Climate change and groundwater resources in Thailand

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Abstract: The average temperature of Thailand is projected to increase by 2-3 °C, and the annual rainfall is projected to increase by 25% and up to 50% in certain areas. The climate change in future is expected to provide changes in hydrological cycle and therefore impacts the groundwater resources too. In this study, we analyzed the general climate change trends and reviewed the groundwater conditions of Thailand. The climate changes, hydrologic variability and the impact of climate change on groundwater sustainability are also discussed based on a national groundwater monitoring program. Currently, there are 864 groundwater monitoring stations and 1 524 monitoring wells installed in Thailand. Moreover, the impact of climate change on groundwater-dependent systems and sectors is also discussed according to certain case studies, such as saline water intrusion in coastal and inland areas. Managing aquifer recharge and other projects are examples of groundwater adaptation project for the future.

Keywords: Climate change; Hydrologic variability; Groundwater resources; Groundwater sustainability; Thailand

1 Status of groundwater resources in Thailand

Groundwater plays an important role in the Thai people's daily life because it is a source of fresh water for domestic consumption. The Department of Groundwater Resources (DGR) under the Ministry of Natural Resources and Environment has specific mandates to oversee the development and regulation of national groundwater resources and provide leadership for the integrated management of the nation's groundwater resources in a manner that is consistent with national socioeconomic development goals and policies. To accomplish these mandates, the DGR has prepared a detailed Groundwater Resources Management Master Plan to provide specific guidelines for all aspects of groundwater resource management. Fig. 1 illustrates the quantitative and qualitative groundwater potentials classified into the following 4 levels: Areas with the groundwater yields of less than 2 m^3/hr, 2-10 m^3/hr, 10-20 m^3/hr, and greater than 20 m^3/hr. The qualitative groundwater potential of an area is categorized into the following 3 levels: Good water quality with total dissolved solid (TDS) content of less than 500 mg/l, fair water quality with TDS content of 500-1 500 mg/l, and poor water quality with TDS content of greater than 1 500 mg/l.

The essential sources of groundwater are derived from unconsolidated aquifers that constitute nearly 80% of the overall extractable groundwater. These aquifers are extensively found throughout Thailand, and examples may be found in the areas of the Chao Phraya flood plain and the Chiang Mai-Lamphun Basin. The age of the unconsolidated deposits varies from the Pleistocene to the Tertiary and recent. The depositional environments vary as reflected in the different groundwater yields and storage. The storage capacity of groundwater in consolidated aquifers depends on the degree of secondary porosity, such as cavities in limestone, faulted zones, jointing systems, fractures from folding or cracks from shrinkage. Different rock types have different fracture patterns and yields. At least 80% of the groundwater wells in northeastern Thailand were drilled and developed in consolidated aquifers. There are 27 groundwater basins in the

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country, and the potential aquifer storage for all basins estimated by the DGR in 2010 is approximately 1 130 000 MCM (million m^3), with an average annual recharge of 101 000 MCM. Throughout the country, the current groundwater abstraction is approximately 11 047 MCM/year with approximately 4 840 (44%), 4 085 (37%) and 2 122 (19%) MCM/year for agriculture, industry and domestic uses respectively. Groundwater resources represent a major water supply for approximately 35 million people in rural and urban areas.

Thailand has currently produced hydro-geological maps at a scale of 1/50 000, and they cover many parts of the country, such as the Upper Chao Phraya Basin and northeast Thailand. Moreover, numerous developing climate change projects and groundwater resource evaluations are underway (DGR website, 2016).

