irrigation or sanitary purposes. Besides, the area surrounding wells is often used for washing clothes during which cleaning agents easily do get into the groundwater. Sampling results, however, showed no significant pollution level with heavy metals like cadmium or copper. Instead, concentrations of coliform bacteria ranged from $3.3 * 10^2$ MPN/ 100 mL in Shibi up to $9.2 * 10^5$ MPN/ 100 mL in Yuangangcun (Fig. 8). According to the Chinese Quality Standard for Groundwater GB/T 14848-93 (NMEPB, 2006), all test results can be designated as class five indicating water with maximum pollution and coliform bacteria concentration > 100 MPN/ L. The results of the in-situ parameters showed a pH-value between 5.42 (Shibi) and 7.3 (Yuangangcun), electrical conductivity in the range from 38 (Shibi) to 1165 µS/ cm (Xincun), an oxygen content of 1.69 (Yuangangcun) to 6.67 mg/ L (Shibi, Xincun), oxygen saturation of 75.6 (Xincun) to 76.5 % (Shibi) and a redox potential from 180 (Xincun) to 325 mV (Shibi). No groundwater could be accessed in Liede. Overall, a comparison between land use and water quality in different stages of urbanization of the urban units would be desirable. However, due to spatial changes (e.g. in Xincun or Yuangangcun) a repeated sampling of all previously tested sites was not possible. Thus, the measurements must therefore be regarded as snapshots, which show, however, clear negative outcomes of urbanization on local ground and surface water.

The water infrastructure for disposing domestic sewage is very similar in all units and the proximity to the new city axis has not yet had any influence onto the restructuring of the sewage disposal: A combination of open and covered wastewater gutters, a main conduit leading into the nearby agricultural area and/ or a creek as well as canalized areas can be found. The existence of open wastewater gutters has a very negative impact on hygiene. One can find domestic waste in the gutters, which makes the area unpleasant to look at and smells badly especially in the summer. Rats and other vermin transmit etiologic agents to humans, especially to children playing outdoors. In order to avoid bad odors and unpleasant sights, many



of the open wastewater gutters and small canals have recently been covered. Enclosures that are installed at the change-over from open wastewater gutter to canalization are intended at preventing raw particles from getting into the canalization and stop rats from coming out of the canalization. Such technical inserts were observed in urban as well as in peri-urban units independent of the spatial proximity to the axis. However, both measures – the covering up of open gutters and the installation of enclosures – are only means of adapting to, instead of actually addressing the problem of a deficient water management as such. While comparing the units with each other and taking the distance to the axis into account, no systematic correlation between the age of the buildings and the form of sewage disposal was detectable. While most domestic sewage from people living in new houses like in Shibi is often discharged in open wastewater gutters, the majority of Xincun's newer houses, which were built in the 1990s, are connected to the public sewerage. Still, most effluents enter the water cycle. Aside from the hydrological impact, it makes many inhabitants feel as if they are treated unfairly since they have to pay 0.70 CNY/ m³ for the treatment of domestic sewage. In this context, analyzing how the people value and appraise the water quality as well the effects of water management and the land use change on human performance is a valuable addition towards a hydrological research: The level of knowledge about poor water quality and its potential effects on human health as well as diverse potential risk exposures lead to differing perceptions and appraisals by the inhabitants. Although the contamination of surface water is obvious due to grey to black color and putrid smell of the water and the abundance of packaging materials, PET- bottles, cans and other garbage in many river parts and fish ponds, the interviewees vary in their appraisals: Many locals of Shibi complain that local factories do not implement mechanisms and processes to treat their wastewater. As the interviews revealed, many working migrants often disregard the river's dirty and smelly condition as they are not worried about the water pollution because their aim is to make as much money as possible so they can some day return to their homes. Evidently, personal factors and the setting always determine whether the relationship between humans and environment is considered vulnerable or not. Environmental conditions or a deficiency in resources makes a person vulnerable only when the deficit refers to something of real importance to the agent in question. In comparison to a migrant who is not emotionally attached to Shibi, the villager feels that his quality of life is impacted on in a negative way as he has been experiencing the ecological changes. From this point of view, the river is no longer usable for fishery, water supply or as recreation area. The extent to which villagers benefit from the river is constrained by the river's harmful contamination. Such differing perceptions and appraisals of locals and migrants regarding a deteriorating water quality were also reported in other units. According to the villager's perceptions, the construction of Guangzhou South

