| Chapter 7 |

Groundwater and Climate Change: No Longer the Hidden Resource

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1. Introduction

Groundwater is an important resource for livelihoods and food security of billions of people, especially in developing countries of Asia. Although trends on abstraction and use in each country are not available, globally groundwater is estimated to provide approximately 50% of current potable water supplies, 40% of the water demand of self-supplied industry and 20% of water use in irrigation. In Asia and the Pacific, about 32% of the population uses groundwater as a drinking water source (Morris et al. 2003).

Groundwater contributes to economic development in the region by providing water for irrigation in area such as India, Bangladesh, Nepal and the Northern China Plains and for industrial production. The value of groundwater to society should not be judged solely in terms of volumetric extraction, however. Compared to surface water, groundwater use often yields larger economic benefits per unit volume, due to its availability at local level, drought reliability and good quality requiring minimal treatment (UN/WWAP 2003). Groundwater use is likely to continue to expand in developing countries. Pressures on groundwater resources over the next 25 years in Asia will come from demographic increases, agricultural practices and increasing water demand per capita, coupled with increased urban areas, industrial activity and energy demand (Gunatilaka 2005).

Despite the significance of groundwater for sustainable development in Asia, it has not always been properly managed, which often has resulted in depletion and degradation of the resource. Without proactive governance, the detrimental effects of poor management will nullify (or even surpass) the social gains made so far (Mukharji and Shah 2005). In addition to these existing challenges, groundwater management now confronts a brand new challenge: how to adapt to the potentially negative impacts of climate change on groundwater and its use?

Climate change impacts may add to existing pressure on groundwater resources by (i) impeding recharge capacities in some areas; and (ii) being called on to fill eventual gaps in surface water availability due to increased variability of precipitation. Groundwater contamination is also expected in low elevation coastal zones due to sea level rise. In some vulnerable areas, such impacts on groundwater resources may render the only available freshwater reserve unavailable or unsuitable for use in the near future (IPCC 2007).

To maintain the advantages of groundwater as an important resource for sustainable development and also as a reserve freshwater resource for current and future generations, groundwater management should be more strategic and proactive to cope with potential impacts of climate change. However, groundwater has received little attention from climate change impact assessments compared to surface water resources (Kundzewicz et al. 2007) and most countries in Asia have not yet responded to the effects of climate change on their water management plans.

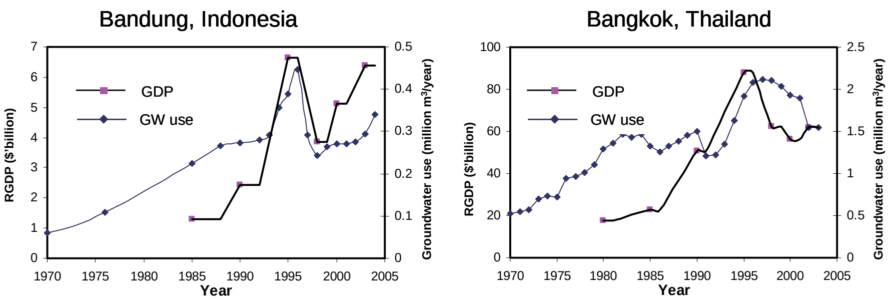
This chapter provides an overview of current groundwater issues and examines the potential and negative effects of climate change on the groundwater resources in Asia. It also explores opportunities for adaptation to the potential impacts of climate change. The risks of climate change impacts are not only a great challenge for water resources management but also for the broader role of water in sustainable development.

2. Groundwater demand and socio-economic development

2.1. Groundwater use

Nearly two billion people in Asia depend on groundwater resources for drinking water. In countries like Bangladesh, China, India, Indonesia, Nepal, the Philippines, Thailand, and Vietnam, more than half of potable water supply is estimated to come from groundwater (UNEP 2002). Some large cities such as Jakarta, Hanoi, and Beijing depend on groundwater as one of the main water sources. Myriad small towns and rural communities also depend on groundwater. For example, 60% of the rural population in Cambodia relies on groundwater (ADB 2007b) and 76% of people who do not have access to piped system depend on tube wells in Bangladesh (ADB 2007c). In urban areas, groundwater tends to be used more for industrial use than human consumption. Industrial use in total groundwater abstraction accounts for 80% in Bandung and 60% in Bangkok. There is a strong correlation between groundwater use and gross domestic product (GDP) in these cities (fig. 7.1).

Figure 7.1. Groundwater abstraction and correlation with city-level GDP

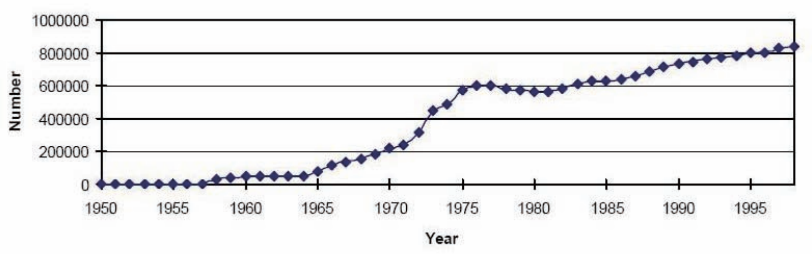


Source: Kataoka et al. 2006

Groundwater supports dynamic agricultural systems in India, Northern Sri Lanka, Pakistan Punjab and the Northern China plains. In India, groundwater provides about 60% of the total agricultural water use accounting more than 50% of the total irrigated area. Similarly, groundwater contributes 50%, 50%, 65% and 70% of total agriculture water supply in Shangdong, Henan, Beijing and Hebei provinces of China respectively (Ministry of Water Resources of China 2000). In Pakistan Punjab, more than 40% of crop water requirement comes from groundwater, producing the majority of food in Pakistan (Qureshi and Barrett-Lennard 1998). The development of tube wells in Hebei Province, China and Punjab, Pakistan (fig. 7.2 and 7.3, respectively) clearly show the increasing dependency of agriculture on groundwater.

