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Climate change and groundwater resources in Cambodia

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Abstract: Climate change has become a major global concern and threatens the security of natural environmental resources, including groundwater, especially for Cambodia. In this study, literature reviews related to climate change and groundwater resources in Cambodia were evaluated to address the impact of climate change on the groundwater environment. In Cambodia, global climate change will likely affect available water resources by driving changes in the groundwater recharge and usage pattern. Despite a general increase in the mean annual rainfall, a reduction in rainfall is anticipated during the dry season, which could lead to shortages of fresh water during the dry season. The impact of climate change on water resource environments can significantly affect national economic development. Thus, strategic management plansfor groundwater in response to climate change should be established to ensure the security of water resources in Cambodia.

Keywords: Groundwater; Water resource; Climate change; Cambodia

1 Introduction

Groundwater is an important water source for domestic use and agriculture in Cambodia. Shallow alluvial aquifers in the Mekong lowlands enable farmers to install shallow dug wells and tube wells to produce dry season crops. Groundwater usage for drinking water and industrial use has also increased in Cambodia. Despite the importance of groundwater resources, insufficient groundwater investigations have been performed and groundwater management is lacking in Cambodia. Global climate change is expected to have a substantial impact on available water resources by changing the groundwater recharge and usage patterns. These unexpected changes and increases in extreme weather events, such as drought and flood, will increase the difficulty of predicting and managing valuable groundwater resources. To secure the water resources and promote the water-dependent economy of Cambodia, strategic climate adaptation plans for groundwater resources should be established based on observational data, predictions, and the socio-economic status of the country. The objectives of this paper are to review the impact of climate change on the groundwater resources of Cambodia and share relevant information for international groundwater resource management plans in the Mekong River Basin.

1.1 Status of groundwater in Cambodia

1.1.1 Basic hydrogeology

The Mekong lowlands in Cambodia consist of thick alluvial deposits over shale, slate, and sandstone (Fig. 1). The alluvial deposits consist of unconsolidated to semi-consolidated alluvial sediments that range in depth from a few m to more than 160 m. In Vietnam, eight major depositional sequences are distinguished in the Mekong lowlands based on the age from the Miocene to the present (Landon M K, 2012), and five main aquifers are observed (IUCN, 2011). In Cambodia, however, the division is simpler, with young alluvium (Holocene river and floodplain deposits) and old alluvium (Pleistocene to Miocene terrace and platform deposits).

In general, young alluvium is finer grained (clays and silts) and a poor material for aquifers,

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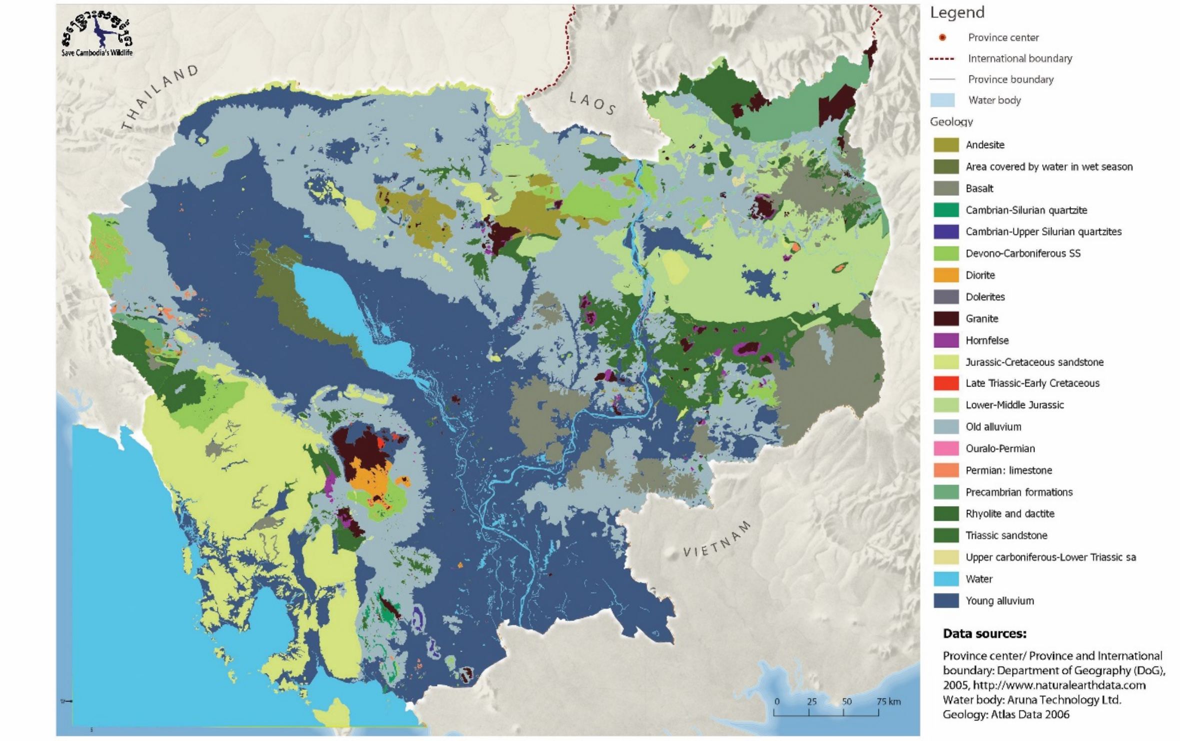
although it can yield good groundwater when it lenses with sand. Old alluvium constitutes a thick pile of coarse sediments with a high yielding aquifer and generally good water quality, although both the groundwater quantity and quality are highly dependent on location (Johnston R and Kummu M, 2012). The alluvial layer in Cambodia includes confined and unconfined systems. Confined aquifers in the Mekong lowlands are usually sub-artesian; therefore, water levels are often 1 to 5 m from the surface (JICA/CMRD, 2002; iDE, 2009). In certain cases, the locations of artesian groundwater have been reported in the provinces Siem Reap and Kampong Thom (Landon M K, 2012).

