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Integrated research on subsurface environments in Asian urban areas

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ABSTRACT

The RIHN project "Human impacts on urban subsurface environments" aims to suggest improved development plans of urban centers for human well-being. This will be done by examining reconstructed past changes in urban environments, and by developing integrated nature-social models. Subsurface environmental indicators are developed from the points of view of: (1) human activities; (2) climate change; and (3) character of urban development and social policies. Water, heat, and material environments and transport vectors are being evaluated by a number of different approaches. Some of these include investigating changes in groundwater resources using satellite observations, reconstructing effects of climate change and urbanization using subsurface thermal regimes, and evaluating past contamination patterns from preserved subsurface records. In this overview paper, we describe the current status of urbanization in Asia, subsurface water conditions, material and contaminant transport to surface waters by groundwater, and subsurface thermal anomalies due to the heat island effect. The rapid pace of urbanization in Asia requires that we develop a better understanding of how to deal with environmental impacts, both above and below ground.

1. Introduction

The world is a very different place today than it was only a short period ago. Urbanization and industrialization are changing the character of the planet. From a historical viewpoint, the development of our major cities progressed in two major transitions. From roughly 1750 to 1950 Europe and North America (and Japan and Oceania) became urbanized in the process of the industrial revolution. By about 1950 the world was divided into two major blocks: the North Atlantic and Japanese wealthy urban-industrial block and the African-Asian-Latin-American poor rural-agrarian block (Ness and Talwar, 2004). At that time, New York City was the world's only "megacity," a city with more than 10 million people. Now there are 17 such cities around the globe, 14 located in coastal areas, and 11 in Asia. And today, Asia, Africa and Latin America are following the West in the urban-industrial transition.

A key point of concern is that the current urban transition is occurring much faster than ever before. What took two centuries in the past will now occur in decades. In addition, the absolute numbers today are much larger than ever. The North Atlantic urban transition involved a few hundred million people; the transition today, especially in Asia, involves billions of people. The greater speed and numbers of this transition impose on Asian urbanization a much greater sense of urgency to identify and address the problems the transition is bringing.

The Research Institute for Humanity and Nature (RIHN) in Kyoto, Japan has been established to address global environmental issues such as climate change, shortage of water

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resources, and decrease of biodiversity by an integrated approach involving both the natural and social sciences. One of RIHN's on-going projects "Human Impacts on Urban Subsurface Environments," is investigating the subsurface as a unique environment. Specifically, we are assessing the effects of human activities and climate changes on groundwater — the primary component of the subterranean environment.

While groundwater has become an increasingly important aspect of human life, its role as part of the urban environment has not as yet been evaluated. This is especially true in Asian coastal cities where urban population numbers and densities have increased very rapidly and uses of the subsurface environment have grown correspondingly. The primary goal of our research is to evaluate the relationships between the development of Asian cities and various subsurface environmental problems. For example, we see reoccurring patterns in groundwater withdrawals, extreme subsidence, groundwater contamination, and subsurface thermal anomalies. We are also addressing the sustainable use of groundwater and subsurface environments to provide for improved future development and human well-being.

Most global environmental studies have long focused on the environmental issues above ground such as air pollution, global warming, seawater pollution, and decrease in biodiversity. However, subsurface environmental issues are also important for human life in the present and future. Unfortunately, these issues have been largely ignored because of the invisibility of the phenomena and difficulty of the evaluations.

Perhaps the most dramatic and obvious subsurface environmental problem occurring in Asian coastal cities is the subsidence due to excessive pumping of groundwater. This has occurred repeatedly in major cities throughout Asia with a time lag depending upon the speed and character of urbanization. When the extent of subsidence becomes unacceptable and serious structural and flooding problems occur, governments typically impose changes in reliable water resources from groundwater to surface water supplies. Unfortunately, this has not stopped subsidence in all cases. On the other hand, even when land subsidence has ceased due to regulation of groundwater pumping (e.g., Tokyo, Osaka), the associated increase in groundwater level has caused other types of damage by flooding and buoyant forces to underground infrastructures (e.g., subways) that were constructed during the drawdown period.

Another important aspect of the subsurface environment concerns material (contaminant) transport to the coast. Research over the last few years has shown that direct groundwater discharge to the coastal zone is a significant water and material pathway from land to ocean (Moore, 1996; Taniguchi et al., 2002; Burnett et al., 2003). We hypothesize that many water quality and associated problems influencing coastal environments around the world today are related to past and on-going contamination of terrestrial groundwaters because those groundwaters are now seeping out along many shorelines. For example, chronic inputs of fertilizers and sewage on land over several decades have resulted in higher concentrations of various nitrogen species in groundwater. Because these groundwaters will eventually display slow yet persistent discharge along the coast, coastal eutrophication may result. Such inputs may thus contribute to the increased occurrences of coastal hypoxia, nuisance algal blooms, and associated ecosystem consequences. Since most Asian mega-cities are located on the coast, material and contaminant transport by groundwater is a key to understanding present

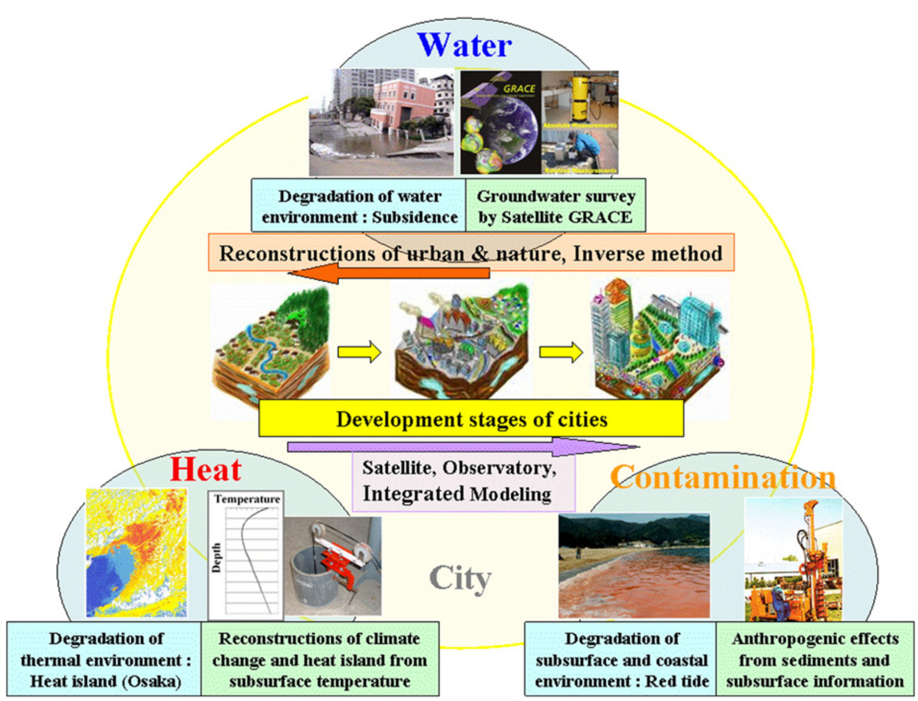

Fig. 1 – Integration of subsurface environmental problems. Four sub-themes, urban water, heat, and contamination in subsurface environments are integrated from the two different points of views, reconstructions of the environment (from current to the past) and development stage of the cities (from the past to current and future).

and future coastal water pollution and effects on associated ecosystems (Capone and Bautista, 1985).

While investigations of groundwater discharge into the coastal zone have increased dramatically over the last several years, few studies have been performed in and around urban centers and there have been very few studies anywhere in Asia outside of Japan (Taniguchi et al., 2002). This may be a significant oversight as the region is characterized by many features that are typically present in areas of high submarine groundwater discharge (SGD). For example, many parts of Southeast Asia contain regions of high rainfall, karst terrains, and high relief.

While global warming is considered a serious contemporary global environmental issue, most discussions of the phenomena have been limited to above-ground issues. However, subsurface temperatures are also affected by surface warming (Huang et al., 2000). In addition, the "heat island effect" due to urbanization creates subsurface thermal contamination in many cities (Taniguchi et al., 2003). The combined effects of these two processes may be recognized up to more than 100 m below the surface. The increased rate of surface and subsurface temperature change in cities is thus caused by these combined effects.

Our research aims to suggest improved development plans of urban centers for human well-being by reconstructing past changes in urban environments (from present to past), and by developing integrated nature-social models (from past, present to future). Subsurface environmental indicators will be developed from the points of view of: (1) human activities; (2) climate change; and (3) character of urban development and social policies. Water, heat, and material environments and transport vectors are being evaluated by investigating changes in groundwater resources using satellite observations, reconstructing climate changes and urbanization using subsurface thermal regimes, and evaluating past contamination patterns from preserved subsurface records. In order to achieve these research objectives within the project period, four sub-themes were chosen and eight methodologies are being applied (Fig. 1). The Asian urban centers Tokyo, Osaka, Bangkok, Jakarta, Taipei, Manila and Seoul are targeted as the study sites (Fig. 2).

2. Urban environment

Asia's urban environment is a fast evolving condition. As noted in the introduction, the macro pattern of urbanization in Asia follows the earlier trajectory that began in Europe and North America three centuries ago. Asia is now following that massive transition from rural-agrarian to urban-industrial society. But in Asia that transition moves much more rapidly and involves far more people than in the past. There are other differences as well, which will be especially salient for these studies of the urban subsurface environment. Thus the best way to describe the current evolving urban environment in Asia, and especially for the cities in this study, will be to examine similarities and differences with the past in Europe and North America. There are four areas that will be most salient for this analysis: 1) the move from inland to coastal cities; 2) the onset and implications of industrialization; 3) the pattern of population growth, with implications for migration; and 4) the different trajectories of urban health.