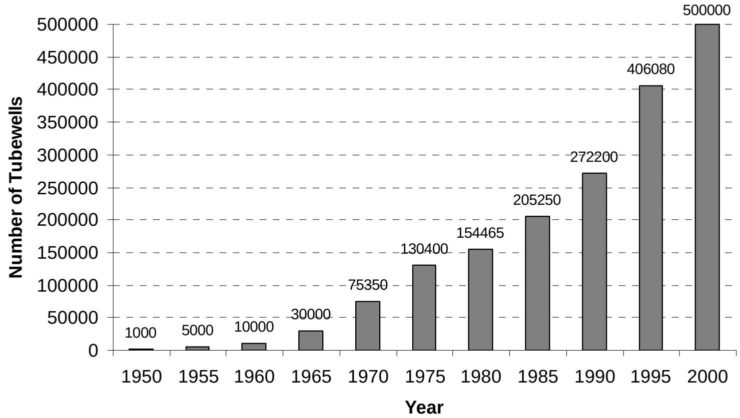
Moreover, groundwater irrigation appears to be more productive than surface water irrigation due to more regular and timely availability of water. In India, it is estimated that groundwater irrigated farms produce 1.2 to 3 times higher crop yield than farms irrigated by surface water. In the Pakistan Punjab, investment of about Rs. 25 billion ($0.4 billion at 2001 prices) in private tube wells generated an annual benefit of about Rs. 150 billion ($2.3 billion). This investment covered more than 2.5 million farmers who either have their private tube wells or buy water from their neighbours' tube wells (Dhawan 1989).

Figure 7.2. Tube well development in Hebei Province, China



Source: Shah et al. 2001

Figure 7.3. Growth trend of private tube wells in Punjab, Pakistan



Source: Shah et al. 2001

2.2. Problems related to groundwater

As an easily accessible and cheap water resource, groundwater is often abstracted beyond its natural recharging capacity, which results in depletion of the resource and/or degradation of its quality. Major problems identified as a result of over-extraction of groundwater in some areas of Asian cities include:

- Land subsidence
- Depletion in groundwater table
- Groundwater contamination (e.g. from arsenic, fluoride and ammonium)
- Saline water intrusion

In China, groundwater level has declined in 30% of 194 key cities and regions monitored (WEPA 2007). Other Asian cities like Bangkok have experienced excessive drawdown of water tables and suffer from land subsidence due to intensive use of groundwater (fig. 7.4) (IGES 2007). The intensity and the cumulative extent of water level depletion and land subsidence in selected Asian cities in the years 1980, 1990 and 2003 shows that the drop in groundwater levels continues in all cities (table 7.1).

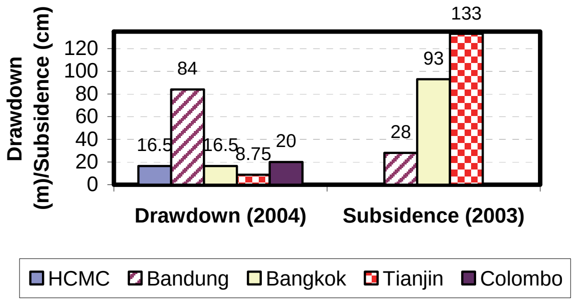
Table 7.1. Effects of groundwater overuse in some Asian cities

Study area	Average drop in water level (m/y)			Average land subsidence (mm/y)		
	1980	1990	2003	1980	1990	2003
Bangkok	1.0	3.0	-1.5	23	25	15
Bandung	1.3	6.5	0.8	-	10	18
Colombo	-	-	1.0	-	-	-
HCMC	0.1	0.95	1.0	-	-	-
Kandy	-	-	2.5	-	-	-
Tianjin	-	-	0.63	119	15	31

Source: IGES 2007

In 2003, the average land subsidence was found to be 15 mm, 18 mm and 31 mm in Bangkok, Bandung, and Tianjin respectively. Land subsidence can affect buildings and structures such as water and sewerage networks and increase groundwater salinity, as observed in Bangkok.

Figure 7.4. Cumulative drop in water level and land subsidence in some Asian cities



Source: IGES 2007

Groundwater quality problems affect the health of millions of people. Arsenic contamination in India, Bangladesh and some other river deltas of Asia has been widely reported but not yet fully controlled. Fluoride contamination constrains provision of safe water access in some parts of India, China and Thailand. A survey in Lamphun Province, Northern Thailand showed that concentration of fluoride in drinking water was up to 15.0 mg/L, while the national drinking water standard for fluoride is 0.7 mg/L. It also revealed that use of fluoride rich water for soaking rice could be a major source of fluoride intake in the surveyed area (Takeda et al. 2007).

In Tianjin, where groundwater also contains a high fluoride concentration, the dental fluorosis rate of local residents was reported to be far higher than national survey results—41% in Tianjin urban area compared to 5.21% national average in city areas (Xu et al. 2008). In addition to naturally occurring contamination, groundwater quality is at a risk from improper sanitation systems, leachate from unmanaged landfill sites, and polluted surface water. Groundwater quality contamination is definitely related to the health of local people, but the state of groundwater quality contamination is not adequately explored due to insufficient monitoring and lack of awareness.

2.3. Current groundwater management practices in Asia

2.3.1. Legislation related to groundwater

Progress in water resource management in Asia is seen in the development and revision of water laws (ADB 2007a). Such basic laws on water resource management often introduce licensing or a permit system for groundwater abstraction which could be a basis of improved groundwater management. Examples include the Water Law of China (2002), Water Resource Law in Lao PDR (1996) and the Water Code of the Philippines (1976). However, implementation is weak because these laws provide only a framework and no sanctions for poor implementation. In addition, in many countries, groundwater use still lacks any proper legislation.

Where the negative impacts of groundwater overexploitation are evident, generally groundwater use regulations have been developed. Countries such as Japan and Thailand have specific national laws which aim to control groundwater use to mitigate groundwater problems such as land subsidence, but actual control of groundwater use is limited to critical areas under these laws. At the local level, there are more regulations aiming to control abstraction to fit local conditions, with or without national laws on groundwater (table 7.2). Local regulations are generally more useful because they reflect local conditions of groundwater and water use.

Table 7.2. Local regulations related to control of groundwater abstraction/use

Name (Country)	Name of regulations	Background/Purpose
Tianjin (China) [1)]	Temporary Measures for Groundwater Management in Tianjin (1987)	To regulate groundwater abstraction to mitigate decline of groundwater level associated with land subsidence
Maharashtra (India) [2)]	Maharashtra Groundwater Act (1993)	To regulate and control groundwater for conservation of the resource for drinking purposes
Kerala (India) [3)]	Kerala Groundwater Act (2002)	To provide for the conservation of groundwater and regulation and control of its extraction and use in the State
Bandung (Indonesia) [1)]	The West Java Provincial Regulation 16/2001 (2001)	To regulate groundwater to mitigate depletion of the resource
Kumamoto (Japan) [4)]	Groundwater Preservation Ordinance of Kumamoto Prefecture in Japan (1992)	To conserve quality and quantity of groundwater as a common resource of the local people

Sources: [1)] IGES 2007, [2)] Phansalkar and Kher 2006, [3)] Environmental Law Alliance Worldwide website (http://www.elaw.org/resources/text.asp?id=2846), [4)] Kumamoto Prefecture website (http://www.pref.kumamoto.jp/eco/project/kankyou/kankyou11_01.htm).