Tertiary basalts (in eastern and central Cambodia) and Permian karsts (in Battambang and Kampot) may also have the potential for significant irrigation usage. Groundwater irrigation in similar basalt terrains has supported the development of important coffee growing areas in the central highlands of Vietnam and the Bolavens Plateau in Lao PDR (Fig. 2).



Data sources:

Province center/ Province and International boundary: Department of Geography (DoG), 2005, http://www.naturalearthdata.com
Water body: Aruna Technology Ltd.
Geology: Atlas Data 2006

Fig. 1 Geological map of Cambodia.

Fig. 2 Groundwater is widely used for domestic water supply in Cambodia and increasingly used for small-scale irrigation

1.1.2 Climate

Cambodia has a tropical climate controlled by the Southwest and Northeast Monsoons and is vulnerable to extreme weather events, such as floods and droughts because of its location within the tropics in the vicinity of the Indian Ocean. The complex topography of the country results in strong spatial variations in temperature and rainfall. Such variations are particularly evident during monsoon seasons between June and September (Southwest Monsoon) and December and March (Northeast Monsoon). The El Nino-Southern Oscillation (ENSO) is the major phenomenon that dominates the variability of the climate on the inter-annual (year to year) time scale, and cold winds that surge from Siberia and Mongolia during the Northeast Monsoon season influence the climate of Cambodia on a shorter time scale, which ranges between 8 and 10 days (Suppiah R and Wu X, 1998). On average, five to six tropical cyclones that form over the western Pacific affect Cambodia each year. Major droughts and forest fires are associated with a failure of Southwest Monsoon rain events, which are influenced by year-to-year changes in the ENSO.

Because of Cambodia’s location within the Asian monsoon region, its climate is predominantly controlled by Northern Hemisphere summer and winter monsoons, and the country experiences a tropical wet and dry climate as a result of marked seasonal differences (Ramage C, 1971). In summer, the Southwest Monsoon from the Indian Ocean affects the country, with rain occurring almost daily during much of this season, and the Northeast Monsoon flow of drier and cooler air lasts from early December to March. From November to February the weather is generally mild and dry, and it becomes hot from February until the onset of the Southwest Monsoon (Sao V, 2009). Transitional seasons, which are marked by differences in humidity, present negligible changes in temperature.

The rainfall distribution in Cambodia is strongly influenced by the topography and the two monsoons; therefore, the spatial pattern of rainfall varies throughout the country. The highest rainfall occurs in the southwest in coastal areas, with annual amounts ranging from 2 000 mm to 3 400 mm. In this region, approximately 80% of the annual rainfall is received during the Southwest Monsoon season. The second highest rainfall occurs in the northeast plateau area where the annual rainfall amounts range from 1 800 mm to over 2 200 mm. The region with the lowest rainfall stretches from the northwest to the southeast and includes the Tonle Sap (the lake and river system between Siem Reap and Pursat), which receives annual rainfall of less than 1 400 mm.

1.1.3 Groundwater usage and status

In Cambodia, groundwater plays a dominant role as one of primary water sources for individual households. Groundwater has been developed and used in the form of tube wells, dug wells, or combined wells in almost all urban and rural areas except for specific urban areas.

In the past, rural areas mostly relied on reservoirs, rivers, dug wells and rain water for domestic and agricultural water supplies, and groundwater was poorly used. Utilization of groundwater resources for domestic and agricultural uses in Cambodia has increased since 1960. In the early 1960s, the agricultural area development initiatives of the USAID resulted in the excavation of approximately 1 100 wells that had depths ranging from 2 to 209 m, with a mean of approximately 23 m. Subsequently, wells for water supply have been developed via support from international organizations, such as UNICEF, OXFAM and World Vision, since the early 1980s. Approximately 31 000 wells (Table 1) with depths ranging from 32 to 38 m and yields ranging from 28.8 to 85.68 m^3/day (mean of approximately 60.72 m^3/day) were developed between 1983 and 2001.