2.1. *From inland to coastal cities*

One of the most striking differences between Asia and the West in the long history of urbanization is that between inland and coastal cities. This is especially clear when we consider the history of the world's 25 largest cities (Table 1). For the past 2000 years and more, up until 1800, the majority of these cities

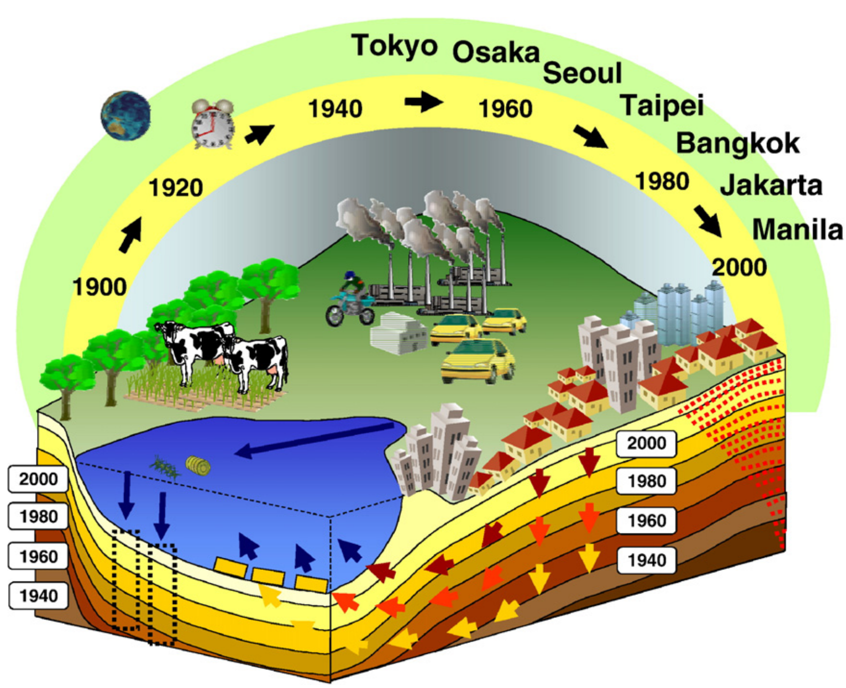

Fig. 2 – Schematic diagram of the study. The different development process and water usage have affected the subsurface environments of seven Asian cities.

Table 1 – The world's 25 largest cities by date and region

Region	1000	1500	1800	1900	2000
N. Atlantic*	Cordoba, Seville	Paris, Venice, Milan, Naples	London, Paris, Naples, Moscow, Lisbon, Vienna, St. Petersburg, Amsterdam	London, New York, Paris, Berlin, Chicago, Vienna, St. Petersburg, Philadelphia, Manchester, Birmingham, Moscow, Boston, Glascow, Liverpool, Hamburg, Budapest, Ruhr	New York, Los Angeles, Paris Moscow, London
S. Asia	Anhilvada, Tanjor, Chunar	Vijayanagar, Guar, Mandu, Delhi, Chitor, Cambay	Lucknow, Patna, Calcutta,, Hyderabad	Calcutta, Bombay	Mumbai, Calcutta, Delhi. Dhaka, Karachi
S.E. Asia	Angkor	Ayutia			Manila, Jakarta
E. Asia	Sian, Chengtu Hangchow Kaifeng, Kyoto, Canton, Liaoyang, Songdo, Soochow, Ninghsia	Peking, Hangchow, Nanking, Canton, Soochow, Sian, Seoul, Chengtu, Kaifeng	Peking, Canton, Hangchow, Yedo, Soochow, Osaka, Kyoto, Sian, Nankong, Ningpo, Seoul	Tokyo, Peking, Osaka, Shanghai	Tokyo,, Shanghai, Osaka, Beijing, Seoul, Tianjin
MENA**	Contantinople Cairo, Rayy, Hasa Bagdad, Nishapur Bokhara, Isfahan	Cairo, Tabriz, Constantinople, Fez, Adrianople	Constantinople, Cairo	Constantinople	Cairo, Istanbul
Africa					Lagos
Latin America				Sao Paulo, Rio de Janiero Beunoa Aires	Mexico City Sao Paulo, Buenos Aires, Rio de Janiero
Oceania					

*Europe and North America. **Middle East, North Africa.
Source: through 1900 Chandler and Fox (1974); 2000 UN (2001).

have been in Asia (Chandler and Fox, 1974; Ness, 1997; Ness and Low, 2000). More importantly, almost all of those great Asian cities were inland rather than coastal cities. They were major administrative centers of large and complex state-like systems that organized a vast and productive hinterland. And it was largely because of the administrative effectiveness of those large state-like systems that they could draw immense wealth from their hinterlands. Asia was characterized by inland empires, whose lands were governed and made productive by urban administrative centers.

By contrast, the cities of the ancient Roman Empire were primarily on the sea, or on rivers close to seaports. During the roughly six centuries that Rome dominated the Mediterranean, it competed with Asia for the majority of the world's 25 largest cities. But the cities of the Roman Empire were sea-oriented. Rome drew immense wealth from more remote lands through a confiscatory taxation system that enriched the Center, often at the expense of the peripheral producing regions. Much of the wealth of Rome came to it by sea. By contrast contemporary Asian Empires organized their immediate hinterlands for high productivity. And that wealth came to the cities over land.

A similar distinction is found between Europe and Asia. The cities of Europe rising after the 10th century were small "break in transport" centers on rivers or the sea. For these cities trade was a major source of livelihood. Like Rome they did not control immediate hinterlands whose productivity was rooted in the city's administrative capacity. They lived far more by trade. For medieval European cities, it was trade in a burgeoning capitalist system that brought increased human productivity and wealth.

It was this burgeoning capitalist system that took Europe beyond its borders to create a world-wide ecosystem that placed its stamp on modern urbanization. From the 15th century, first Iberian, then Western European expansion by guns and sails (Cipolla, 1965) established a new world order under Western Capitalist (increasingly industrial capitalist) hegemony. By 1850 this can be seen in the composition of the world's 25 largest cities. Asia still had the plurality, 11 of the 25, but Europe now had 7 and the US 2. Now it was London that led the list. By 1875 Europe had 11 and the US 4. Three were in China and Japan, and three new large cities were in British India. As Western Capitalist penetration expanded in the 19th century, a striking transformation came over the world urbanization pattern. Great cities emerged as seaports. At first these were located primarily in the West and in Asia. By 2000, however, great cities are found on every continent, and 20 of the largest 25 are seaports.

Thus the cities of this study, as large coastal or sea-oriented enclaves, are new for Asia, but reflect the three centuries of Western urbanization. They are now part of a truly global phenomenon. Many of the conditions that are the subject of this large research project — subsidence, groundwater withdrawal, salt water intrusion, the seepage of industrial pollutants into the sea, and the impact of water policies on underground water levels fed by rivers — are phenomena of the new coastal locations born of an urban-industrial world tied together by seaports.

If the shift from inland to coastal cities marks a major transformation for Asia, another condition shows greater continuity. For two millennia and more Asia has been home to some of the world's most extensive empires. Both China and India knew large complex state-like organizations long before they were known in Europe, where our modern urban-industrial system was born. Even where these were relatively small, as in Southeast Asia, we have seen the gradual rise of complex state-like systems for the last millennium and more (Lieberman, 2003). Except for Manila, the cities of this study arose within large, centralized political systems. Thus even as they have become sea-oriented trading centers in an increasingly global environment, they are governed very much by the strong nation states in which they are set. In this they differ from cities in sub-Saharan Africa or Latin America. This gives these cities something of an advantage in that they are part of a political system capable of both making and implementing important policy decisions that will affect their livelihood and welfare.

In this, Manila may be an instructive exception. The Philippines alone in Southeast Asia lacked a centralized political system before the arrival of the West in the form of the Spanish Empire. Nor did the history of Spanish or American colonialism prove very effective in building a strong state. The Philippine political system still appears more like a tribal system of powerful families than an effective state system (McCoy, 1993, Kang, 2002). This is now having a pronounced impact on urban water systems. Manila's water system (Jago-On et al., this volume) is being seriously depleted in part because the government is incapable of controlling private well digging. The same is happening in Cebu City (Flieger in Ness and Low, 2000, p. 166). Uncontrolled private well digging is drawing down the aquifer more rapidly than natural recharging, resulting in seawater intrusion some 3.5 km by 2000. The state lacks the administrative capacity to control this private well digging. This is merely one small indication of the lack of the kind of political-administrative capacity that we can find much more fully developed in those parts of Asia with long histories of indigenous state-like systems. Bangkok provides a contrast with Manila that reinforces this argument. It has been able to reduce pumping subsurface water, resulting in a rapid rise of the underground water table.

2.2. *Industrialization*

Industrialization and urbanization are closely associated historically, but again the West–Asian difference is instructive. The Industrial Revolution originated in United Kingdom in the later 18th and early 19th century. There are many beginnings and much theorizing of the causes of the Revolution and especially of its emergence in England and the West (Smelser, 1959; Landis, 2003; Pomeranz, 2000). There is much agreement, however, on the broad lines of development and of the technological changes that underlay the Revolution. One development of special importance for this volume is the role of steam engines, especially the earliest engines, which were developed in England in the early 18th century. Thomas Newcomb's "Atmospheric Engine" was invented in 1712; and it was used primarily for pumping water from deep coal mines. This represented one of the major advantages English technologies had over the Chinese. It enabled the British to extract a large quantity of relatively high quality coal, which later in the century provided the power for the Revolution.

If the Newcomb steam engine could pump deep mine water as early as 1712, it was not for another half century (1769) until James Watt developed a more efficient engine, which could be industrially useful. At the same time, a series of other inventions were coming together to produce the Industrial Revolution. The cotton gin (1793), the power loom (1769), the spinning jenny (1764), and the flying shuttle (1733) combined to make textiles one of the leading edges of the Revolution. This began two centuries of a remarkable technological development. When Asia (other than Japan, which began the modern transition before 1900) began its major thrust to industrialization, after 1950, all of these technological developments were not only made, they were massively improved upon, and they were easily transported to anywhere on the globe. Thus Asia's industrialization could be much faster that that in the West. The cities of this study built factories and pumped water far more quickly that did the West in its initial Industrial Revolution. The downside of this technological advantage lies in the problems of subsidence and subsurface pollution, which is the topic of this volume.