2.3.2. Organisational arrangements in the public sector

In many cases, two or more agencies or ministries work on groundwater management at national level, and local governments are responsible for implementation. However, coordination between agencies at national level as well as between national and local governments is not always strong enough to implement groundwater control measures. In HCMC, four departments (Natural Resources and Environment, Industry, Agriculture and Rural Development, Transportation and Public Works) have activities related to groundwater management but weak coordination is a barrier to effective implementation and data accumulation (IGES 2007).

In addition, groundwater is often managed separately from surface water. In Indonesia, the Ministry of Public Works is responsible for surface water management and the Ministry of Energy and Mineral Resources for groundwater. Surface water and groundwater are managed by two different departments under the Ministry of Natural Resource and Environment in Thailand. Agricultural ministries also have limited responsibility for agricultural groundwater use in these countries. In China and the

Philippines, a single ministry or a national water policy making body has primary responsibility for both surface water and groundwater management at national level. At the implementation level, however, responsibility tends to be delegated to different sectoral departments, such as irrigation, water supply and industry. Such a sectoral approach without adequate coordination tends to be a barrier to effective use and management of water resources.

2.3.3. Charging system

Groundwater has been exploited free of charge for a long time, but some charges on groundwater abstraction have begun to be introduced in the form of a user charge or tax, in most cases intended as a disincentive to groundwater abstraction. A groundwater charge/tax has been introduced in Bangkok, Bandung, Tianjin, and recently in HCMC. However, effectiveness of these charges on groundwater demand is still limited. For example, in Bandung and Tianjin, groundwater is cheaper than water from the public water supply scheme which is expected to provide an alternative to groundwater. In Tianjin, the agricultural sector, which is the largest user of groundwater, is exempted from the groundwater charge, so charging is not effective in decreasing groundwater demand (IGES 2007).

2.3.4. Alternative water sources

Groundwater pumping cannot be effectively controlled without other water sources to substitute for groundwater demand. In Tianjin, groundwater exploitation in the urban area was reduced by providing alternative water through water transfer from another basin (which may raise additional problems). In the 1960s, Osaka mitigated its groundwater overexploitation problems by development of surface water for industrial use. Groundwater pumping in Bandung could not be reduced despite licensing and pricing measures, partly because there is not enough surface water supply available to meet the demands of the industrial sector, the largest water user in the city. In general, because of limited water availability, groundwater management should address demand rather than developing other sources of water to substitute for groundwater.

3. Potential impacts of climate change on groundwater resources

The potential impacts of climate change on water resources in general have been recognised for some time, although there has been comparatively little research relating to groundwater (IPCC 2001). The principal focus of climate change research with regard to groundwater has been on quantifying the likely direct impacts of changing precipitation and temperature patterns (Yusoff et al. 2002; Loaiciga et al. 2000; Arnell 1998). Such studies have used a range of modelling techniques such as soil water balance models (Kruger et al. 2001; Arnell 1998), empirical models (Chen et al. 2002), conceptual models (Cooper et al. 1995) and more complex distributed models (Croley and Luukkonen 2003; Kirshen 2002; Yusoff et al. 2002), but all have derived changes in groundwater recharge by assuming that parameters other than precipitation and temperature remain constant.

Box 7.1. Examples of potential impacts of climate change on groundwater resources

Direct impacts
• Variation in duration, amount and intensity of precipitation and evapotranspiration will increase or decrease recharge rates. • Rising sea levels will allow saltwater to penetrate farther inland and upstream in low lying river deltas. • Variation in CO_2 concentrations may affect carbonate dissolution and the formation of karst.
Indirect impacts
• Land cover changes (viz. natural vegetation and crops) may increase or decrease recharge. • Increase in groundwater extraction due to decrease in reliability of surface water as a result of increased floods and droughts. • Increase in flood frequencies may affect groundwater quality of alluvial aquifers. • Variation in soil organic carbon content may affect the infiltration properties above aquifers.

3.1. Potential impacts due to change of temperature and precipitation

Spatial and temporal changes in temperature and precipitation may modify the surface hydraulic boundary conditions of, and ultimately cause a shift in the water balance of an aquifer. For example, variations in the amount of precipitation, the timing of precipitation events, and the form of precipitation are all key factors in determining the amount and timing of recharge to aquifers. In Central Asia, output from the MRI-CGCM2.3.2 coupled atmosphere-sea surface global circulation model for the period 2080-2100 shows a rise in temperature of 3.5−4.5^{o}C and a decrease in precipitation. For South Asia, 2.5−3.5^{o}C increase of temperature and an increase in precipitation are projected. Changes in the amount of precipitation are expected to decrease mean runoff by 1 mm/day in Central Asia and to increase mean runoff by a similar amount in South Asia. Due to the change in the variability of precipitation, surface water resources are likely to become more unreliable, thus precipitating a shift to development of more "reliable" groundwater resources, as has been observed in Taiwan (Hiscock and Tanaka 2006).

The changing frequency of droughts or heavy precipitation can also be expected to impact on water levels in aquifers. Droughts result in declining water levels not only because of reduction in rainfall, but also due to increased evaporation and a reduction in infiltration that may accompany the development of dry topsoils. Paradoxically, extreme precipitation events may lead to less recharge to groundwater in upland areas because more of the precipitation is lost as runoff. Similarly, flood magnitude and frequency could increase as a consequence of increased frequency of heavy precipitation events, which could increase groundwater recharge in some floodplains.

3.2. Degradation of groundwater quality by sea level rise

As global temperatures rise, sea level rise is also expected due to the melting of ice sheets and glaciers. Rising sea levels would allow saltwater to penetrate farther inland

and upstream in low lying river deltas (IPCC 1998). Higher salinity impairs surface and groundwater supplies, damaging urban water supplies, ecosystems, and coastal farmland (IPCC 1998). Furthermore, a reduced groundwater head caused by lower rainfall will aggravate the impacts of sea level rise. Saline intrusion into alluvial aquifers may be moderate, but higher in limestone aquifers. Reduced rates of groundwater recharge, flow and discharge and higher aquifer temperatures may increase the levels of bacterial, pesticide, nutrient and metal contamination. Similarly, increased flooding could increase the flushing of urban and agricultural waste into groundwater systems, especially into unconfined aquifers, and further deteriorate groundwater quality.

About 45% of population in the world lives in the low elevation coastal zone and about two thirds of the population residing in this zone are in Asia (IHDP 2007). Sea level rise has already affected a large population, resulting in a huge loss of capital value, land, and precious wetlands, and incurring a high adaptation/protection cost (table 7.2). In Asia alone, projected sea level rise could flood the residences of millions of people living in the coastal zones of South, Southeast and East Asia such as Vietnam, Bangladesh, India and China (Wassmann et al. 2004; Stern 2006; Cruz et al. 2007).