As of 2005, at least 100 000 wells were being developed or used for water supply in rural areas throughout the country. However, approximately 20% of shallow wells dried up and are currently unavailable. The borehole diameters and depths of wells were analyzed based on a well database from UNICEF and the Ministry of Water Resource and Meteorology (MOWRAM). The analyzed data included 14 255 wells distributed in 13 areas, and the borehole diameters of the wells ranged mostly from 100 to 200 mm, although certain wells had borehole diameters that exceeded 200 mm. The borehole depths of the wells ranged from 25 to 37 m, with a mean depth of 30.4 m. The regional well characteristics are summarized in Table 2. The total water usage and groundwater usage in Cambodia are presented in Table 3. Groundwater is mostly used for agricultural activities, which account for more than 80% of the total groundwater usage in Cambodia.

Table 1 Status of the total number of regional groundwater wells developed from 1983 to 2001 (Ministry of Planning, 2003)

No.	Province	UNICEF/MRD	NGOs	Total
1	BanteyMeanchey	615	628	1 243
2	Battambang	750	1 193	1 943
3	Kandal	641	340	981
4	Kampot	2 869	244	3 113
5	Keb	32	80	112
6	Kampong Cham	1 127	1 213	2 340
7	Kampong Chhnang	832	954	1 786
8	Kampong Speu	269	992	1 261
9	Kampong Thom	137	778	915
10	Koh Kong	24	17	41
11	Kratie	522	168	690
12	Mondol Kiri	1	0	1
13	OurdorMeanchey	0	0	0
14	Pailin	33	4	37
15	Phnom Penh	1 014	0	1 014
16	PreahVihear	51	286	337
17	Prey Veng	1 418	4 622	6 040
18	Pursat	274	154	428
19	Ratanak Kiri	20	64	84
20	Siem Reap	405	284	689
21	Sihanouk Ville	77	20	97
22	Stung Treng	31	220	251
23	SvayRieng	506	5 599	6 105
24	Takeo	1 596	405	2 001
	Total	13 244	18 265	31 509

Table 2 Characteristics of regional groundwater development wells in Cambodia

Province	No. of wells tested	Well depth (m)		
		Mean	Maximum	Minimum
Kampong Cham	1 254	28.2	72.0	5.6
Kampong Chhnang	1 542	25.5	61.0	4.0
Kampong Speu	1 659	27.9	83.0	4.0
Kandal	2 136	28.7	96.0	4.0
Phnom Penh	1 100	24.8	96.0	4.1
Prey Veng	1 342	36.7	80.0	4.0
SvayRieng	684	36.6	101.0	15.0
Takeo	1 932	28.0	67.8	4.0
Battambang	692	36.3	90.0	4.0
BanteayMeanchey	615	34.6	266.0	8.0
Pursat	701	31.4	60.0	12.0
Siem Reap	524	26.7	99.0	4.0
Sihanouk Ville	74	29.4	54.0	3.0

Table 3 Status of groundwater use in Cambodia

Province	Total domestic water use	Groundwater use (m^3/day)			
		Total	Percentage of groundwater (%)	Rural	Urban
BanteyMeanchey	40 356	18 979	47.0	16 638	2 341
Battambang	49 855	28 484	57.1	26 144	2 340
Kampong Cham	63 515	63 515	100.0	49 223	14 292
Kampong Chhnang	23 691	16 462	69.5	15 671	791
Kampong Speu	28 014	28 014	100.0	19 981	8 033
Kampong Thom	23 181	18 758	80.9	18 274	484
Kampot	25 120	18 323	72.9	17 579	744
Kandal	57 382	35 614	62.1	33 230	2 384
Kep	2 803	2 803	100.0	1 598	1 205
KohKong	7 999	3 062	38.3	2 522	540
Kratie	15 954	9 833	61.6	9 163	670
Mondol Kiri	1 572	1 572	100.0	1 104	468
OtdorMeanchey	6 880	6 880	100.0	3 446	3 434
Pailin	3 095	3 095	100.0	817	2 278
Phnom Penh	134 537	2 186	1.6	0	2 186
PreahVihear	6 010	6 009	100.0	4 541	1 468
Prey Veng	36 603	36 603	100.0	31 065	5 538
Pursat	18 896	14 243	75.4	13 734	509
Rotanak Kiri	4 627	4 627	100.0	2 845	1 782
Siem Reap	27 814	27 814	100.0	20 488	7 326
Sihanouk Ville	15 117	4 478	29.6	3 313	1 165
Stung Treng	4 874	2 606	53.5	2 359	247
SvayRieng	18 480	18 480	100.0	15 804	2 676
Takeo	29 984	27 961	93.3	27 740	221
Total	646 358	400 400	61.9	337 279	63 121