Another technological development parallels the different speeds of urbanization in Asia compared with the history of the West. This lies in building construction. Until the 19th century, the height of buildings was constrained by the load that could be carried by stone walls. The great Gothic Cathedrals of Western Europe were architectural innovations that reached for the sky. The Gothic Arch was a magnificent innovation not only for its beauty, but because it allowed church naves to be taller, to reach closer to God. But there are severe limits to the load that stone walls can contain. The great cathedral at Chartres has a spire that rises only 113 m (Favier, 1990), and here the walls support only the narrow spire. In the 19th century sky scrapers began to appear in Europe and the United States. The tallest building with masonry load bearing walls, The Mondanook Building, was built in Chicago in 1901. It soared to 167 m, only 50 m higher than medieval churches. But by that time, engineers were building with a revolutionary design. They used steel frames, or skeletons to bear the weight of the buildings, and this meant that the sky was the limit. By 1900 steel framed "skyscrapers" were going to 200 m. By 1950 it was 400 m. Today the two tallest buildings are Taipei's Taipei 101 at 509 m and the Kuala Lumpur's Petronas Towers at 452 m.

Again, the point is the speed of the Urban-Industrial Revolution. What took two centuries in the past happens today in a few decades. Indeed, the pace of change is still accelerating, as we can see in the height of buildings. The 200 tallest buildings in the world (www.emporis.com) are all more than 225 m; 100 m higher than the Chartres Spires, or 50 m higher than the tallest masonry bearing building. Thirty are over 300 m and six are over 400. The oldest is the Woolworth Building in New York, built in 1913. There were five more built in the 1930s; none in the 1940s and two in the 1950s. In the 1960s six of the tallest were built. Then the pace quickens: 16 in the 1970s, 28 in the 1980s and 54 in the 1990s. Since 2000, 88 of the world's 200 largest buildings were built; 31 of those were built in 2006 and 2007 alone.

We have not yet calculated the impact that the sheer weight of buildings has on the new urban environment. It must be enormous! And it must also contribute substantially to the impact the new urbanization has on the subsurface environment.

Technological developments in chemicals have also produced a profound difference between earlier and current urbanization processes. Pollution in the burgeoning cities of the early industrial revolution came largely from human wastes, producing diseases like Cholera. In 19th century cities pandemics of Cholera were a major scourge (Johnson 2006). WHO lists seven major pandemics of Cholera starting with Bengal in 1816–26. In the third pandemic, 1852–60, Dr. John Snow made history by tracking the disease to water polluted by human wastes in London's Soho District. He removed the handle from a suspect pump and brought the epidemic to a close. This led to wide spread developments of public water treatment and sewage management systems throughout the Western World. The process is now being promoted in many poorer countries undergoing rapid urbanization.

Chemical developments have also produced another form of more serious and less easily treated pollution. This is from new organic and inorganic chemicals and heavy metals. The U.S. Environmental Protection Agency now lists 8 disinfectants, 16 inorganic and 53 organic chemical pollutants in drinking water that can adversely affect health. Managing infectious diseases is relatively easy (though costly) through protecting water supplies and proper sewage management. Dealing with dangerous chemicals requires more complex handling and filtering procedures that the new urban environments find difficult to manage. Moreover the exceedingly high rates of urban population growth in Asia (see below) exacerbate the problem is dealing with water and wastes.

2.3. *Population growth: two demographic transitions*

The history of the human population is one of a long period of very slow growth and a recent period of exponential growth. Up until about 1700 the world population grew only very slowly, less than 0.2% per year, with many regions and period of long term negative growth. Thus by about 1000, world population had only reached about 250 million; 500 years later it had grown about 80% (about 0.16% per year) to some 424 million people (McEvedy and Jones, 1978). With the opening of the oceans to exploration and trade, growth rates in Asia and Europe rose to about 0.5% per year. This opening also led, however, to the crash of indigenous populations in the Americas, as natives succumbed to diseases brought by the Europeans. The Americas were subsequently repopulated by further European immigration. After 1700 the pace of growth quickened to just over 1%, especially in Europe and North America. In the post World War II era, population growth rates rose dramatically, peaking at 2.04% in 1965–70, then began a gradual decline (UN, 2004). Most of this post 1950 growth was in the Less Developed Regions, where rates rose above 3% before declining. When the peak growth rate was reached in 1965–70 world population stood at just over 2.5 billion. It is now (2007) 6.5 billion and growing at roughly 1.8% per year (Fig. 3).

This dramatic growth has come about in two major spurts, and is defined by what demographers call The Demographic Transition or the transition from high to low birth and death rates (Ness, 1993; Ness and Low 2000). Throughout human history birth and death rates have been relatively high and close together, implying slow growth, usually less than 0.2% per year. With major scientific, transportation, agricultural and industrial revolutions following 1700, death rates in Western Europe and North America began a slow decline. When death rates began their gradual decline about 1700, crude birth and death rates in some of Europe stood at about 30 and 25 per 1000, implying a natural growth rate of 0.5% per year. Prior to 1700, and even in some years in the late 18th century death rates were higher than birth rates, implying

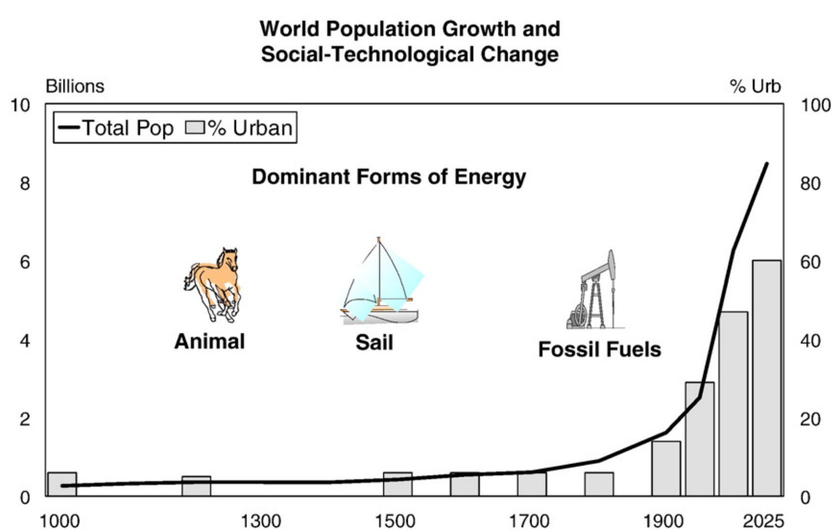

Fig. 3 – World population growth and social–technological changes.

negative growth. The cause of the long term decline was a general rise in the standard of living brought by the revolutions. While mortality declined, fertility remained high, bringing a period of rapid population growth, with growth rates rising to slightly above 1% per year through the later 18th and early 19th centuries. Then the urban-industrial revolution arrived that brought declines in fertility. Birth rates fell to come into line again with the lowered death rates and the demographic transition was completed.

This was, however, only the first of two demographic transitions. It happened all over Europe, North America and in Japan and Oceania. By 1950 the world was divided into two major demographic regimes: the low mortality-fertility regimes of the West and Japan, which the United Nations now refers to as the More Developed Regions (MDR); and the high mortality-fertility regimes of most of Africa, Asia and Latin America. The latter are what the United Nations refers to as the Less Developed Regions (LDR). Then the second demographic transition began in the LDRs. The general trajectory is the same as the first: mortality declines first while fertility remains high, producing a period of rapid growth; then fertility declines to come into line with the lowered mortality and population growth slows. This is now happening throughout the LDRs, where many countries, especially China, and shortly India, have already completed the transition. In the poorest countries of Africa and Southern Asia mortality is down but fertility has not yet fallen sufficiently to close the demographic transition.

Although the trajectories of the two transitions are similar their causes, magnitudes and speeds differ remarkably. In the West death rates declined *slowly* due to the general rise of living standards, *without any major breakthroughs in medical technology*. Today, mortality declines very *rapidly*, largely due to the *new medical and public health technology* that was ushered in with industrialization, and grew very rapidly during World War II. This technology is powerful against infectious diseases, and can be applied relatively quickly over a wide population. For example, DDT used in world-wide anti-Malaria campaigns, often reduced the infant mortality rate as much in one or two decades as had taken a century in the past of the Western world. Moreover, for reasons still debated, the original (1950) birth and death rates in the LDRs were considerably higher than those in the past of the West. This meant that when mortality fell quickly while fertility remained high, rates of population growth soared. Rates of 1% per year were common in the past of the West; rates in the LDRs reached 3% and more. Starting from a larger population base, this meant an immense growth in numbers. In 1950 there were 0.8 billion people in the MDRs and 1.7 billion in the LDRs; in 2005 there were 1.2 billion in the MDRs and 5.3 billion in the LDRs.

Fertility can also fall more rapidly today than in the past, again because of the new contraceptive technology that has been widely available only since about 1965. China, Taiwan, The Republic of Korea and Thailand, have seen fertility decline from traditional to modern controlled levels in two decades; the same decline took two generations and more in the West. This has also helped hasten the fall of mortality. When fertility falls, infant and maternal mortality also fall dramatically.

The Past Demographic Transition in the West marked the movement from rural-agrarian to urban-industrial society. The Transition is having the same impact in the LDRs today; no where more rapidly than in Asia. In fact the Republic of Korea and Taiwan have seen the fastest transitions witnessed anywhere. In the span of just 40 years, each went from being a poor, high mortality-fertility, rural-agrarian society to a wealthy, low mortality-fertility, urban-industrial society. (China and Thailand have had similar rapid fertility declines, but have not yet become fully urbanized and industrialized.)