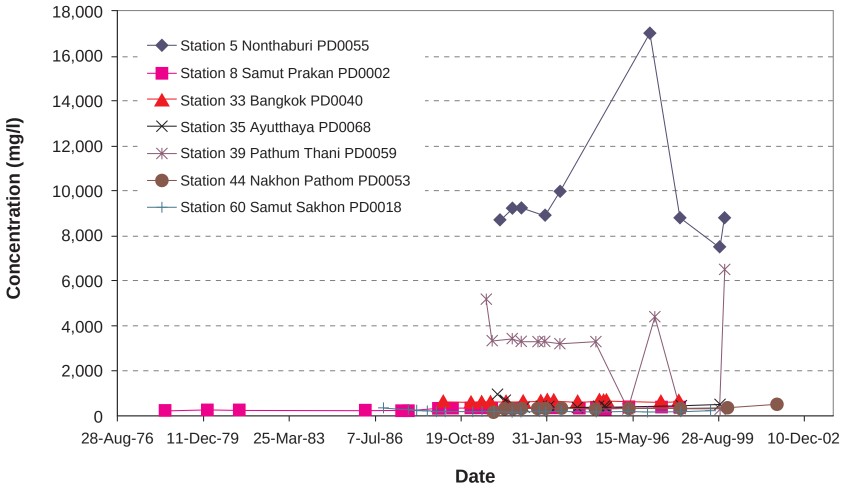
Table 7.3. Impacts of sea level rise in the Asia-Pacific region

Country	**People Affected**		**Capital Value at Loss**		**Land at Loss**		**Wetland at Loss**	**Adaptation/ Protection Costs**	
	Number of People ('000)	% total	$ 'million	% GNP	km^2	% total	km^2	$ 'million	% GNP
Bangladesh	71,000	60	-	-	25,000	17.5	5,800	>1,000	>0.06
China	72,000	7	-	-	35,000	-	-	-	-
Japan	15,400	15	849,000	72	2,300	2.4	-	>156,000	>0.12
Kiribati	9	100	2	8	4	12.5	-	3	0.10
Marshall Is.	20	100	160	324	9	80	-	>360	>7.04

Note: Assuming existing development and a 1m rise in sea level. All impacts assumed no adaptation while adaptation assumes protection, except in areas of low population density. Costs are 1990 US dollars. Source: OECD 2003

The salinization of aquifers has been detected in many areas of Asian cities located in coastal areas. The chloride concentration exceeds the allowable limit of 250 mg/L in some monitoring locations of Bangkok (IGES 2007). As an example, a seasonal concentration of chloride concentration in Phra Pradaeng aquifer of Bangkok is shown in figure 7.5. In monitoring stations 8 (Samut Prakan PD0002) and 60 (Samut Sakhon NL 0032) that are located adjacent to the coast, salinity levels are likely to be increased as a result of sea level rise.

Figure 7.5. Chloride concentration in Phra Pradaeng aquifer, Bangkok



Source: Babel et al. 2006

In HCMC, saltwater intrusion has been observed in some districts and this phenomenon seems to have been escalating, with continuing drawdown of the water table due to excessive groundwater abstraction to meet the growing water demands in the city (IGES 2007). In Manila, tidal inflow of seawater during high tide into the Pasig River contributes to the high salinity of groundwater in Pasig City and vicinity (Philippines National Water Resource Board 2004). Sea level rise due to climate change may increase seawater inflow into freshwater aquifers in parts of these coastal cities where hydraulic connections to aquifer beds are exposed at the sea floor.

3.3. Potential impacts of land use change caused by climate change

Climate change studies suggest that some Asia-Pacific forests and vegetation may experience some initially beneficial effects from climate change and enhanced atmospheric CO_2 concentrations. Any vegetation change scenarios will have direct and indirect impacts on groundwater recharge. For example, the projected decline of steppe and desert biomes on the Tibetan Plateau may be accompanied by an expansion of conifer, broad-leaved, and evergreen forests and shrubland. Expanded forest cover may increase groundwater recharge in the Tibetan Plateau, with consequent changes in downstream river flows. In addition, studies suggest significant shifts in the distribution of tree species in China in response to warming of 2–4°C, including the migration of forest communities into non-forested areas of East China (CSIRO 2006). The increase in forest area may increase the groundwater recharge in East China.

Changes in precipitation and temperature caused by the elevated level of CO_2 in the atmosphere can increase the infiltration rate of water through the vadose zone. A model that simulates the effect of increased CO_2 level on plants, groundwater and the vadose zone was applied in subtropical and Mediterranean regions of Australia. The subtropical regions responded more to the frequency and volume of precipitation whereas the Mediterranean region was influenced more by changes in temperature. In both locations, groundwater recharge rate varied significantly i.e., 75-500% faster in Mediterranean region and from 34% slower to 119% faster in subtropical regions (Green et al. 2007).

Urban built-up areas have expanded rapidly, replacing either forest or agricultural land (i.e., replacing vegetation with concrete and bitumen). In cases such as Bandung, Bangkok, Shanghai, Colombo and Kandy, the change in agricultural land is mainly from rice paddies. Further, in Colombo and Kandy peri-urban areas, the cropping efficiency in the late 1970s was nearly 200% with two cultivation seasons, while in the last decade, this dropped to an average of 140%. This has reduced waterlogging of the paddy fields and thus reduced the consequent subsurface flow and groundwater recharge, influencing water resources in the surrounding urban region (IGES 2007). Reduced waterlogging of other peri-urban areas can be expected to reduce groundwater recharge to aquifers used by urban industry and populations.

3.4. Potential degradation of groundwater by afforestation and carbon sequestration

Forests play an important role in mitigating climate change. The IPCC recognises that sustainable forestry offers reduction in emissions from deforestation and forest degradation (REDD), afforestation, increasing sequestration in existing forests, supplying biomass for bio-energy and providing wood as a substitute for more energy intensive products such as concrete, aluminium, steel and plastics, as potential carbon mitigation options. The heightened global interest in providing incentives for forest conservation by valuing standing forests as carbon sinks and reservoirs is encouraging (see Chapter 4, this volume). However, increased forest cover will have impacts on groundwater recharge, through increased evapotranspiration, that may require on-site research before proceeding with specific projects. Some research has revealed that groundwater recharge is generally lower in forested areas than non-forested areas (Scanlon et al. 2006).

Carbon sequestration in aquifers may have unforeseen impacts on human health due to groundwater contamination (Jackson et al. 2005). When carbon dioxide enters the groundwater it can increase its acidity, potentially leaching toxic chemicals, such as lead, from rocks into the water, making groundwater unsuitable for use. To address and manage this risk, further study is needed on soil, geology, and optimum amounts of sequestration that will not cause increased acidity in groundwater.