Railway Station in Shibi accelerates the changing of the living conditions and harms the environment. Most of the farmland was sold off; so many villagers have lost their basic source of income and in addition have to fear resettlement due to the pending demolition of some parts of the village. The interviewees did not recognize or know about potential impacts of this mega-project on the water-related processes and structures such as changes in the underground or surface water quantity and quality. One of the main concerns of Shibi's locals is losing a secure place to live as a consequence of being relocated. Hence, it became clear that a person's view on the value of secure living conditions fundamentally affects his/ her social vulnerability. The uncertainty of not knowing what is going to happen to one's life in the near future increases the level of social vulnerability, the villagers' livelihood aspirations are at stake without the guarantee of achieving them and hardly any resources to do so are at their disposal. Results show that vulnerability is determined by the relationship between the individual's pattern of commitments and his/ her resources to defend those commitments against threats. In this sense, vulnerability can be described as a potential threat which is converted into an active threat if an important matter is jeopardized. Due to diverse hopes, commitment patterns and personal factors, crises are thus appraised differently depending on the individual's experiences with vulnerability. This as well as the extent to which an individual is exposed to threats makes water contaminations seem less important. Moreover, the opening of the railway station, being Guangzhou's biggest infrastructure project, offers the possibility of individual benefits and Shibi's connection to the urban center. In addition to the overall changing spatial features and the individual awareness of risk and vulnerability, the analyses showed that new forms of urban space and usage (self-regulating processes) are emerging on the micro-scale. They show the degree of ecological and social vulnerability as well as the variety of already existing coping strategies. Up to a certain degree, urban dwellers adapt to existing spatial circumstances in a passive way. But there is a growing active adaptation to the existing situation and individual demands in terms of adaptability and self-organization in the examined urban units (Fig. 9). In addition to these settlement uses, self-regulating measures also do occur in the field of water use and water infrastructure, as e.g. groundwater use for the daily diet or informal building constructions with low standards of waste water infrastructures and thus open sewage disposal. This again impacts negatively on the ground and surface water quality. The function, shape, design and quality of all measures depend on the socio-cultural background, the needs and the economic options of the users. These tendencies are for one an expression of the drastic changes of the urban system and the personal and social identity of the inhabitants and their needs (cp. Watson & Bentley, 2007). On the other hand, coping strategies such as drinking groundwater due to tap water contamination show the ability to adapt within a constantly changing mega-urban living situation. In particular, the units' structure and the increasing urban density offer a large range of individual coping strategies. Those can mostly be found in historically old, developed areas. A vacuum in the national regulations and laws allows for a large variety of structural alterations and extensions, low cost housing and informal sources of income to arise. In the different phases of urbanization, especially the local government plays a key role for both, the immigration and the restructuring of the considered urban areas. The liberalization of migration policy in 1978 resulted in a substantial increase of migrant

workers pouring into Guangzhou. In 1989, Beijing issued the Law 'Transfer of Land-Use Rights', regulating the use of the land outside the Special Economic Zones. This enabled the local government and the urban villagers to participate in the rental market. Thus, a shift of governmental investment-driven to property-driven development took place, resulting in a rising market value of farmland. In the urban areas of the PRD, farmers, now entrepreneurs overnight lent their land-use rights to developers (Craciun, 2001). Since the beginning of the 2000s, the political interest concerning the inner-city areas increased leading to a massive promotion of renewal projects such as in Xincun and Liede. The formal conditions envisage transferring the right of disposal from the rural population to the urban administration. While the official goal is to prevent the inner-city 'slum' formation, it can rather be assumed that local government agencies have great interest to seize rural land for urban development and access considerable off-budget benefits as their part of the local household is up to 75 % (Ding & Knaap, 2003).