Everywhere in the LDRs the urban transition is taking place, and today it, too, is moving much faster than in the past. In Asia, urban population growth rates are higher than rural or total rates everywhere (Ness and Talwar, 2004). Indeed, in many countries the rural growth rates are now negative and all the growth is occurring in cities. Already China, Indonesia, Japan, The Republic of Korea and the Philippines show negative rural growth. By 2030 they will be joined by Bangladesh, India, Malaysia, Myanmar, Sri Lanka, Thailand and Vietnam. Moreover, as noted in the introduction, the numbers today far outstrip those of the past Western transition. The European and American urban transition involved a few hundred millions of people; that in Asia alone today involves billions. By 2030 the Asian urban population will have grown ten times from 244 million in 1950 to 2.7 billion in 2030 (UN, 2001). This rapid and massive growth places great strains on all urban infrastructures, and on the natural environment, especially on the subsystems of the urban areas.

2.4. *The health of cities*

Another dramatic difference between past Western and present Asian urbanization processes lies in the health of urban populations. Cities of the past, but especially in 18th and 19th century's pre-industrial West were extremely unhealthy places. High urban population densities provided microorganisms with a veritable supermarket of hosts. Often centers of trade, cities also experienced the introduction of new microorganisms, such as the great plagues of the 14th century in Europe. Urban death rates were usually higher than those in the rural areas. This meant that cities grew primarily by net in migration from rural areas. This was also true in Asia as late as the early part of the 20th century. In colonial Burma, Malaysia, Indonesia, Vietnam and the Philippines, Infant Mortality Rates were higher in urban than in rural areas (Boothe, 2007).

By contrast cities of the LDRs today, and especially those of Asia, are healthier than the rural areas. Death rates are lower in urban than in rural areas, largely due to the new medical and public health technologies, which can be more economically applied to high density urban populations than to scattered rural populations. This is having a profound impact on the population dynamics of Asian cities, though only with indirect implications for the urban subsurface environments.

First is the implication for sex ratios. Rapid urbanization in Asia is due to both natural increases, the excess of birth over death rates, and to net in migration. This means that we can expect more even sex ratios in Asia than we found in the history of Western urbanization. At least that would be true but for another technological development that is linked to cultural differences. Ultrasound technology has enabled parents to identify the sex of the unborn child. Where there is preference for boy babies, this leads to abortion of female fetuses, by processes that have become simple and safe along with the rise of new medical technologies. Asian cultures differ greatly in the value attached to boy and girl babies. The greatest demand for male children is found in South Asia; it is slightly lower in East Asia; and almost non existent in Southeast Asia. This has already resulted in very large imbalance in the sex ratios of China and India, which is most likely to result in great urban violence and political instability. This is because men without women are violent. Bachelor gangs are notoriously violent, both internally against their own members, and externally against the larger public (Hudson and den Boer 2004). Urban violence and political instability can seriously retard a city's capacity to develop the infrastructure needed to protect its environment, both below and above the surface.

This sex ratio imbalance is not likely to have an important impact on the cities of this study, however. Bangkok, Jakarta and Manila, are part of the Southeast Asian cultural region. Here, there is very little preference for male children. Boys and girls and equally welcome, and there is very little use of ultrasound sex identification and abortion of female fetuses. Japan, Taiwan and South Korea, are part of the east Asian cultural region, where there is stronger male child preference, but this has been largely washed out by the process of economic development. As societies get wealthy the sex ratio tends to move toward greater equality and then to female dominance. Thus there are no shortages of females in the cities of these three countries.

This leads us to another important implication of the greater health of modern Asian cities: aging. The process is a natural implication of the demographic transition. As mortality falls, a population becomes younger. The proportion under 15 rises, sometimes dramatically. The faster mortality falls, the faster is the rise of the young. When mortality in the Republic of Korea fell rapidly, the proportion of the population under 15 rose to 45%. Then as fertility falls the proportion under 15 declines and the proportion 65 and over rises. In Japan this process is now well advanced, and Japan today has the world's oldest population; 20% of its population is 65 years and older, and by 2050 that proportion will reach 36%. The faster fertility falls, the more rapid is the aging process. China's very rapid fertility decline has already brought its aged population to 8%, and it is projected to rise to 24% by 2050. Thailand also had a rapid fertility decline, giving it 7% aged in 2005 with a projected rise to 22% by 2050. The Philippines, on the other hand has had a much slower fertility decline, giving it an aged population of only 4% in 2005, projected to be only 14% in 2050.

The aging process has important implications for economic and social policies, some of which are positive, others negative. On the positive side, aging is associated with a rise in the savings and thus investment levels, which will promote economic development (Yaari, 1965. See also the extensive literature in the new National Transfer Accounts project: www.schemearts.com/proj/nta/show.working%20Papers.). This increases a society's capacity to protect its environment. On the other hand, the rise of the aged imposes a cost born by those of working ages. This also implies the demand for new institutions to transfer wealth from productive working age people to consuming older people. Such institutional development is part of the standard history of the MDRs where public institutions replaced families as the providers of care for the aged. This development is now part of the demands on Asian societies that are urbanizing and industrializing rapidly. Here again, however, the speed and size of the new transformations place heavy burdens on the new Asian megacities. Traditionally, the family has provided care for the aged. But where urbanization and industrialization are very rapid, the family looses its capacity to provide the needed care before other institutions of support have been developed. In Weihai, China, for example, it is estimated that some 10,000 people 65 and over have been abandoned by their children (AUICK, 2007. See also the broad review of aging in nine Asian cities, organized by the Asian Urban Information center of Kobe, www.auick.org.). The city now has a plan to build housing for these needy aged, but again, the cost of providing such services and infrastructure competes with the demands for protection of the environment.

2.5. Summary of this section

These comparisons of Western past and Asian present urbanization show that the current Asian urban environment is one of immense pressure. The pressures on the urban subsystem environment are great and are likely to become even greater. The greater speed and magnitude of the Asian urban transformation compared to that in the west implies greater degradation of the environment from human and industrial wastes.

It implies greater capacities to extract subsurface water, drawing down aquifers at rates greater than natural recharging, and thus leading to subsidence. The technological developments imply far greater capacities to load the urban landscape with buildings of immense weight. The rapid population growth also implies a heavier load from people alone. All of these pressures can be managed and mitigated by the development of a more protective urban infrastructure. Waste control, water protection and conservation, pollution mitigation can all be controlled much more effectively today, given the new technology that has developed along with the urban-industrial transformation. But that technology is expensive. Moreover, the rapid pace of urbanization implies a large array of other social problems that require infrastructure and institutional development, whose costs will compete with those of environmental protection. Although the cities and countries of Asia are experiencing economic development, which may help them acquire the protective technology they need, the rapid pace of urbanization implies that even in the best of worlds there will be a large gap, or time lag, between the increasing pressure on the urban subsystem environment and the capacity to mitigate that pressure.

3. Water environment

3.1. Subsidence due to groundwater pumping and saltwater intrusion

Subsidence due to excessive groundwater pumping has occurred repeatedly in large Asian cities as a result of an increase in demand for water resources (Fig. 4). Compaction of

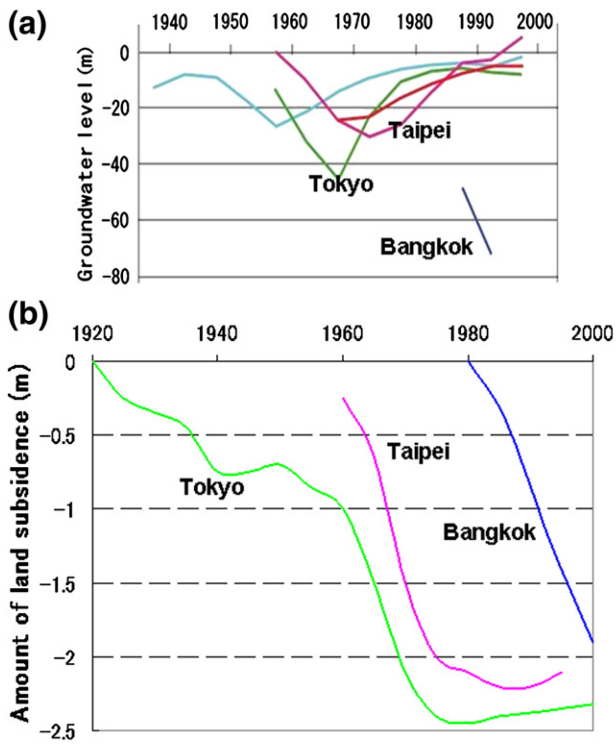

Fig. 4 – Change in (a) groundwater level and (b) amount of subsidence.

sediments after subtracting pore water in the aquifer is the main reason for the subsidence. The magnitude of the subsidence depends on the drawdown depth of groundwater level, the duration time of the groundwater pumping and physical characteristics of the aquifer (i.e., clay or silt).

Changes in reliable water resources from groundwater to surface water supplies have been initiated by government policies in many cases, yet subsidence is still not being prevented in many areas. This has resulted in a serious risk of flooding in many coastal cities in Asia. For example, some sections of Bangkok now flood during each Spring tide.

On the other hand, although land subsidence has ceased in the Tokyo and Osaka areas due to regulated reductions of groundwater pumping, the associated increase in groundwater level has caused new types of damages caused by buoyant forces exerted to underground infrastructures (e.g., subways) which were constructed during the drawdown period (Fig. 5).

3.2. *Changes in reliable water resources*

Changes in reliable water resources from groundwater to surface water (e.g., via dam construction) have occurred in including Asian cities. This is attributed to the increase of water demand due to increase in population. At the early stage of settlement in the city, people use more groundwater because it is relatively easy to access without major infrastructure. With increasing water demand due to population growth in the city, the groundwater itself does not meet the demand, and then new facilities such as dams are built for water storage on the surface instead of groundwater storage in the subsurface. This is one approach to the change in reliable water resources.