3.5. Increase of groundwater dependency due to changes in water use

In the future, dependence on groundwater may increase due to the increasing unreliability of using surface water. It is projected that in many areas the quantity of surface water will vary and its quality will be degraded because of increased drought and flood events as a result of climate change (Kundzewicz et al. 2007). IPCC summary reports indicate that there is a very high likelihood that current water management practices will be inadequate to reduce the negative impacts of climate change on water supply reliability.

4. Adaptation measures and strategies

To minimise risk to stable water supplies, water managers design their water supply plans in accordance with climate variability based on historic climate data. However, such data may be less useful for future water management because of increased variability caused by climate change. Water resource managers will need to build new models of climate variability and greater allowance for risk into future water supply plans, in which groundwater management should be well integrated.

There is no panacea to minimise the risk of climate change to groundwater. The first step is to mainstream adaptation into water management plans, strengthening the existing management systems and measures to cope with both current and potential impacts. Groundwater volumes in aquifers need to be increased in order to conserve groundwater, maintaining groundwater ecosystems and storing reserve water supplies underground. Second, water sources should be diversified and water conservation should be promoted to minimise the risk of water shortages especially in droughts. Third, institutional arrangements to promote adaptation options are needed, which may require a paradigm shift in groundwater management. Some of the structural and institutional options available are discussed in this section.

4.1. Structural adaptation

Structural adaptation consists of building physical infrastructure or techniques that can increase storage capacity of aquifers or abstraction from watercourses or that minimise the deterioration of water quality. Some structural adaptation measures are:

- rainwater harvesting,
- artificial recharge of aquifers,
- desalinisation plants,
- underground dams,
- reservoirs and check dams.

In this chapter rainwater harvesting, artificial recharge of aquifers and construction of ponds are discussed, as they are simple, low cost and feasible in developing countries.

4.1.1. Promoting water harvesting and conservation technologies

Rainwater harvesting is a simple and low cost technique that involves the capture and storage of rainwater from roofs and ground catchments for domestic, agricultural, industrial and environmental purposes. Water harvesting has many advantages in rapidly growing cities and under future climate change scenarios. In many Asian cities, river water is already unsuitable for domestic and other purposes, and needs a huge financial investment and major institutional reform to restore the polluted and degraded river to its original condition. Rainwater harvesting can enhance the water availability at any specified location and time, increase groundwater levels and improve groundwater ecosystems. Elevated rainwater tanks save energy as groundwater has to be pumped from underground. In addition, rainwater harvesting reduces floods and soil erosion. Therefore, rainwater harvesting yields numerous social and economic benefits, and contributes to poverty alleviation and sustainable development.

Some traditional and innovative techniques are available to collect rainfall and runoff that can serve as alternative water sources in drought prone areas to minimise the stress on groundwater and in low elevation coastal zones where contaminated aquifers are a problem. Allocating 1-5% of catchment areas to water harvesting can meet the needs of water deficit communities (Sharma and Smakhtin 2006). However, a policy framework and institutional mechanism is needed to promote water harvesting at different administrative levels and jurisdictions.

Rainwater harvesting for domestic use – In Asia, rainwater harvesting for domestic use is common. Rainwater harvesting from roof top areas is also beneficial in low elevation coastal zones where groundwater recharge is not useful due to saline contamination of aquifers. In addition to domestic use, rainwater harvesting can also be used for groundwater recharge with some recharge technologies. Recharging aquifers by rainwater in coastal areas can dilute to some extent the elevated salinity concentration, making marginal supplies usable.

Box 7.2. Potential of roof top rainwater harvesting

The potential of roof top rainwater harvesting for a plot size 250 m^2 for an average annual rainfall of 1,000 mm, assuming 50% of plot area as roof area would be (0.5x250x1x1000) 125,000 litres. Assuming that only 60% of this potential could be stored, the quantity of water available would be (0.6x125, 000) 75,000 litres/year. The quantity of water available each day would be (75,000/365) 250 litres per plot. With a family of 5, the availability of water would be (250/5) 50 litres per person per day. As the average daily water requirement is approximately 100 litres per day, rainwater harvested from the roof could satisfy half of the daily water requirement.

Source: WAC, UNHABITAT and DUADGMP 2007

In some states and cities of India, rainwater harvesting is mandatory for new buildings and is imposed based on size of footprint area, plot area, number of storeys, and private, government, commercial or residential use. Some states such as Indore provide incentives such as a reduction in property tax while others like Tamil Nadu have strict enforcement by mandatory installation and cost recovery from owners.

Table 7.4. Legislation on rainwater harvesting in some Indian states/cities

State/City	Responsible agency	Mandatory	Conditions
New Delhi	Ministry of Urban Affairs and Poverty Alleviation	Yes	All new buildings with a roof area >100m^2, New buildings to be developed with an area >1000m^2
Indore	-	Yes	All new buildings with an area of >250 m^2. A 6% reduction in property tax has been offered
Hyderabad	-	Yes	All new buildings with an area of equal to or more than 300 m^2
Chennai	-	Yes	All new three-storied buildings (irrespective of the size of the rooftop area)
Rajasthan	-	Yes	All public infrastructures on plots covering more than 500 m^2 in urban areas
Mumbai	-	Yes	All buildings constructed on plots size of > 1,000 m^2
Gujarat	State Roads and Buildings	Yes	All government buildings

Source: WAC, UNHABITAT and DUADGMP 2007

Water policies and regulations affect the popularity of rainwater harvesting projects. Policies can be improved by addressing the concerns of key stakeholders, providing rainwater harvesting education and diffusion techniques, determining the optimal role of rainwater harvesting beside the supply from other water sources in different regions of the country, and providing an optimum mix of incentives and regulations to maximise uptake of rainwater harvesting (Sundaravadivel et al. 2006).

Box 7.3. Sustainable rainwater harvesting project in the Philippines

The rainwater harvesting project in Capiz province of the Philippines was an innovative and sustainable project, supported by IDRC, Canada in 1989. The project consisted of two components (i) construction of 500 rainwater harvesting tanks ranging from 2-10 m^3 in size; and (ii) provision of loans for income generating activities such as livestock rearing.

The villagers were provided a loan of $200 which could be paid back over 3 years. The villagers bought pigs for about $25 each and after some time they sold them at a very good price, about $90 each. The profit from selling the pigs was used to pay back the cost of rainwater harvesting tanks and the loan itself. Therefore, the project provided multiple benefits viz. access to water, earnings for livelihood and also manure for agricultural production.