1.2 Climate change

1.2.1 Predicted climate change scenarios

Globally measured atmospheric greenhouse gas concentrations have increased rapidly over the past century and are likely to increase in the future (IPCC, 2007). Global Climate Models (GCMs) are the best available tools for simulating future climates based on various greenhouse gas and aerosol emission scenarios (Fig. 3). GCM experiments indicate a global average warming of 1.1 to 6.40 °C by the year 2100 under the B1 (low) and A1FI (high) emissions scenarios, respectively, relative to 1990 (IPCC, 2007). This warming will likely lead to changes in weather patterns and sea level rises and have impacts on ecosystems, water resources, agriculture, forests, fisheries, industries, urban and rural settlements, energy usage, tourism, and health.

Future climate projections for Cambodia and the likely impact of climate change on various sectors are often considered in the context of the wider Asia-Pacific region. Several studies have focused on the impacts of drought on various sectors in Cambodia and proposed a number of strategies to manage the associated risks (Nguyen H *et al.* 2013). Climate change projections for Cambodia have been provided by the Cambodian Ministry of Environment using simulations performed for the IPCC Fourth Assessment Report (Ministry of Environment, 2001). These climate change projections were based on the previous

Special Report on Emission Scenarios (SRES) IPCC, 2000). Under a high emission scenario (SRES A1FI), the mean air temperature in Cambodia was projected to increase by approximately 0.50 °C by 2020 and 1.00 °C by 2050. Under a low emission scenario (SRES B1), the mean air temperature was projected to increase by approximately 0.30 °C by 2020 and by 0.70 °C by 2050. The projections also showed that wet season rainfall may increase and dry season rainfall may decrease (Fig. 4-6).

High-resolution climate change projections for Cambodia produced by the Center for Climate Systems Research (CCSR) and Commonwealth Scientific and Industrial Research Organization (CSIRO) as part of a United Nations Development Program (2009) were analyzed for the SRES A2 and SRES B1 emission scenarios. Projected increases in temperature ranged from 1.35 to 2.50 °C and increases in annual rainfall ranged from 3 to 35% by 2100.

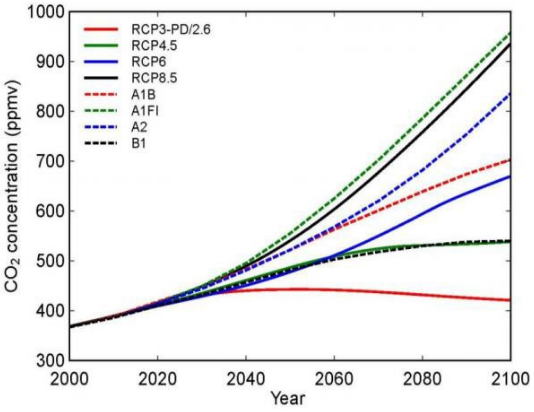


Fig. 3 Comparison of CO_2 concentrations (ppwv) from SRES (A1B, A1FI, A2, B1) and RCPs (3.0, 4.5, 6.0, 8.5) for the years 2000-2100 (Meinshausen M *et al*. 2011).

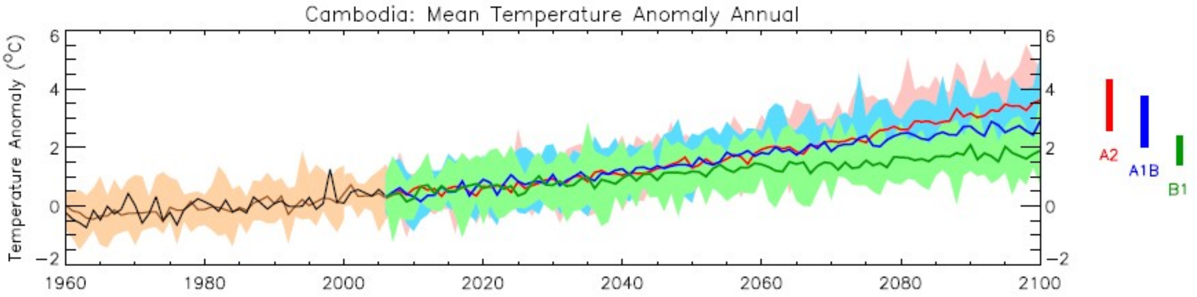


Fig. 4 Trends in the annual mean temperature for the recent past and projected future (UNDP, 2007)