On the other hand, climate change, such as changes in precipitation patterns due to global warming, have resulted in some Asian cities shifting their water resources in the opposite direction, i.e., from surface water to groundwater. For example, Taiwan is now using more groundwater because of the decrease in reliability of their surface water resources stored behind dams (Wang, 2005, Fig. 6).

One of the key elements in integrated water management may be management under the condition of “water imbalance.” Water imbalances exist in various scales of time and space including urban areas, and result in problems of “too much water” such as flooding, and “too little water” that occurs during droughts. Water imbalances in space are caused by nature globally (climatic zones), locally (access to the water bodies), and via human activities (population growth, industries, agriculture etc.). Water imbalances in time are caused by changes such as climate change, as well as seasonal and annual variations. Water imbalances in the nature–human relationship also exist because of societal (economy, governance, etc.) and cultural (tradition, local knowledge, etc.) influences.

The first RIHN international symposium on “Water and Human Life” discussed this water imbalance (Taniguchi, 2007), and found that “too far water” such as virtual water or “too slow water” such as deep groundwater has an unknown impact on water imbalance. Therefore, we should pay more attention to these concepts for sustainability. (Fig. 7).

At the early stage of urban development, people use “near water,” that is easily obtained such as rainwater, river water, and shallow groundwater. After this stage, increased population demands more water resources, then people construct reservoirs and dams for trapping water, which is relatively far from the cities. Today, even more distant water such as bottled water (sometimes imported from other basins and

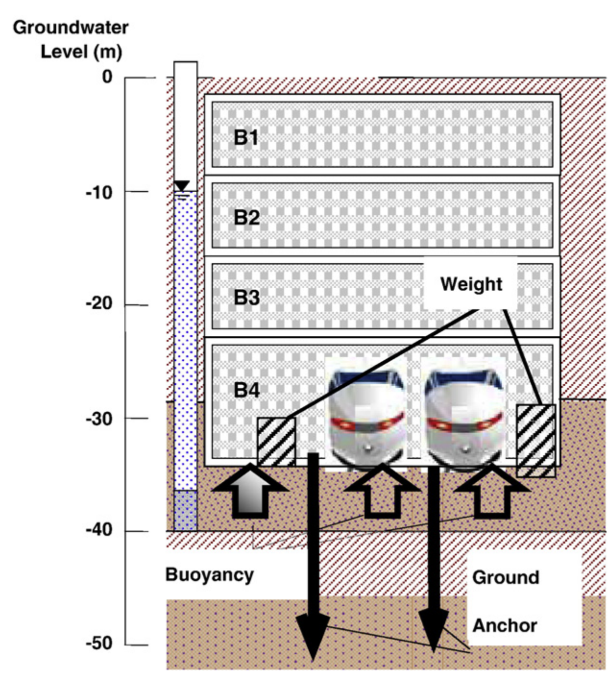

Fig. 5 – Procedures against buoyancy due to increase in groundwater level using weight and ground anchor (Aichi et al., 2006).

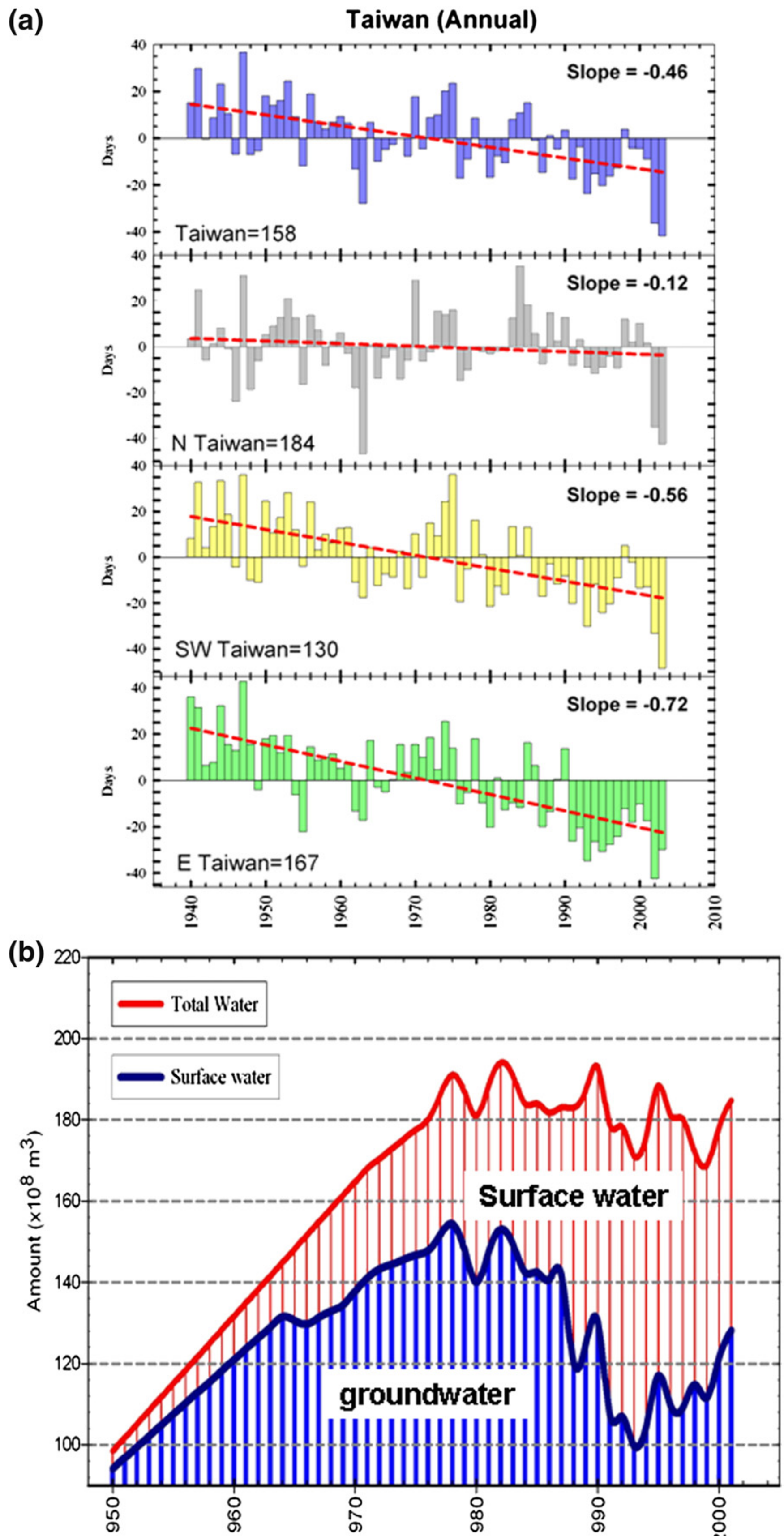

Fig. 6 – Decrease in (a) number of rainy day without changing the annual precipitation and (b) change in water uses in Taiwan (Wang, 2005).

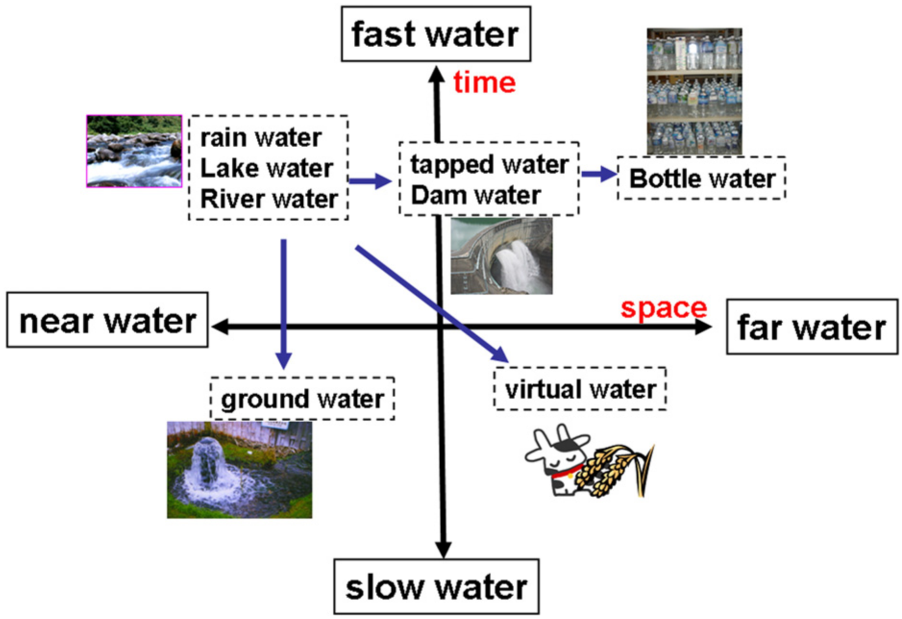

Fig. 7 – Water imbalance; "fast-slow" water and "near-far" water.

countries) is commonly used. This represents the movement of the location of water resources from "near water" to "far water." The "far water" produces more "water imbalance" inadvertently. For example, some water transport is not a real water movement but a "virtual" water trade through the importation/exportation of foods and other products that consume water. These virtual water trades have even been made from arid to humid regions, further accelerating the water imbalance on the earth.

In addition, at early stages of urbanization, people use "fast water" such as river water, lake water, and shallow groundwater, which circulates relatively quickly, (i.e., has a short residence time). However, with increased population or more demand for agricultural production requires additional water resources, prompting people to use "slow water" such as deep groundwater which may have a very long residence time. This is not sustainable when we use deep groundwater that is a fossil resource. However, the damage to underground structures caused by rising groundwater mentioned earlier is attributed to the "fast water" circulation in the shallow aquifer in humid regions. Therefore, precious groundwater resources should be considered not only in the context of "too much or too little water", but also as "too fast or too slow water" that considers the residence time of the water cycle.