Source :UNEP-IETC 2002

Whether rainwater harvesting can be adopted in a particular location depends on the amount and intensity of rainfall. In Asia, the rainfall is not uniform throughout the year, so rainwater harvesting serves as only a supplementary source for domestic use. The success of rainwater harvesting systems depends on (i) the quantity and quality of other water sources available; (ii) the size of household and per capita water demand;

and (iii) financial conditions. Rainwater harvesting systems are more cost effective than tube wells, especially if installed in existing buildings with suitable roofing material. In Northeast Thailand, the cost of a rainwater storage tank (jar) is about $1/L, with negligible operation and maintenance costs (UNEP-IETC 2002). Care must be taken, however, to check water quality parameters if the water is to be used for drinking purposes, as lead and zinc contamination from corrugated iron roofs can be higher than allowed by drinking water standards.

Rainwater and run-off water harvesting for agriculture - As agriculture is the largest user of groundwater in Asia, the anticipated stress on groundwater due to climate change can be minimised by promoting farming based on rainwater and runoff harvesting. Micro-catchment based cropping with field bunding, contour bunding, ridging, conservation furrows, key line and contour cultivation can concentrate rainwater in a small portion of the cultivated area to be used for irrigating crops. Arid horticulture crops such as pomegranate, dates and other crops can be successfully grown in water scarce regions (Sharma and Smakhtin 2006).

Khadin is a system of water harvesting and moisture conservation that is very popular in India. Khadin is best in deep soil plots surrounded by a natural catchment, but can be used where rainfall is as low as 150-350 mm/year. The runoff from upland areas is collected in the adjoining valley by constructing an earthen bund. The average productivity of chickpeas cultivated in this system ranges from 2.5 to 3.0 tonnes per hectare (t/ha), even without using commercial fertilisers (Sharma and Smakhtin 2006).

Similarly, small and medium sized water harvesting ponds can harvest precipitation and runoff to mitigate water scarcity. One successful example of a conservation pond in Dhading watershed in Nepal provides a reliable source of water for irrigation and livestock. The immediate area has 25 families cultivating crops and raising 226 head of livestock. The 105 m^3 water supply from the $2,000 pond provides irrigation and livestock needs, even during the dry season. Management of the pond by the local community is working well (Clemente et al. 2003).

On-farm reservoirs (OFR) can be used to store enough water for irrigation and fish culture in the eastern part of India (Pandey et al. 2005). One study on the viability of a rice-fish-mustard integrated farming system, showed that an OFR with a side slope of 1:1 and depth of 2.4 m occupying 17.5% of the field area (field size was only 800 m^2) can meet the demand for supplemental irrigation for rice, pre-sowing irrigation for mustard and water for fish culture. Economic analysis revealed a benefit/cost ratio of 1.87. In the Soan River catchment in the northwest Himalayas, benefit/cost ratios from 0.41 to 1.33 were found for water harvesting structures of different sizes for maize and wheat production (Goel and Kumar 2005).

Despite the potential of rainwater and runoff harvesting for domestic and agricultural use in Asia, few governments have made rainwater harvesting structures mandatory. Government policies on water resources and development should consider the need to encourage community participation while planning and executing any water resources development and management projects. Existing traditional methods on water harvesting and conservation can be improved by modern technologies. Participatory water harvesting systems for domestic and agricultural use can be integrated into water resources development and management plans at local, regional and national levels (Sharma and Smakhtin 2006).

Managed aquifer recharging – There are more than 800,000 dams constructed around the world, but these store only 20% of surface runoff. In India, which has built the majority of the dams in the world, about 1,150 km^3 per year of rainwater still runs into the sea in the form of “rejected recharge” (INCID 1999). Groundwater supplies could be increased significantly if only a small portion of this rejected recharge was stored underground. But this requires sound aquifer management with planned decline of the water table in the pre-monsoon dry months. Partially empty aquifers enhance recharge from both monsoon rains and return flows from irrigation water. Many developed nations have already practiced this kind of aquifer management. For example, artificial groundwater recharge contributes to total groundwater use at the rate of 30% in Western Germany, 25% in Switzerland, 22% in the USA, 22% in Holland, 15% in Sweden and 12% in England (Li 2001).

In Asia, few studies have been conducted on artificial recharge of aquifers. In India, the Central Ground Water Board (CGWB) conducted a feasibility study on artificial recharge in drought prone areas of Gujarat, Maharashtra, Tamil Nadu and Kerala. It found that the cost for construction and operation of artificial recharge structures was reasonable, but the cost for artificial recharge of wells in alluvial aquifers and tidal areas was very expensive. Moreover, the cost of artificially recharged water used for irrigation was comparatively higher than other sources. The cost of recharged water was about $15-50/ha/crop. The cost of artificially recharged water for domestic use (about $0.05-$0.15/person/year) was considered reasonable, especially in water scarce areas. The initial investment and operation cost of artificial recharge was much less than potable water supplied by tankers. Furthermore, if governments implement aquifer recharge programmes as relief work (which generally excludes labour costs), the cost could be further reduced.

The combination of several technologies can also reduce the costs. For example, in Maharashtra, the cost of a hybrid, connector well tank system was only $900 as compared to a percolation tank system (approximately $120,000), although both systems have a similar degree of recharge (CGWB-UNESCO 2000) (tables 7.5 and 7.6 show the costs of some artificial recharge methods and systems.

Table 7.5. Economics of artificial recharge methods in India

Type of Artificial Recharge Structure	Capital Cost per 1,000 m^3 of Recharge Structure	Operations Cost per 1000 m^3/year
Injection well (alluvial area)	$551	$21
Injection well (hard rock)	$2	$5
Spreading channel (alluvial area)	$8	$20
Recharge pit (alluvial area)	$515	$2
Recharge pond or percolation pond (alluvial area)	$1	$1
Percolation tank (hard rock area)	$5	$1
Vasant Bandhava or check dam	$1	$1
Tidal regulator	$56	$15

Source: http://www.unep.or.jp/ietc/Publications/TechPublications/TechPub-8e/recharge.asp

Table 7.6. Cost of artificial recharge system

System	Volume (m^3)	Cost ($)
Cement jar	1	20
Fibro-cement tank	70-80	756-1,513
Masonry underground tanks	21 200 300	202 1,412 4,538
Recharge trench	-	50-252
Recharge through hand pump	-	13-63
Recharge through dug well	-	126-252

Source: CGWB-UNESCO 2000

In addition to the harvested rainwater and runoff water, reclaimed wastewater can also be used for groundwater recharge. Groundwater recharge by treated wastewater has already been practiced in some countries. This practice has some advantages such as additional natural treatment or storage to buffer seasonal variations of water availability. However it should always be evaluated carefully before being adopted in developing countries. The major concerns of groundwater recharge by reclaimed wastewater are risks of microbiological and chemical contamination present in the reclaimed wastewater.