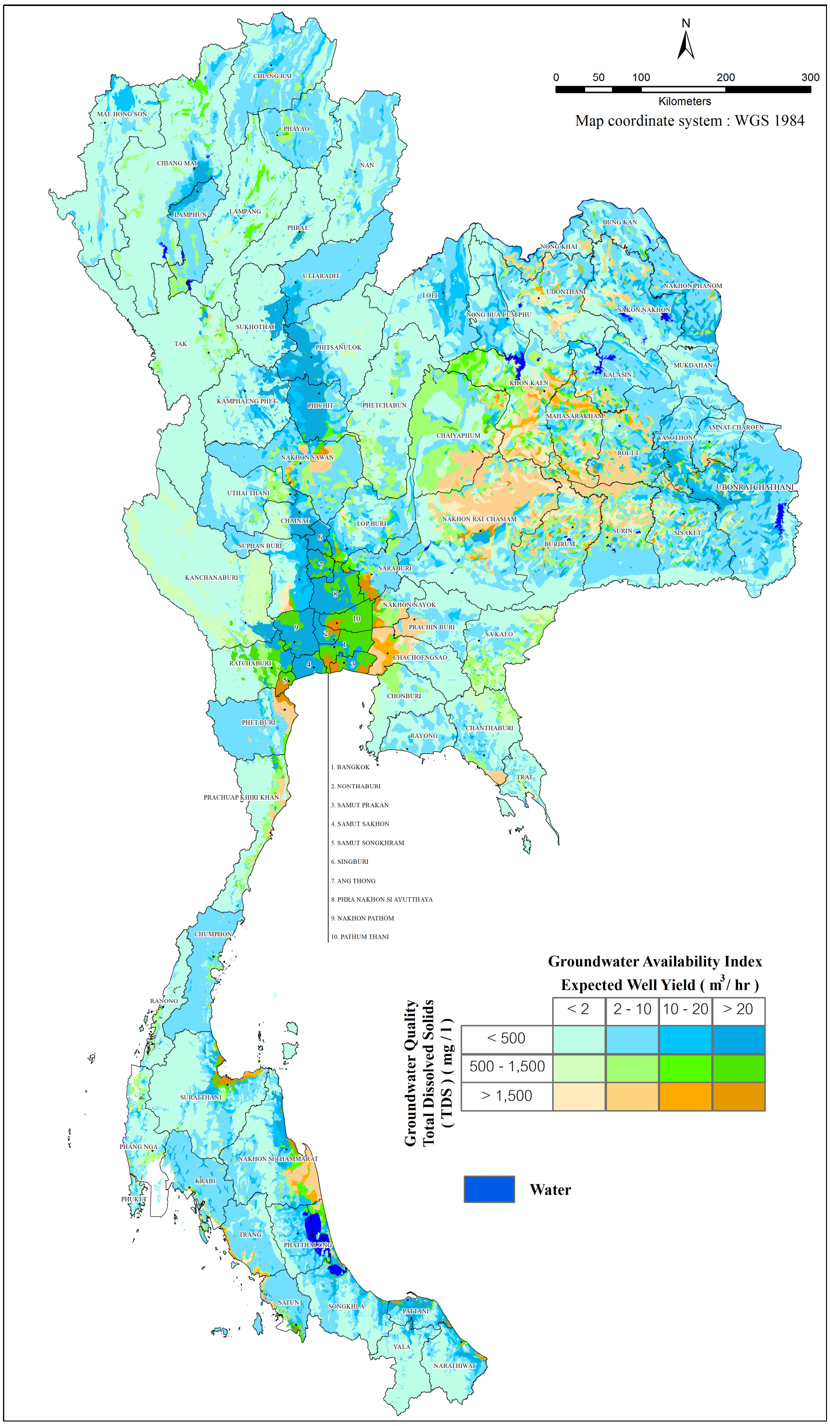

Fig. 1 Groundwater availability map of Thailand

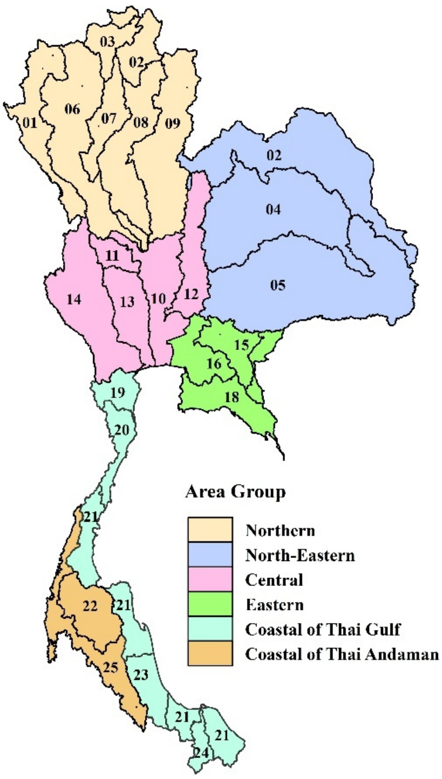

Fig. 2 Classification of climate based on the similarity of river basin data (Chatdarong V *et al*. 2009)

2 Climate change

Global climate change is defined as a climate situation in any area that has changed or differed over the past 30 years (HAII, 2016). The annual climate change of Thailand, which includes the mean temperature, maximum temperature, and minimum temperature, over the last 40 years (from 1971 to 2007) has increased in most areas of Thailand (Chatdarong V, 2009). The trend of climate change was classified by Chatdarong V (2009) into the following 6 groups with respect to the characteristics and similarity of areas: Northern group, Northeastern group, Central group, Eastern group, Coastal Thai Gulf group, and Coastal Andaman Sea group (Fig. 2).