3.3. *New technology for evaluating change in groundwater storage*

In order to establish a new technique for monitoring groundwater variations in urban areas, precise in-situ gravimetric measurements and satellite gravimetry can be applied. On land, the effects of groundwater variations are one of the largest sources of gravity anomalies, especially for high-precision gravity measurements using superconducting gravimeters and/or absolute gravimeters. Conversely, this means that the gravitational effects give us important information about the hydrological characteristics in the area concerned, if the effects are appropriately analyzed. Satellite gravimetry is a brand new technique and it is expected to reveal global water storage patterns. Satellite gravity missions are a new technique for the 21st Century (National Research Council, 1997). For example, the GRACE (Gravity Recovery And Climate Experiment) mission which was launched in March 2002 is important in terms of time varying gravity fields. It has been shown that GRACE data provided temporal variations of the Earth's gravity fields due to groundwater changes on earth (Tapley et al., 2004). Even though it may be difficult to employ GRACE data directly for studies of local or urban scale phenomena, it is still important to see the background of more large-scale gravity changes. GRACE data can also provide information on seasonal changes in groundwater storage. Gravity anomalies obtained from GRACE for April and May 2002 with mean radius of 1000 km are shown in Fig. 8a (Fukuda et al., 2005). Comparisons of GRACE and model data for a total of four river basins (Chao Phraya, Mekong, Salween and Irrawaddy) are shown in Fig. 8b (Fukuda et al., 2005). Although the spatial resolution is still sparse, the comparisons between GRACE data and modeled water balance show reasonable agreement. The change of "soil" in Fig. 8b includes both changes of soil water and groundwater, and this component is most important for the seasonal changes of water balance.

4. Material (contaminant) transport

4.1. *Groundwater to surface water discharges*

The advective flux of terrestrially-driven groundwater through coastal sediments is becoming recognized as an important pathway for transferring material from the land to the ocean (Valiela and D'Elia, 1990; Moore, 1996; Michael et al., 2005). This flow may occur through the surficial aquifer or through breaches in deeper semi-confined coastal aquifers (Moore, 1999). While the overall flow of fresh groundwater into the ocean is likely no more

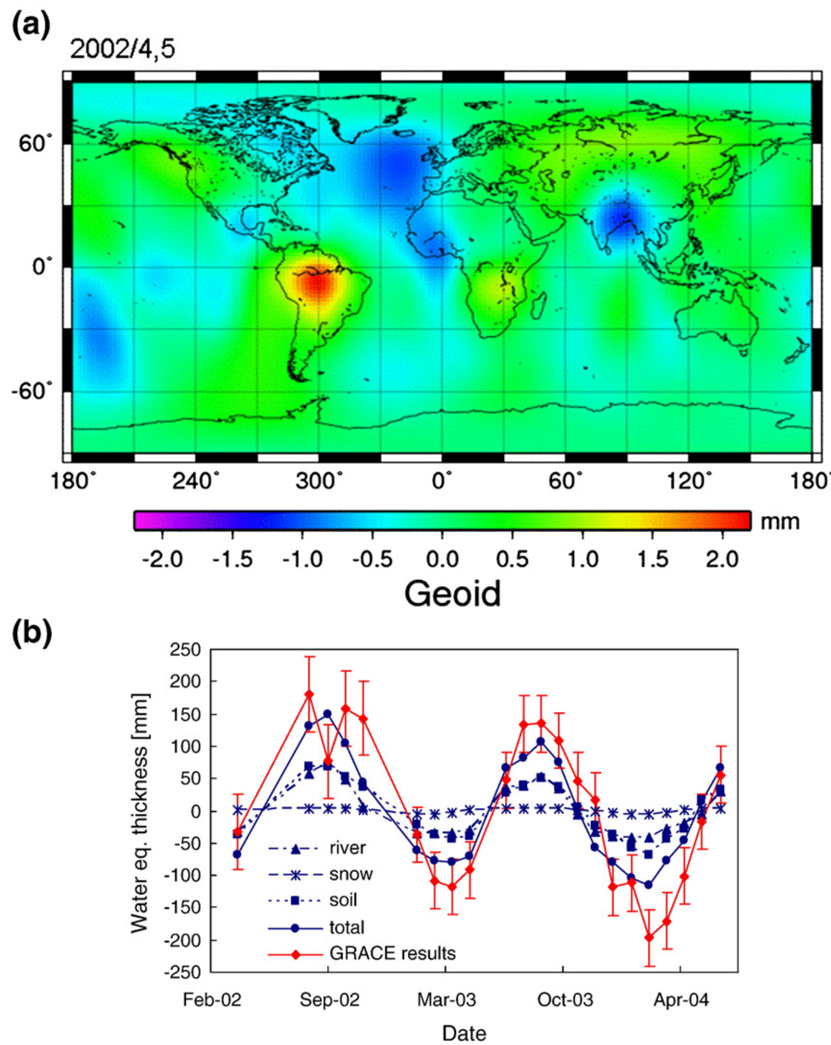

Fig. 8 – Gravity anomalies obtained from (a) GRACE for April and May 2002 with mean radius of 1000 km (Fukuda et al., 2005), and (b) comparisons of GRACE and model data for four river basins (Chao Phraya, Mekong, Salween and Irrawaddy) (Fukuda et al., 2005).

than about 6% of river runoff, it has been estimated that the total dissolved salt contributed by terrestrially-derived SGD may be as much as 50% of that contributed by rivers (Zektser and Loaiciga, 1993). This process will thus affect the biogeochemistry of estuaries and the coastal ocean through the addition of nutrients, metals, and carbon (Taniguchi et al., 2002; Kim et al., 2005; Hwang et al., 2005). In addition, high dissolved N:P ratios in groundwater relative to surface waters may drive the coastal ocean towards P-limitation within the coming decades, perhaps changing the present N-limited coastal primary production (Slomp and Van Cappellen, 2004). In addition to inputs of terrestrially-derived groundwaters, recirculation of seawater through sediments by tidal pumping and other processes can also provide significant biogeochemical inputs and is also considered "submarine groundwater discharge" (Riedl et al., 1972; Li et al., 1999; Burnett et al., 2003).

4.2. *Nature of these discharges*

Groundwater seepage into coastal environments is patchy, diffuse, temporally variable, and may be in response to multiple driving forces. Slow yet persistent seepage of fresh groundwater through sediments occurs wherever an aquifer with a positive head is hydraulically connected to a surface water body. The biogeochemical importance of groundwater discharge to the coastal ocean is dependent on several variables, including the amount and type of nutrient enrichment, water column circulation and tidal flushing, and the groundwater flow rate, which is determined by the porosity and permeability of the underlying strata and the hydraulic head.

During the passage of terrestrially-derived fluids through sediments in a coastal aquifer, mixing of seawater with fresh groundwater and chemical reactions of the fluids with solid phases will occur. Thus, the emerging fluid is often chemically distinct from both the groundwater and seawater end members. Concentrations of nutrients, trace metals, organic carbon, and other components may be considerably higher than coastal ocean waters. Groundwater may have nutrient concentrations several orders of magnitude greater than surface waters either from contamination sources (septic systems, etc.) or natural processes. Thus, nutrient concentrations in coastal groundwaters may be a significant factor in the eutrophication of near-shore waters (Valiela and D'Elia, 1990) and may provide nutrition to sea floor vascular plants (Rutkowski et al., 1999).

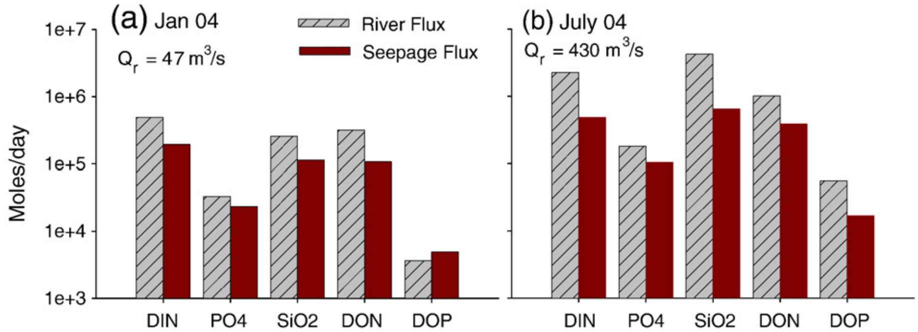

Fig. 9 – Estimated fluxes of dissolved inorganic nitrogen (DIN), PO_4, Si, dissolved organic nitrogen (DON), and dissolved organic phosphate (DOP) from the Chao Phraya River and via SGD to the Upper Gulf of Thailand (data from Burnett et al., 2007).

Noting similarities to surface estuaries, Moore (1999) advanced the concept that many coastal aquifers may be considered "subterranean estuaries." While conceptually similar, the subterranean processes can be quite different than their surface counterparts, involving chemical reactions among groundwater, recirculating seawater, and sediments.

4.3. *Examples from urban Asia*

Specific examples of nutrient fluxes via SGD in comparison to river fluxes into the same areas have recently been reported from two locations in Asia: Thailand (Burnett et al., 2007) and the Philippines (Taniguchi et al., 2008). The potential importance of SGD for inputs of nutrients into the upper Gulf of Thailand was assessed by comparing nutrient flux results from the Chao Phraya River, the main source of fresh water to the Gulf, with seepage measurements made at two coastal locations. Measurements were performed during both the dry (January) and wet (July) seasons in 2004.