4.2. Institutional adaptations and considerations

4.2.1. From groundwater management to groundwater governance

It is essential to shift from management mode to governance mode to successfully address and solve the key issues and problems related to groundwater. Global Water Partnership (2000) defines water governance as a range of political, social, economic and institutional systems that are in place to develop and manage water resources and the delivery of water services at different levels of society. The different roles and responsibilities of agencies working in the water sector need to be clearly defined with one agency mandated to develop, implement and enforce a groundwater protection plan. This agency should not have any conflicts of interest that will compromise its ability to work independently. An agency involved in approval of water source development and control of the quality of the resource but not directly involved in water source development is usually preferred.

Groundwater management involves hydrologists and water managers, but groundwater governance also takes into account the concerns of multiple stakeholders including hydrologists (and other scientists), policymakers, and most importantly, users. Groundwater governance includes participation by the state, markets and even individuals depending on the nature of the groundwater challenge. Attention has to shift from government policy to governance which is multi-level, multi-actor, multi-faceted, multi-instrumental, and multi-resource based (Mukharji and Shah 2006).

Promoting local management in groundwater - Unlike surface water, groundwater development is often carried out on an individual or small group basis and does not demand a larger institutional framework for water provision (Bhandari and Shivakoti 2005). Therefore, local groundwater management can be an effective way of managing groundwater resources. Decentralised collective management is often mentioned as an alternative or supplementary option (Chebaane et al. 2004). However, promoting local groundwater management needs guidance and support from central governments.

Groundwater users often employ self-regulation to control and manage groundwater resources locally (table 7.7). Some of the lessons that can be drawn from local groundwater management are (i) potential users should be included in making the regulations; (ii) local groundwater management is possible even without a formal local organisation; (iii) simple rules also work; (iv) support from local government can help to widen the scope of groundwater management with other disciplines; and (v) promoting local groundwater regulation is not difficult, costly or sensitive. Therefore, promoting and supporting local groundwater management can reduce the burden on central governments and ensure the sustainability of groundwater resources management.

Table 7.7. Summary of local groundwater management cases

Case	Country	Size (ha)	Type of management	Measures
Panjgur	Pakistan	2,000-3,000	Informal norms	Ban on dug wells
Mastung	Pakistan	2,000-3,000	Informal norms, committee	Spacing rules, zoning
Nellore	India	1,500	Informal norms, local government	Water saving, recharge, ban on boreholes
Saurashtra	India	Scattered	Informal norms, religious leaders	Recharge, regulation of wells

Source: Steenbergen 2006

Assigning groundwater use rights

Well defined groundwater use rights entitle individual users or user groups to an abstraction allocation at a certain point in time or during a specified time period in certain aquifer conditions. Groundwater use rights needs to be carefully designed, changed and adapted to different conditions. For groundwater use rights to function as a management instrument, the following aspects need to be in place (i) initial allocation; (ii) a registration mechanism and maintained registry system; (iii) a functioning monitoring system; (iv) enforcement of limits set by individual or communal use rights; and (v) a credible sanctioning system (Kemper 2007). To establish groundwater use rights, groundwater should be regarded first as a public good among groundwater users.

Table 7.8. Definition of ownership of groundwater in selected Asian countries

	Definition	Country
Group 1	Groundwater is defined as a common property by statute. The Government is delegated responsibility to manage and allocate water resources.	Bangladesh, China, Laos, Indonesia, the Philippines, Vietnam
Group 2	There is no definition of groundwater ownership in statutory form, but it is generally recognised that groundwater is a common property and the national government has a responsibility to manage and allocate the resource.	Thailand
Group 3	Groundwater is regarded as private property of landowners in common practice or in common law.	Japan, India, Sri Lanka

Introducing a pricing scheme

While some countries in Asia have already introduced groundwater tariffs or fees, in most cases they are not successful, as discussed in section 2.3.3. Since abstraction of groundwater usually takes places on private land and with private equipment, a unique pricing mechanism is needed. In addition to a price of the groundwater resource itself, pricing the other inputs needed in order to pump groundwater such as the pump, borehole, or energy can also be included in a pricing scheme (Kemper 2007).

Pricing the groundwater resource - If users pay for abstraction of groundwater resources based on volumetric metering, there must be effective tools to monitor groundwater use and levels. One tool is remote sensing, which can help calculate groundwater use based on the crop cover (Kemper 2007).

The groundwater pricing mechanism in Bangkok can be taken as a successful example. A groundwater charge was introduced in 1985 in the Bangkok metropolitan region, except for Nakhon Pathom and a part of Samut Sakhon. However it had a little effect on the reduction of groundwater abstraction partly because the rate was cheaper than the piped water supply. To reduce groundwater extraction, the groundwater charge increased gradually until 2003, and an additional charge entitled “groundwater preservation charge” was introduced in 2004. As a result, groundwater users now pay more for groundwater than water from the piped public water supply scheme. By combining a strict pricing system with expansion of public water supply, abstraction of groundwater has decreased and land subsidence has been partly mitigated. The groundwater preservation charge is innovative because it is earmarked for research and groundwater conservation activities by the Groundwater Act.

Energy pricing - Energy pricing is seen as a political agenda in many developing countries and some countries even apply zero tariffs (e.g. the states of Tamil Nadu and Andhra Pradesh in India (Bhatia 2005)). This kind of pricing mechanism will have detrimental effects on groundwater and a true price of groundwater cannot be maintained. One option could be lump sum payments to small farmers that would permit them either to pay the full electricity bill or, if they reduce their pumping, pay a lower bill and use the “gain” for something else. This mechanism, to some extent, would not distort the true price of groundwater (World Bank 2006).

Defining groundwater protection zones

Each aquifer has its own recharge rate and can sustain a certain amount of groundwater withdrawal. If groundwater extraction volumes exceed the recharge rate several negative consequences will occur such as water level decline, land subsidence, and increased salinity. Therefore, defining groundwater protection zones according to the safe yield of the aquifer will help to implement policy instruments such as a ban on boreholes and dug wells, defining the limits of withdrawal, imposing groundwater extraction fees, and other incentives. Groundwater protection zones can be classified according to the level of vulnerability to groundwater extraction and these should be protected from some potentially polluting activities, viz. urbanization, solid waste dumping, and chemical disposal, mining and quarrying. To prevent diffuse pollution from agricultural land use, groundwater protection options include bans or import controls on pesticides and the adoption of good agricultural practice codes. Once groundwater protection zones are defined, more complementary approaches can be initiated such as public information campaigns and groundwater user groups.