The results show a trend of monthly changes in the characteristics and behaviors of temperature. The temperature tended to increase in every group, although the distribution level was moderate. The trend of monthly temperature increased in winter more than in summer. In the east region, the mean and minimum temperature did not change in either season. In the Eastern group, Coastal Thai Gulf group, and Coastal Andaman Sea group had maximum temperature changes at a moderate level (Chatdarong V, 2009).

The annual rainfall of Thailand over 40 years (from 1971-2007) tended to decrease in all regions. The decreasing rate of rainfall in most parts of Thailand was approximately -0.51 to -8.89 mm per year. Only the Nan River Basin had increasing rainfall of +1.46 mm per year (HAII, 2016). The cumulative rainfall of Thailand tended to decrease by -0.51 mm per year. The rainfall distribution varied independent of the area. In the Northern and Northeastern groups, which included the Mekong and Mun Rivers and the Coastal Thai Gulf group, rainfall tended to increase, whereas in other areas, such as the Thachin River Basin, Tonlesap and East Coast River Basin, it tended to decrease (Chatdarong V, 2009).

A slow and complex process of climate change in Thailand induced by global warming was studied by Chinvano S (2009). In 2009, Manomaiphiboon K *et al.* (2009) applied a regional climate model, RegCM3, to Thailand and its neighboring areas. According to the RCP8.5 scenario, the temperature is predicted to increase by 1.8 °C for the next 4 decades, with an average increase of 0.22 °C every 5 years. According to the

RCP8.5 scenario, the precipitation for the whole country is predicted to increase by approximately 5% within 40 years, with an average increase of 0.7% every 5 years. The model showed that August and September have the highest precipitation each year, whereas the period from December to March has the lowest precipitation. Precipitation levels will steadily increase under the RCP8.5 scenario. Currently, Southern Thailand has the most abundant rainfall compared with other regions (Manomaiphiboon K *et al.* 2009). The other abundant rainfall areas are in the eastern region, western part of the northeastern region and the western region of Thailand. Precipitation levels will slightly change over the periods from 2015 to 2035 and 2055. These changes are predicted to occur in every part of Thailand.

3 Climate changes and groundwater sustainability

3.1 Climate changes and hydrologic variability

Climate change is expected to modify the hydrological cycle and affect freshwater resources. Groundwater is a critical source of fresh drinking water for almost half of the world’s population and it also supplies irrigated agriculture. Groundwater is also important in sustaining streams, lakes, wetlands, and associated ecosystems (Treidel H *et al.* 2011). However, the impacts of climate change on groundwater quantity and quality in Thailand are poorly understood.

At this moment, the groundwater-ecosystem interactions in integrated watershed management plans for the country are not well understood, and the impacts of climate change on these interactions in the future are not clear.

3.2 Impacts of climate change on groundwater

The direct impacts of climate change on natural processes (groundwater recharge, discharge, storage, saltwater intrusion, biogeochemical reactions, chemical fate and transport) may be exacerbated by human activities (indirect impacts, Treidel H *et al.* 2011). Increased groundwater abstraction, for example, may be required in areas with unsustainable or contaminated surface water resources caused by droughts and floods. Groundwater response to global change is a complex function that depends on climate change and variability, topography, aquifer characteristics, vegetation dynamics, and human activities. Several studies have reported that the climate of Thailand will become warmer and wetter in the future. The average temperature of the entire country is projected to increase by 2-3 °C, and the annual rainfall is projected to increase by 25% and up to 50% in certain areas (Chinvanno S, 2009). Future climate changes are expected to alter the hydrological cycle and therefore impact groundwater resources as well. In coastal areas, reductions in the groundwater head caused by lower rainfall will aggravate the impacts of sea level rises. Saline intrusions 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 bacteria, 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. Sea level rise because of climate change may increase seawater inflow into freshwater aquifers (saline water intrusion) in parts of the coastal areas of Thailand.