The results showed that during the dry season, inorganic and organic nutrients added via groundwater seepage were comparable to that added by the Chao Phraya River. Estimates ranged from 30 to 130% of the river-derived fluxes (Fig. 9). The results for the wet season showed less impact relative to the Chao Phraya because the river discharge (and thus nutrient flux) was also much higher at that time. In spite of that, the estimated seepage fluxes for nutrients were still significant at 20–60% of that of the Chao Phraya River. These results suggest that nutrient inputs via seepage are of the same order as the most important river draining into the Gulf of Thailand. This is even more impressive when one considers that the Chao Phraya is a very contaminated river with extremely high nutrient concentrations from industrial, agricultural, and domestic activities in and around Bangkok.

In the Philippines study (Taniguchi et al., 2008), seepage and nutrient measurements were made off the Bataan Peninsula, Manila Bay. Based on literature values for river discharge and average nutrient concentrations for nutrients in rivers flowing into Manila Bay, riverine nutrient fluxes were calculated and compared to the estimated SGD fluxes (Fig. 10). The calculated fluxes of dissolved inorganic nitrogen (DIN) by SGD were 42% and 96% of the fluxes from the Pampanga and Pasig rivers, respectively. This implies that SGD is comparable as a source of inorganic nitrogen as each of the two main river systems that discharge into Manila Bay. While admittedly crude because of limited data sets at both the Thailand and Philippines sites, these results provide motivation to examine groundwater discharge in more detail as a possible important source of biogeochemically active constituents.

How these advective processes affect the biogeochemistry of estuaries and the continental shelf is only beginning to be appreciated. A great deal of work remains before SGD can be evaluated relative to more conventional processes. For example, nutrients may enter the coastal ocean through rivers, the atmosphere, or upwelling at the shelf break, as well as SGD. The biological effects of these inputs depend not only on the magnitude of the input but how and where the nutrients are delivered. A relatively small input to an isolated embayment may have an effect much different than a more substantial input spread over a large fraction of the shelf. Differing amounts of nitrogen, phosphorus, and silica may also create distinct responses. To achieve a more complete understanding of the role of groundwater discharges to urban coastal environments, studies over a range of scales and environments are required.

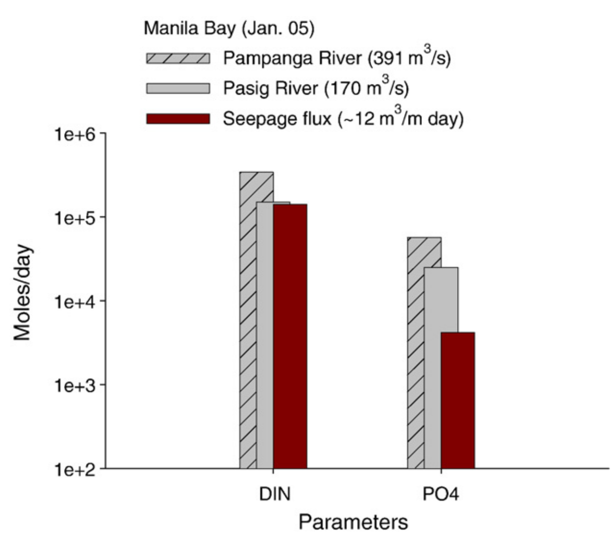

Fig. 10 – Estimated fluxes of dissolved inorganic nitrogen (DIN) and PO_4 via SGD and from the two most important rivers draining into Manila Bay (data from Taniguchi et al., 2008).

5. Thermal environment

5.1. *Effects of surface warming on subsurface temperature*

The combination of the heat island effect due to urbanization and global warming on subsurface temperatures relates to global groundwater quality issues. This relationship holds because increased subsurface temperatures alter the groundwater system chemically and microbiologically via geochemical and geobiological reactions (e.g., Knorr et al., 2005). Since these reactions are temperature sensitive, the process may increase degradation of groundwater resources. This issue is also being addressed by UNESCO-GRAPHIC (Groundwater Resources under the Pressures of Humanity and Climate Change) project (Aureli and Taniguchi, 2006).

Subsurface temperature patterns may be used to reconstruct past climate change because the ground-to-surface temperature gradients are preserved in the subsurface thermal regime (Pollack et al., 1998; Huang et al., 2000, Taniguchi et al., 2003). Recent air temperatures in cities have been increasing by global warming and heat island effects due to urbanization. Studies on the effects of heat from urban area on subsurface temperature are limited, but have been performed in some urbanized areas. Investigations restricted to the effects of surface warming due to urbanization are also limited to local investigations. It may also be possible to separate the urbanization and global warming effects by comparing urban center results to global meteorological records (Kalnay and Cai, 2003; Kalnay et al., 2006). However, understanding both surface warming and fluid flow effects clearly require additional work.

5.2. *Heat island effects in Asian cities*

Average subsurface temperature profiles in four Asian cities (Tokyo, Osaka, Seoul, and Bangkok) were compared by Taniguchi et al., (2007) and analyzed to evaluate the effects of surface warming. The magnitude of surface warming is evaluated to be the largest in Tokyo (2.8 °C), followed by Seoul (2.5 °C), Osaka (2.2 °C; Fig. 11), and Bangkok (1.8 °C). Comparisons between analytical solutions and observations show that the mean depth of deviation from the regional geothermal gradient in each urban area may be a useful indicator of the history of urbanization, i.e., the time from the start of the additional heat from urbanization. These subsurface results agreed with air temperature records in the cities during the last 100 years. Thus, the measurement of subsurface temperature profiles provides important information for understanding the joint effects of urbanization and global warming on groundwater systems (Taniguchi et al., 2007).

5.3. *Spatial distribution of subsurface warming due to urbanization*

The distribution of the urban heat island effect is different than surface air temperature patterns. For example, subsurface temperatures in Bangkok, where population numbers and density increased rapidly, were analyzed to evaluate the effects of surface warming due to urbanization in terms of the spatial distribution of heat island effect in the city (Taniguchi et al., 2007). The magnitude of surface warming evaluated from the subsurface temperature profiles was 1.8 °C, and the depth of minimum temperature was deeper

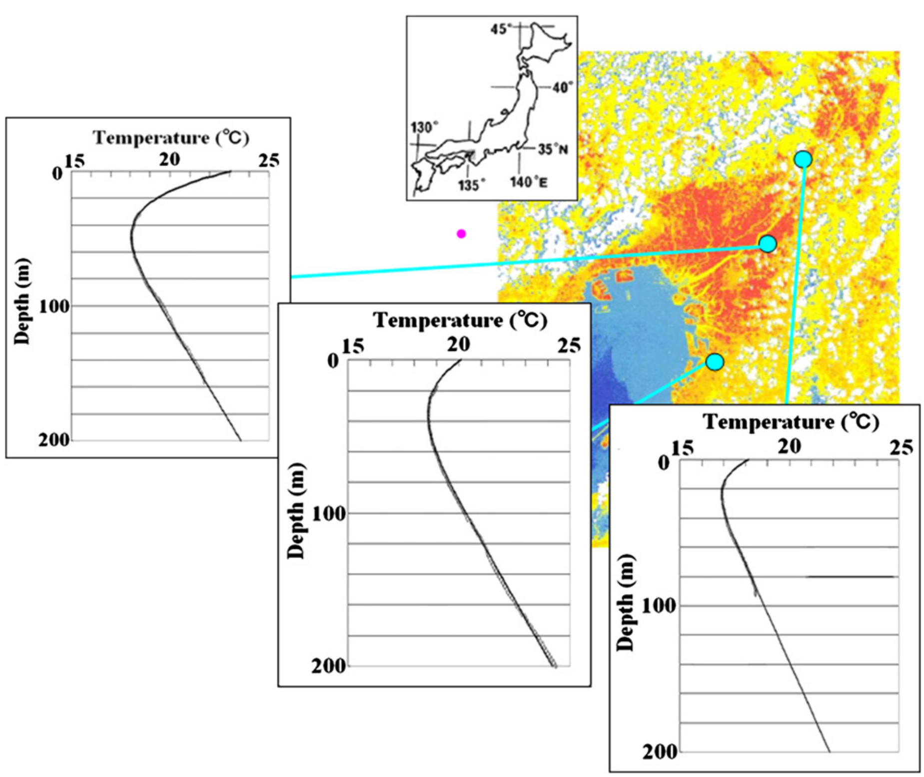

Fig. 11 – Subsurface thermal anomalies in urban area of Osaka.

in the center of the city than those in suburban areas. The departure from a steady thermal gradient serves as an indicator of the magnitude of the surface warming due to additional heat from urbanization. In order to separate surface warming due to global warming from urbanization effects, analyses of subsurface temperature have been done at different distances from the city center.

Three scenarios of surface warming have been calculated assuming that the increase in surface warming at the city center was 1.8 °C over the last 50 years. Although additional heat due to urbanization does not correspond precisely to the population distribution within the city, the increase in air temperature was assumed to decrease exponentially from the city center (as does population) for these calculations (Taniguchi, 2007).

In order to isolate the heat island effect due to urbanization, the rate of global warming was assumed to be 0.25 °C/50 years (Hansen and Lebedeff, 1987; Huang et al., 2000). Based on the most recognized comparison between observed and calculated subsurface temperatures, a location with an increase in air temperature of 0.25 °C/50 years is 80–90 km from the city center. Therefore, our analyses of subsurface temperature without global warming effects show that the heat island effect due to urbanization reaches up to 80–90 km. Studies are now planned to separate urbanization from global warming effects by comparing the results with global meteorological studies (Kalnay and Cai, 2003; Kalnay et al., 2006; Lim et al., 2005).

The RIHN project "Human impacts on urban subsurface environments" has started to deal with these issues: (1) relationships between the developmental character of the cities and subsurface environmental problems assessed by socio-economic analyses and reconstructions of urban areas by uses of historical records; (2) serious problems in subsurface environments and changes in reliable water resources, in addition to evaluations of groundwater flow systems and changes in groundwater storage by use of hydrogeochemical and in-situ/satellite GRACE gravity data; (3) evaluation of accumulations of the contaminant materials in the subsurface and their transports from land to ocean including groundwater pathways by use of chemical analyses of subsurface waters, sediments and tracers; and (4) subsurface thermal contamination due to the "heat island" effect in urban areas by reconstruction of surface temperature history and urban meteorological analyses.