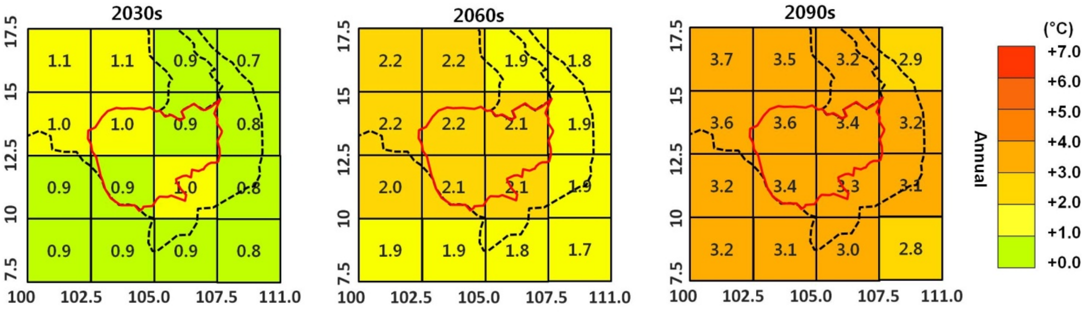


Fig. 5 Spatial patterns of projected changes in the mean annual temperature for 10 year periods in the future under the SRESA2 scenario (UNDP, 2007)

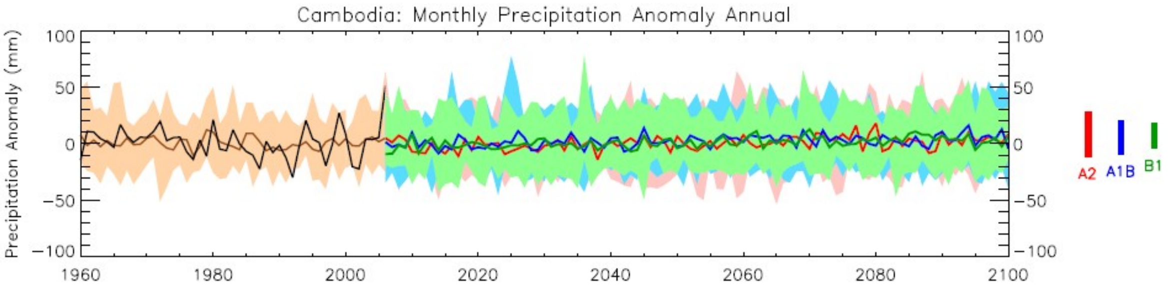


Fig. 6 Trends in monthly precipitation for the recent past and projected future. All values shown are anomalies relative to the 1970–1999 mean climates (UNDP, 2007)

2 Climate changes and groundwater sustainability

2.1 Climate changes and hydrologic variability

2.1.1Hydrological cycle and groundwater

The Mekong Basin has been highlighted in global assessments as a river basin that will experience the most severe effects of climate change (UNEP, 2009). Climate change will affect the water cycle and produce shifts in the timing, duration and intensity of rainfall patterns and seasons, change the hydrology of major rivers and tributaries and groundwater recharge, and alter the quantity, quality, availability and distribution of water (TKK and SEA START RC, 2009).

According to the TKK and SEA START RC (2009), the potential impacts of climate change on the hydrologic cycle and water resources in Cambodia include (1) altering the hydrological regime that land fisheries and agriculture depend on (MRC, 2010); (2) changing the seasonal distribution of rainfall, with drier and longer dry seasons and shorter more intense wet seasons (Ministry of Environment, 2010); (3) increasing the volume and intensity of rainfall during the wet season, increasing the flood frequency, and marginally decreasing the dry season rainfall (Clausen T J, 2009; Eastham J *et al.* 2008); (4) reducing the flow of the Mekong and its tributaries during the dry season and increasing the flow during the rainy season (TKK and SEA START RC, 2009); (5) increasing the drought risks in most of Cambodia’s agricultural areas (Ministry of Environment, 2010); and (6) increasing the temperature, with corresponding increases in evapotranspiration (Fraiture C D *et al*. 2007).

Eastham J *et al.* (2008) estimated the changes in water resources in the Mekong River Basin and predicted that by 2030, the mean annual runoff of the basin within the Cambodia territory would increase by 50-150 mm during the wet season. The percentage increase in annual runoff compared with current condition is estimated to be 10 (Tonle Sap) to 65% (Phnom Penh). Substantial increases in surface runoff during the wet season indicate that despite an increase of annual precipitation, groundwater recharge would not increase (or even decrease) because the large portion of rainfall would be lost via runoff. An expansion of inundation areas by increased runoff during the wet season and enhanced annual variations in rainfall could cause serious damage to agricultural activities over these areas. In addition, the mean annual runoff during the dry season is expected to show spatial variations, with minor decreases in the Tonle Sap sub-basin and small increases in Phnom Penh. In addition, an increase in mean annual temperatures is likely to increase evapotranspiration, which would decrease the available water resources and increase the risk of periodic droughts.