Organizational and structural self-sustenance generates a self-renewing urbanism, which changes the social and cultural character of the entire city which is up to a certain degree able to help itself. Urban restructuring in terms of major construction projects along the axis were visible within a short period of time. Taking this into account, the aim of turning Guangzhou into an "international eco-metropolis" (e.g. by expanding the capacity of wastewater treatment plants, enhancing water supply, implementing river improvement programs and creating green areas) is a medium to long-term goal as the results of the groundwater and surface water samples proved, too. This mirrors the fact that still millions of residents and a large number of migrants, living in both urban and peri-urban areas, have to live with no access to adequate sanitation. That again leads to further contamination of surface and groundwater through the uncontrolled disposal of domestic sewage. However, the responsibility and means of improving water supply and sanitation services for a growing number of inhabitants lie with Guangzhou Municipality. It also entails that with the need for more living space and changing land use patterns ecological and social vulnerability could increase. Nevertheless, many ecological improvements to enhance the city's image within the range of the axis have already taken place. For example, the Chinese tradition of urban garden design finds its way back into the cityscape: Public greenbelts are constructed and 'private' green spaces are integrated into new apartment complexes to upgrade them, but also to improve the sales performance. While surface water, especially in the old city, had to give way to the construction of roads and buildings in the past, today it is used for sewage disposal and integrated in the urban space in form of reservoirs for water storage, flood protection and recreational areas. Artificial surface water bodies like lakes, waterfalls or fountains are already integrated as modern design elements in the cityscape – currently forming a considerable contrast to severely polluted creeks and ponds.

The problems and challenges of mega-urban developments can be deduced from the systematic characteristics of the urban units such as density, surface sealing as well as water infrastructure and quality. The selected urban units, each characterized by their more or less highly dynamic and rapidly transforming structures, can be seen as examples for how interdisciplinary analysis and discussion on social and ecological vulnerability in a complex and fast-growing (mega) urban surrounding can be done. The authors consider the megacity to be a vibrant system. Its main attribute may be described by the Chinese word 'tongbian' which means continuity through change. Constantly changing functions and interdependencies were revealed by comparing changes in the settlement area and water surfaces in particular by remote sensing, water sampling, field mappings and interviews. The examination of the morphologic features – based on different urbanization stages resulting from changing political interventions over time – makes it possible to identify such interactions on the micro-scale and as a consequence get a detailed understanding of the broader mega-urban context and the reciprocal influences on the urban water household. Thus, the urban units are not to be seen as a rigid system, but as a basis for the analysis of complex structures such as (in) formal living spaces, which each have characteristic infrastructures, types of water supply or sewage disposal systems. They constantly go through dynamic changes like a rising urban density or shifting supply channels. Thus, the trinomial approach can help to reveal formal and informal characteristics of the urban unit. It puts special emphasis on the development of built up and open space, in particular the urban units' transforming areas. Apart from population density and structure, the development and quality of the spatial density, the simultaneously increasing surface sealing and the

decreasing open space can be seen as indicators for a progressive development process. In the same way, self-regulating processes such as phenomena on the micro-scale show the degree of ecological and human vulnerability. They highlight the variety of already existing coping strategies like compensating for bad tap water quality by buying plastic bottles or using groundwater, too. In comparison to the objective hydrological and morphological analyses as well as the sampling of water, studying the subjective social vulnerability and the human-environment relationship are other cores of research. This suggests that from a personal point of view not all potential stressors are actually seen as a threat to one's own vulnerability (cp. Bercht & Wehrhahn, 2010). Results indicated that people who are exposed to the same environmental conditions appraise certain risks differently. It is based on varying personal factors and access to appropriate resources. The social vulnerability perspective supplements the ecological vulnerability factors and the influence of macro-scale factors (e.g. institutions, water systems). Within this research framework the social perspective looks at the effects from a subjective perspective to better capture peoples' way of thinking and their emotional states. Hence, it explains the different levels of vulnerability and coping behavior. However, in this context a quantitative analysis of water-related structures and water quality is required to, for instance, for verifying subjective evaluations of the (poor) quality of drinking or surface water to prove a contamination.

CONCLUSION

Using the trinomial approach, it became possible to break the overwhelming set-up of the megacity down into the most important elements, which are characteristic and instructive for a long-term development analysis, sustainable approaches to urban and water management planning and improved governability. The various urban unit types with their ecological, economic and social characteristics and transformations act as reference areas and are thus a model for the entire megacity. Applying a micro-typology has turned out to be a good starting point to compare and standardize urban and water planning structures and measures. Restructuring processes implemented on the macro-scale do also lead to the restructuring of local impacts on the micro-scale. By embedding the units' characteristics in the broader context, the understanding of the relationship between (changing) landscape patterns and water quality can be improved. Critical influences of the land use (including varying supply and disposal systems) on the local water quality, as well as on peoples' living conditions and their need to develop coping strategies can be determined.