6. Conclusion

In this overview paper, we have discussed the current status of urbanization in Asia, and for selected cities discussed subsurface water conditions, material and contaminant transport by groundwater, and subsurface thermal anomalies due to the heat island effect. Comparisons of Western past and Asian present urbanization show that the current Asian urban environment is one of immense pressure. The greater speed and magnitude of the Asian urban transformation has resulted in greater degradation of the environment. The rapid pace of urbanization brings a large array of other social problems that require infrastructure and institutional development, whose costs will compete with those of environmental protection. Groundwater transport of nutrients and contaminants to surface waters has been shown to be important in some Asian coastal cities. Even though it is difficult to assess, contamination has accumulated in subsurface urban environments and some will eventually discharge to groundwater in the future. The residence time of groundwater may be a key issue, and new technologies to evaluate change in groundwater storage by in-situ gravity measurements, satellite GRACE, and tracer techniques are useful for this evaluation. Subsurface thermal anomalies due to heat island effects of urbanization are also a global environmental issue because increased subsurface temperatures alter the groundwater system chemically and microbiologically via geochemical and geobiological reactions. Indicators of these changes can be found in the subsurface thermal regimes depending on the magnitude and timing of urbanization.

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REFERENCES

Aichi M, Hayashi T, Tokunaga T. Temporal change of groundwater potential distribution and groundwater flow/land subsidence coupled modeling In: Kanto Plain, Japan. Proc. of RIHN Project 2-4, Human impacts on urban subsurface environments. 2006:99–104.

AUICK. Feature: population aging and appropriate measures for the aged. AUICK newsletter, Asian peoples and cities, vol. 48. ; 2007. p. 2–27. March, 2007.

Aureli A, Taniguchi M. Groundwater assessment under the pressures of humanity and climate changes. UNESCO-IHP brochure; 2006. 19pp.

Booth Anne. Did it really help to be a Japanese colony? East Asian economic performance in historical perspective. Japan focus; 2007. May 15, onlne www.JapanFcus.org.

Burnett WC, Bokuniewicz H, Huettel M, Moore WS, Taniguchi M. Groundwater and porewater inputs to the coastal zone. Biogeochemistry 2003;66:3–33.

Burnett WC, Wattayakorn G, Taniguchi M, Dulaiova H, Sojisuporn P, Rungsupa S, et al. Groundwater-derived nutrient inputs to the Upper Gulf of Thailand. Cont Shelf Res 2007;27(2):176–90.

Capone DG, Bautista MF. A groundwater source of nitrate in nearshore marine sediments. Nature 1985;313:214–6.

Chandler T, Fox G. 3000 years of urban growth. New York: Academic Press; 1974.

Cipolla C. Guns and sails in the early phase of European expansion. London: Collins; 1965.

Favier Jean. The world of Chartres. New York: Henry N. Adams; 1990.

Fukuda Y, Yamamoto K, Nakaegawa T, Nishijima J. Monitoring of the ground water variation in urban area by combining GRACE

data and in-situ gravity measurement. Proceeding of RIHN international symposium on human impacts on urban subsurface environment, October 18–20, 2005, Kyoto, Japan; 2005. p. 26–31.
Hansen J, Lebedeff S. Global trends of measured surface air temperature. J Geophys Res 1987;15(4):323–6.
Huang S, Pollack HN, Po-Yu Shen. Temperature trends over the past five centuries reconstructed from borehole temperatures. Nature 2000;403:756–8.
Hudson Valerie M, den Boer Adrea M. Bare branches: the security implications of Asia's surplus male population. Camabridge, MA: MIT Press; 2004.
Hwang DW, Kim G, Lee Y-W, Yang H-S. Estimating submarine inputs of groundwater and nutrients to a coastal bay using radium isotopes. Mar Chem 2005;96:61–71.
Johnson S. The ghost map: the story of London's deadliest epidemic — and how it changed the way we think about disease, cities, science, and the modern world. New York: Penguin Books; 2006.
Kang David C. Crony capitalism: corruption and development in South Korea and the Philippines. Cambridge: Cambridge University Press; 2002.
Kim G, Ryu JW, Yang HS, Yun ST. Submarine groundwater discharge (SGD) into the Yellow Sea revealed by Ra-228 and Ra-226 isotopes: implications for global silicate fluxes. Earth Planet Sci Lett 2005;237 (1-2):156–66.
Kalnay E, Cai M. Impact of urbanization and land-use change on climate. Nature 2003;423(6939):528–31.
Kalnay E, Cai M, Li H, Tobin J. Estimation of the impact of land-surface forcings on temperature trends in eastern United States. J Geophys Res 2006;111(D06106). doi:10.1029/2005JD006555.
Knorr W, Prentice IC, House JI, Holland EA. Long-term sensitivity of soil carbon turnover to warming. Nature 2005;433:298–301. doi:10.1038/nature03226.
Landis D. The unbound Prometheus: technological change and industrial development in Europe from 1750 to the present. New York: Cambridge University Press; 2003.
Li L, Barry DA, Stagnitti F, Parlange JU. Submarine groundwater discharge and associated chemical input into a coastal sea. Water Resour Res 1999;35:3253–9.
Lieberman Victor. Strange parallels: Southeast Asia in global context, c., 800–1830. New York: Cambridge University Press; 2003.
Lim Y-K, Cai M, Kalnay E, Zhou L. Observational evidence of sensitivity of surface climate changes to land types and urbanization. Geophys Res Lett 2005;32(L22712). doi:10.1029/2005GL024267.
McCoy A. An anarchy of families: state and family in the Philippines. Madison, WI: University of Wisconsin Center for Southeast Asian Studies; 1993.
McEvedy C, Jones Richard. Atlas of world population history. New York: Penguin Books; 1978.
Michael HA, Mulligan AE, Harvey CF. Seasonal oscillations in water exchange between aquifers and the coastal ocean. Nature 2005;436:1145–8.
Moore WS. Large groundwater inputs to coastal waters revealed by ^{226}Ra enrichments. Nature 1996;380:612–4.
Moore WS. The subterranean estuary: a reaction zone of ground water and sea water. Mar Chem 1999;65:111–25.
National Research Council (NRC). Satellite gravity and the geosphere. Washington, D.C.: National Academy Press; 1997. p. 1–112.
Ness Gayl D. The long view: population-environment dynamics in historical perspective. Ness, Brechin and Drake; 1993.
Ness, Gayl D., "World population growth," in the Global environment: science technology and management, edited by Dag Brune, Deborah V. Chapman, Michael D. Gwynne, and Jozef M Pacyna, Vol. II, PP 637-656, (Oslo: Scandinavian Science Publication; Weinheim; VCH), 1997.
Ness Gayl D, Low Michael. Five cities: modelling Asian urban population environment dynamics. Singapore: Oxford University Press; 2000.
Ness Gayl D, Talwar Prem. Asian urbanization for the new millennium. Singapore: Michael Cavendish; 2004.
Pollack HN, Huang S, Shen PY. Climate change record in subsurface temperatures: a global perspective. Science 1998;282:279–81.
Pomeranz K. The great divergence: Europe, China and the making of the modern world economy. Princeton, NJ: Princeton University Press; 2000.
Riedl R, Huang N, Machan R. The subtidal pump: a mechanism of interstitial water exchange by wave action. Mar Biol 1972;13:210–21.
Rutkowski CM, Burnett WC, Iverson RL, Chanton JP. The effect of groundwater seepage on nutrient delivery and seagrass distribution in the northeastern Gulf of Mexico. Estuaries 1999;22:1033–40.
Slomp CP, Van Cappellen P. Nutrient inputs to the coastal ocean through submarine groundwater discharge: controls and potential impact. J Hydrol 2004;295:64–86.
Smelser N. Social change and the industrial revolution. Chicago: University of Chicago press; 1959.
Taniguchi M. Summary of open discussion. Proceedings of RIHN 1st International Symposium on Water and Better Human Life in the Future, Kyoto, Nov. 6-8, 2006. p. 72–3; 2007.
Taniguchi M, Burnett WC, Cable JE, Turner JV. Investigations of submarine groundwater discharge. Hydrol Process 2002;16:2115–29.
Taniguchi M, Shimada J, Uemura T. Transient effects of surface temperature and groundwater flow on subsurface temperature in Kumamoto Plain, Japan. Phys Chem Earth 2003;28:477–86.
Taniguchi M, Uemura T, Jago-on K. Combined effects of urbanization and global warming on subsurface temperature in four Asian cities. Vadose Zone J 2007;6:591–6. doi:10.2136/vzj2006.0094.
Taniguchi M, Burnett WC, Dulaiova H, Siringan F, Foronda JM, Wattayakorn G, et al. Groundwater discharge as an important land-sea pathway in Manila Bay, Philippines. J Coast Res 2008;24:15–24.
Tapley BD, Bettadpur S, Ries JC, Thompson PF, Watkins MM. GRACE measurements of mass variability in the earth system. Science 2004;305(23):503–5.
United Nations. World urbanization prospects, the 2001 revision. New York: United Nations; 2001.
United Nations. World population prospects: the 2004 revision. New York: United Nations; 2004.
Valiela I, D'Elia C. Groundwater inputs to coastal waters. Special Issue Biogeochemistry, vol. 10. ; 1990. 328 pp.
Wang C-H. Subsurface environmental changes in Taipei, Taiwan: current status, human impacts on urban subsurface environment. Proceeding of RIHN International Symposium; 2005. p. 55–9.
Yaari ME. Uncertain lifetime: life insurance and the theory of the consumer. Rev Econ Stud 1965;32(2):137–50.
Zektser IS, Loaiciga HA. Groundwater fluxes in the global hydrologic cycle: past, present and future. J Hydrol 1993;144:405–27.