The impacts of climate change on the hydrological cycle might be exacerbated without suitable management of current watersheds, catchments and flood plains because of the associated effects on runoff and groundwater recharge. Further degradation of catchments, watersheds and flood plains will lead to enhanced variations in hydrological cycles and difficulties in predicting available water resources in response to climate change.

2.2 Impacts of climate change on groundwater

2.2.1 Predicted sustainability of groundwater resources under climate change

Although few studies have investigated the impact of climate change on the groundwater resources in Cambodia, the potential effect of climate change on groundwater can be estimated based on global prediction results. According to the IPCC’s Fourth Assessment Report (2007), climate change will affect groundwater recharge rates, renewable groundwater resources, and groundwater levels in many parts of the world. In addition, climate change will also change the vegetation cover of the land area, which will lead to additional variations in the groundwater recharge rate. These findings strongly suggest that the future sustainability of groundwater resources will be strongly influenced by climate change.

Ebran L E and Gorelick S M (2016) evaluated the area of Cambodia with deficits of irrigation water and predicted future groundwater sustainability using remote sensing data and numerical simulations. According to their study, groundwater levels in many regions of Cambodia will drop below the lift limit of suction pump wells. Consequently, approximately 1.5 million Cambodian farmers could experience serious problems related to limited water supplies to their crops within 15 years if groundwater irrigation continues to expand at current rates.

Increases in sea level because of climate change could exacerbate seawater intrusions into the coastal aquifer and threaten the sustainability of coastal groundwater. The coastal area in Cambodia will be affected by an expected rise in sea level of 0.18 to 0.56 m by the 2090s (UNDP, 2009). Sea level rise together with overexploitation of coastal groundwater can cause seawater to be drawn toward the freshwater zone, which may result in the inflow of salt water into coastal groundwater wells. Such intrusions could become a serious problem in many coastal cities and small islands that use groundwater for domestic water supplies.

Higher water temperature and variations in runoff are likely to produce adverse changes in water quality and subsequently affect human health, ecosystems, and water use (Patz J A, 2001; Lehman J T, 2002; O'Reilly C M *et al*. 2003; Hurd B H *et al*. 2004). Higher surface water temperatures will promote algal blooms and increase the bacterial and fungal contents of water systems. Such changes may lead to the chlorination of drinking water and the occurrence of toxins (Moulton R J and Cuthbert D R, 2000; Robarts R *et al*. 2005). Poor water quality and reduced water availability for domestic use would have enormous impacts on human health because most rural populationsare dependent on natural water bodies for drinking water.

2.2.2 Major threats on the water resources, environment and society because of the climate change

Cambodia's economy is highly dependent on water resources. Rivers, lakes, and groundwater serve as important sources for agriculture, manufacturing, hydropower, tourism, environmental protection, and daily life. Consequently, changes in the water resource environment because of climate change can have a significant impact on the national economic development. The major threats related to climate change include an increased frequency of flood and drought, shortage of fresh water, especially during the dry season, sea level rises and inundated coastal areas as well as adverse impacts on crop productivity, fisheries, transportation, *etc*.

Floods have been frequent in Cambodia over the last decade and appear to be increasing since 1989, when statistics were consistently recorded. Severe floods have resulted in a high number of casualties and destruction of infrastructure. The most severe flood occurred in 2000 and killed approximately 350 people and caused US$150 million in damage to crops and infrastructure. Additional floods that occurred during the period from 2000–2002 were the worst in the recent history of Cambodia and resulted in 438 casualties as well as a high number of internally displaced people, economic losses, and damage amounting to US $205 million in total (NCDM, 2002).

An increase in extreme droughts during the dry season under climate change is another major concern that threatens the sustainability of water resources in Cambodia, including the groundwater. The impact of drought in certain regions in Cambodia has been previously assessed (NCDM, 2002). Prolonged drought occurred from 1997 to 1998, and consecutive droughts occurred in 2001, 2002, 2004 and 2005. A short dry spell of 20 to 30 days during the rainy season (May–November) can result in extensive damage to crops. The most severe drought caused by a lack of rainfall, which occurred in 2002, severely affected more than 2 million people and destroyed more than 100 000 ha of paddy fields. A recent severe drought occurred in Ratanakkiri Province in 2014, and most of the streams and shallow wells dried out and local residents suffered from serious water shortages.

One of the most vulnerable areas to climate change in Cambodia is the coastal zone. Climate change can encompass seasonal variability and inter-annual variability, which are occasionally manifested in extreme weather occurrences, such as storms, cyclones, flooding, heat waves, *etc*. The combined effect of a sea level rise, a decline in mangrove forests, and an increase in the frequency and intensity of storms and storm surges has exacerbated coastal inundation, which produces dramatic effects on the communities along the coastal line. One consequence is the salinization of the surface and groundwater, which has a severe impact on the fertility of the areas used for farming and freshwater-based ecosystems. These impacts pose a threat to food security and livelihoods because most of the agriculture in the coastal zone is concentrated on these flood-prone low-lying coastal areas. The infrastructure in the coastal zone is also affected, which can lead to an increased vulnerability over time and loss in income from tourism.