The interdisciplinary analyses of the land use (changes) on micro-scale have shown various hotspots of vulnerability with regard to the water resources, settlement structures and inhabitants: The shape, use and spatial structure especially of the urban units' open space changed drastically within the different units. The ecological vulnerability was clearly noticeable, particularly in terms of water quality. The interdependencies of a rapid population growth and an increasing use of water, land use patterns, peoples' ways of thinking and responding as well as surface and groundwater systems became obvious e.g. by high concentrations of coliform bacteria. The negative outcomes on ground and surface water were very apparent in Liede and Xincun located in the new central business district, but also in the peri-urban areas Yuangangcun and Shibi. A downward gradient in relation to the axis became clear – with the exception of groundwater contamination as the highest concentration of coliform bacteria was measured within the old city and thus not in the axis' range. Yet, it could be assumed that coliform bacteria are primarily of excrement origin since large amounts of domestic wastewater were pumped into the water circulation untreated and accumulated while flowing through the urban area. Countless other examples like open wastewater ditches or eutrophicated feeders showed the vulnerability of water supply and sanitation. Open wastewater gutters reduce the quality of life as well as the environment and pose health risks to humans, especially to children. Actions such as makeshift covers over those ditches in order to reduce bad odors and sights express the population's need for better living and environmental standards. In many cases, a lack of modern sewage disposal facilities is accompanied by a deficient public water supply: Several people living on the periphery were still not connected to the public supply network and thus had to buy water bottles or use polluted groundwater for daily purposes. Others who were already provided tap water had to boil it for drinking water purposes due to the degraded quality or they used publicly available water vending machines or alternatively private suppliers (cp. Wehrhahn *et al.*, 2008).

Due to China's dualistic urban-rural management system and the growing power and influence of the local government, in particular the social and economic development of more or less heterogeneously grown

units such as the 'urbanized villages' have not been integrated into city planning yet – although they belong to the urban agglomeration. With future developments scenarios in mind, the observed ongoing land use changes can be regarded as important indicators for what could happen in the medium term, e.g. to the historic town center. It can be expected that land use changes within the axis will primarily happen due to the demolition of traditional and low-standard houses and that large-scale land use changes will especially take place on the southern and eastern periphery following the program of the overarching master plan. Buildings will 'grow' on agricultural areas instead of vegetables as it can be seen in Xincun and Yuangangcun. Particularly large-scale land use changes and the growth of population will have far-reaching impacts on Guangzhou's water household: On the one hand, decreasing unsealed surfaces does not allow for infiltration and natural groundwater recharge. On the other hand, the supply pressure will increase due to the need for access to clean drinking water and adequate sanitation as well as transforming consumption and disposal patterns. Even though the administration has successfully started improving the environment by enhancing its sewage treatment and water supply capacities as well as river cleaning programs and creating green belts, further improvements – both in the supply and sanitation sector – are required in order to secure the water resources for future generations.

Against this background, it can be substantiated that information drawn from interdisciplinary studies are important inputs to land use and water resources planning. This applies not only to the allocation of surface water and the function of groundwater, but also to the water quality as well as the spatial and psychological processes involved. A comprehensive analysis of Guangzhou's water quality, the use of adapted technical solutions, the enforcement of laws, capacity building and improved as well as forward-looking urban planning measures are all of the utmost importance for a sustainable city planning and water resources management. The crucial point is to understand the degree of vulnerability the environment or a person is exposed to. But, to achieve this is very difficult. Thus, an interdisciplinary approach is needed in which the two sub-systems are considered as one entity. In this paper, theoretical backgrounds and insights from natural sciences are thus combined with those from social science to concretize the impacts of the structural changes along Guangzhou's city axis on environmental as well as social factors.

ACKNOWLEDGEMENT

The authors would like to thank the German Research Foundation, as the research material is based upon work within the Priority Program 1233 Megacities: Informal Dynamics of Global Change. Special thanks go to the anonymous reviewers for their valuable comments on the earlier draft of this paper.

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