4.3. Integrating adaptation strategies into national policy and planning

Adaptation measures need to be addressed in the context of development policies on poverty reduction, agricultural development, water resources development and disaster prevention. Integrating adaptation concerns into sustainable development planning processes is a necessary strategy for long term groundwater protection. In many developing countries it is difficult to integrate adaptation concerns into national policy due to (i) low staff capacity for planning, monitoring and evaluation; (ii) poor data on adaptation options and weak information sharing across sectors; and (iii) limited awareness of adaptation among stakeholders (UNFCC 2007).

Since groundwater plays a vital role in economic development of developing countries, prohibiting or limiting access to groundwater is tantamount to stopping development. Agriculture and industry depend heavily on groundwater, so policies dealing with agriculture and industrial development must try to incorporate the impacts of climate change on groundwater resources.

As discussed in section 4.1.1 structural adaptation measures such as rainwater harvesting techniques for domestic use and for groundwater recharge is considered as a low cost and highly decentralised technique. Therefore, these adaptation options with the provision of suitable incentives should be taken as a part of integrated water resources management (IWRM) principles and incorporated into national water management plans.

4.4. Capacity building, education, training and public awareness

Stakeholders' inclusion, empowerment and capacity building at all levels, especially in universities and centres of excellence, are vital to enable developing countries to adapt to climate change. Providing education and training to local communities about rainwater and runoff water harvesting for domestic use, agriculture use and for groundwater recharge will enhance the structural adaptation options to cope with current and anticipated future problems. External support is needed for institutional capacity building, including establishing and strengthening centres of excellence and building up hydro-meteorological networks. Training for stakeholders in all sectors would help to develop specialised tools for planning and implementing adaptation activities and thus promote action by local and national governments (UNFCC 2007).

In general, many government agencies of developing countries fail to explain the importance of groundwater resources and the potential impacts of climate change on groundwater. Accordingly professional groups and the public lack interest in working on groundwater resources management issues. Therefore, all water users and stakeholders, including government staff, need to be educated about the importance of groundwater to ensure sustainable management of groundwater resources.

4.5. Opportunities for adaptation funds

Funding is needed for successful implementation of adaptation plans and projects, especially in developing countries. With guidance from the UNFCC, the Global Environment Facility (GEF) is operating the GEF Trust Fund, Special Climate Change Fund (SCCF) and Least Developed Country Fund (LDCF). Other funding opportunities for adaptation projects include (i) Adaptation Fund under the Kyoto Protocol; (ii) funds from other multilateral environmental agreements (MEA); and (iii) bilateral and multilateral development funds.

The financial resources available for adaptation in the funds currently operated by GEF only amounted to $275 million in August 2007. The Adaptation Fund could receive $80-300 million per year for the period 2008–2012 (UNFCC 2008) from a 2% levy on clean development mechanism projects. Funds should be mainstreamed into structural and institutional adaptation countermeasures such as rainwater harvesting in coastal areas and urban centres. Some funds are needed for capacity building to identify investment needs and to assess the vulnerability of groundwater resources to climate change. Additional funding is needed to strengthen institutions responsible for climate change and groundwater resources management.

5. Knowledge gaps and future research needs

Very few studies have been conducted on the potential direct and indirect impacts of climate change on groundwater resources and consequently its impacts on socio-economic condition in local, regional and national level of developing countries. Therefore research should start from very basic steps such as data collection (where basic data does not exist) to adaptation options which are necessary to fill in the knowledge gaps on the potential negative impacts of climate on groundwater resources and reducing the associated risks. The immediate research questions include:

(i) What are the social and economic impacts of climate change on groundwater resources?
(ii) What are the potential impacts of climate changes on groundwater resources at local scales? What downscaling studies of global climate change models are needed to predict the impact of climate change on a local scale and on groundwater resources?
(iii) What are the critical thresholds of groundwater extraction amount under climate change scenarios?
(iv)How can groundwater monitoring under the climate change scenarios be improved?
(v) Are current groundwater water management structures and institutional capacity able to deal with projected climate change impacts?
(vi) What are the adaptation options available to cope with climate change impacts on groundwater resources and have their economic viability, social acceptance and environmental impacts been adequately evaluated?
(vii) How can an appropriate network and platform be created to investigate groundwater impacts and share up-to-date data/information necessary for formulating structural and institutional measures to adapt to the climate change impacts on groundwater?

6. Conclusions and recommendations

In many regions and for billions of people in Asia, groundwater is an irreplaceable resource for livelihoods and agriculture. Adverse impacts of climate change on groundwater resources are expected, including changes in recharge rates, saline intrusion in coastal aquifers, and decreased long term groundwater storage. Overall, however, groundwater is expected to be relatively unaffected by the climate change due to its buffering capacity. Groundwater, therefore, may increase in importance and help to ameliorate the worst effects of climate change on water resources and sustainable development. However, once seriously damaged, recovering groundwater resources requires vast amounts of funds and time.

Stresses on groundwater have been increasing in Asia due to population growth and economic development, and groundwater management already faces critical implementation challenges. Climate change will add greater pressure on the resource, jeopardise sustainability, and intensify inter-sectoral and international conflicts over water, if appropriate adaptation strategies are not implemented. Structural adaptation measures (such as promoting water harvesting and conservation technologies) and institutional adaptation strategies (such as promoting local groundwater management) should be incorporated into comprehensive water management plans.

The impact of climate change on groundwater resources and adaptation opportunities provide a new agenda for water management. To fill the knowledge gaps and reduce uncertainty regarding the predictions and impacts of climate change on groundwater resources and future groundwater management options, more research is needed. Priority research topics include downscaling studies of global climate change models and assessment of current groundwater management structures and institutions.

Some key messages derived from the study to date include:

(i) Existing water management institutions, policies and water infrastructure in Asia have not been successful in coping with current groundwater problems, so extra effort will be needed to counter the additional negative effects of climate change;
(ii) Measures to cope with current groundwater stress and potential impacts of climate change include conserving and increasing groundwater storage and diversifying water sources to minimise the risk of water shortages;
(iii) Rainwater harvesting structures for groundwater recharge and for domestic and agricultural use is a feasible structural adaptation option but new policies to promote rainwater harvesting need to be developed;
(iv) Institutional adaptation should be promoted, including enhancement of groundwater governance and strengthened local groundwater management. Groundwater management policies can be made more effective by raising local awareness;
(v) Innovative funding, like the Adaptation Fund, should be used to strengthen institutions, build capacity, educate the public and conduct research on the effects of climate change on groundwater resources; and
(vi) Extensive research at local scales is needed to reduce the knowledge gap regarding the potential impact of climate change on groundwater resources. This information will help to formulate policies to counteract the impacts of climate change.

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