The effect of climate changes on water resources and the environment will be felt differently by different parts of the country and different people. For example, people living in the Tonle Sap region will experience a direct impact caused by the changes in the natural flood pulse, increased water levels, longer flood durations, and drought. Tonle Sap is the largest lake in Cambodia, and it is directly connected to the Mekong River. Under this connection, the lake enlarges during the monsoon season by four fold because of surface water inflow from the Mekong River. During the dry season, the lake experiences reverse flow back into the Mekong River. As a result of periodic flooding and reverse flow regimes, Tonle Sap Lake has an exceptionally productive flood plain ecosystem and is one of the greatest sources of freshwater fish in the world. This water body also provides the surrounding agricultural land with vital resources for rice cultivation. Consequently, any changes in the water quality or quantity of the Mekong River can have severe impacts on the lake and human security. Changes to the natural hydrology would alter the flood pulse (the reverse flow into the Tonle Sap from the Mekong), which drives changes in the natural productivity. The most immediate and dramatic effects are then felt in fisheries.

Without improved management, changes in water availability could lead to reduced water quality and greater water scarcity, particularly in the dry season, which in turn lead to increased competition between sectors and among different users. These effects are felt most acutely by small-scale farmers and fishers and the poor. In addition, collecting water from further afield would produce greater labor and time costs and would likely be felt most accurately by women and children. In certain cases, water would have to be purchased, thereby placing an additional economic burden on poor households.

3 Adaptation to climate changes

3.1 Policies and management for theprotection of water resources under climate change

Cambodia has implemented improved polices and management strategies for water resources, thereby improving irrigation systems, rehabilitating pumping stations and water pumps, enhancing water supplies and sanitation, and establishing a farmer water user community (FWUCs). In addition, Cambodia has prepared for mitigation and adaptation strategies for water resources in response to climate changes. The main objectives of the climate change strategic plan of Cambodia are as follows (MOWRAM, 2012):

(1) Provide for the effective, equitable and sustainable protection, management and use of water resources under the negative impacts of climate change;

(2) Regulate, modify and implement water resources service fees for all water resources development activities in addition to promoting climate change adaptation and/mitigation schemes;

(3) Maximize sustainable water resources contributions to poverty reduction, enhanced livelihoods and equitable economic growth;

(4) Adapt to climate change and mitigate its effects on water resources based livelihoods;

(5) Apply Integrated Water Resources Management (IWRM) schemes that allow for holistic planning across sectors, jurisdictions and local government borders for climate change adaptation and mitigation;

(6) Promote stronger community participation in water resources management and development, such as Farmer Water User Committees, to address impacts or obtain benefits from climate change-induced opportunities;

(7) Raise the awareness, institutional capacity and decision-making quality with regard to climate change adaptations and mitigation strategies to enable the sustainable development and management of water resources;

(8) Ensurethe environmental protection and conservation of water resources;

(9) Apply modern sustainable management models that are adaptive to climate change contexts; and

(10) Develop sustainable financial systems in partnership with private sectors.

The laws and regulations pertaining to climate change issues are still in the development stage, and climate change strategies should focus on the following challenges for groundwater adaptations and mitigation plans (MOWRAM, 2012):

(1) Awareness and knowledge of the effect of climate change on water resource management and development must be promoted within all water-related sectorsat local, provincial and national levels viatelevised sports and radio and media campaigns;

(2) Enhance the capabilities of personnel with regard to water resources/climate change through long-term studies, short-course training programs and exchange study tours both within and outside of the country and the region;

(3) Establish a data management system for collecting and sharing data and information on water resources/related climate change issues, and adaptation/mitigation capacities of related stake holders;

(4) Establish and/or improve networks for meteorological and hydrological processes to manage and control the impacts of temperature, rainfall, flood, drought and weather;

(5) Mobilize secured financial resources from government agencies and develop partnerships for programs/projects, research and development on water resources/climate change adaptation or mitigation;

(6) Strengthen the capacity of local farmers, especially FWCU members, for the selection of lower-water crop varieties and planning of lower-water crop systemsa climate change adaptation;

(7) Develop long-term water resources integrated with planning to provide the greatest likelihood of minimizing the negative effects of sealevel rises;

(8) Strengthen cooperation and coordinate mechanisms among different sector agencies at local, national, regional and international levels by applying IWRM aspects as a response to climate change adaptation and/or mitigation;

(9) Improve and introduce technologies in water work development as a response to the negative impacts of climate change.

3.2 Technical measures to protect water resources under the climate changes

Groundwater storage and recharge can be valuable for maintaining water levels and ensuring the quality and availability of water for current and future uses. Relative to reservoirs, aquifers eliminate evaporative losses and reduce the likelihood of contamination. Shah T (2009) notes that “The response of aquifers to droughts and climatic fluctuations is much slower than that to surface storages; as a result, compared with surface storages, aquifers act as a more resilient buffer during the dry spells, especially when they have large storages”. The adaptation capacity of groundwater to climate change can be substantially improved under appropriate technical measures, such as artificial recharge.

Artificial aquifer recharge (also called groundwater banking, managed aquifer recharge, or aquifer storage and recovery) can be used to store water, prevent salt water intrusion, and remedy prior overextraction. Artificial recharge can be useful in areas with varied seasonal runoff patterns, particularly if the season of high water demand coincides with low runoff periods. Even minor civil engineering works can increase infiltration and water availability in the dry season. Using simple applications, old and abandoned wells can be used to recharge water. New wells can also be drilled or dug for this purpose. Infiltration basins that consist of shallow ponds with a permeable (sand) bottom can be designed to promote infiltration in aquifers.

The effectiveness of artificial aquifer recharge is dependent on both physical and technical conditions and socioeconomic conditions (Galeetal A *et al.* 2002). The physical and technical determinants of effectiveness consist of the soil type, source water, storage capacity, recharge method, and maintenance schemes. To reduce water loss from leakage and increase the efficiency of artificial recharge, geologic characterizations and investigations of the candidate aquifers must be performed.

4 Challenges and problems

4.1 Challenges and problems

The major challenges associated with climate change adaptionsin Cambodia are as follows:

- Insufficient information/data are available on the effects of climate change, including several natural disasters;

- Insufficient predictions/evaluations are available on the impact of climate change on the water environment;

- Limited data and information are available and tend to be fragmented by institutions;

- Limited early warning systems, networking and communications are available;

- Insufficient capacity and capabilities (*e.g.*, lack of operational budget, facilities and technology, *etc.*) are available to effectively minimize such serious crises.

4.2 National and international cooperation

The National Climate Change Committee (NCCC) was established in 2006 to coordinate national climate change responses in Cambodia. The Climate Change Department (CCD) in the Ministry of Environment is the secretariat of the NCCC and has been in charge of developing the National Adaptation Plan (NAP) and Cambodia Climate Change Strategic Plan (CCCSP) since 2010. In May 2015, the functions of the NCCC have been taken over by the National Green Growth Council for Sustainable Development (NCSD) to promote more effective inter-sectorial coordination among ministries. Under the NCSD, the Climate Change Technical Team (CCTT) became the focal point of each line ministry. In the future, the NCSD will be in charge of implementing NAP process.

In addition to CCCSP development, eight line ministries and one agency have also developed their own “Sectorial Climate Change Strategic Plans” (SCCSPs). Furthermore, 14 line ministries/ agencies have developed sector-specific “Climate Change Actions Plans” (CCAPs) to promote the implementation of actions at the sectorial level. The Cambodia Climate Change Alliance (CCCA) has provided support for the development and implementation of the CCCSP, SCCSP, and CCAP.

The NAP road map was created with international support from UNDP, UNEP, and GIZ, which is an international development company from the German Federal Government, by request of the Cambodian government to operationalize the CCCSP. CCCSP development was led by the Government of Cambodia and received financial support from the European Union, the Swedish International Development Cooperation Agency (SIDA), the Danish International Development Agency (DANIDA), and the United Nations UNDP through the CCCA. GIZ will support the NCSD in developing a financing strategy for NAP implementation.

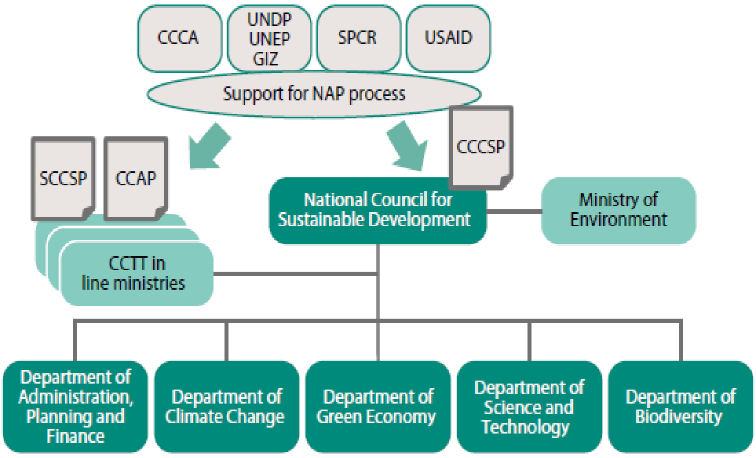


Fig. 7 Institutional arrangements for the climate change adaptation in Cambodia

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