In 2015 and 2016, the El Nino phenomenon following a lack of rainfall caused the most severe water crisis in two decades throughout the country, especially in the central region. As Thailand entered dry season, water levels in the country’s largest dams, such as the Bhumibol and Sirikit Dams, were at the most critical levels since 1994. The drought hit 22 of 76 provinces, whereas 31 others provinces were at risk. Agriculture was severely affected. Several major reservoirs in the country were below 50 percent of their water capacity. A series of measures were adopted by the Thai government to ensure that the country had enough water resources at least until the rainy season, including a provision for more than 6 000 groundwater wells with approximately 3 400 million baht allocated to drought-hit provinces. Government agencies and private sectors were involved in developing numerous groundwater wells to relieve the drought situation.

3.3 Groundwater monitoring and DGR projects

Groundwater monitoring systems are a component of groundwater management and provide data for identifying vulnerable groundwater resources. These data can then be used to help plan for sustainable groundwater management. Therefore, hundreds of groundwater monitoring systems will be installed and activated to obtain measurements to help monitor the impact of groundwater exploitation and climate change, especially in the central region.

Currently, 864 groundwater monitoring stations and 1 524 monitoring wells are installed in Thailand. The DGR has launched a project supported by the Groundwater Development Fund known as the “Groundwater Impact Assessment in the Critical Area and the Lower Chao Phraya Basin” in 2015 (DGR, 2015). The project started in April 2014 and will end in June 2018. This project aims to improve groundwater activity monitoring, including the groundwater and land subsidence monitoring network. More than 30 exploration boreholes will be drilled at depths of 300-480 m. An additional 64 groundwater monitoring wells with a maximum depth of 700 m will be installed across 8 stations. To obtain accurate measurements of the actual subsidence rates at certain intervals, a leveling network survey and InSAR technology survey will be conducted from 2016-2018. Moreover, the DGR will monitor the impact of changing water pressure on the soil and underground structures using multi-level extensometers and piezometers at 12 stations. The water levels will be measured by manual and automatic recordings, including water sampling for chemical analyses. From 2015-2017, the DGR plans to install automatic water level and water quality recorders to measure the environmental impacts on groundwater resources.

Recently, the DGR has launched another project with support by the Groundwater Development Fund: “The Impact Assessment on shallow groundwater in the Lower Chao Phraya Basin”. More than 100 groundwater monitoring stations with 200 monitoring wells will be installed and a study on the water demand and water usage will be conducted in this area.

The Thailand Research Fund recognized that climate change has an impact on the groundwater resources and saline water and saline soils in the Huai Luang River Basin of Northeast Thailand. A series of measures were adopted by the Thai government to ensure that the country has enough water resources at least until the rainy season, including a provision for more than 6 000 groundwater wells with approximately 3 400 million baht allocated to drought-hit provinces. Government agencies and private sectors were involved in developing numerous groundwater wells to relieve the drought conditions.

Two significant sub-projects have been conducted from 2014 to the present. The research team from Khon Kaen University (supported by the TRF) has focused on climate change impacts on saline water, saline soils and groundwater resources in the Huai Luang River Basin under the following projects: Potential Impact of Climate Change on Salt-Affected Areas in Important Rice Production Areas of Udon Thani Province (2014-2016) and Potential Impact of Climate Change on Groundwater Development Potential and Salt-Affected Areas in Huai Luang River Basin, NE Thailand (2015-2017). From 2015 to 2017, the Department of Groundwater Resources has been collaborating with Khon Kaen University to comprehensively study climate change and groundwater in the Huai Sai Bak Watershed, Khon Kaen Province.

3.4 Impact of climate change on groundwater dependent systems and sectors

Groundwater is important for both economic progress and ecosystem conservation. Climate processes have a complex influence on groundwater flow patterns and flow systems and present a number of direct and indirect effects. To understand the impacts of climate change on ecosystems, we must understand all of the pressures and their potential impacts on the ecosystem or regional groundwater flow systems and the potential feedbacks. The response will be scale dependent, which is a source of uncertainty because these responses are not well understood on smaller scales. Large-scale changes in hydrology are not always observed at the aquifer scale where the local hydrogeology is dominant. For groundwater systems, the natural variability in groundwater quantity and quality will depend on the size of the capture zone and the scale of the groundwater system (Kløve B *et al*. 2014). Groundwater plays an integrated role in sustaining certain types of aquatic, terrestrial and coastal ecosystems and the associated landscapes (humid and arid). A lack of control over groundwater resource development and protection has negative impacts on certain aquatic fauna (Foster S and Kemper K, 2004).

3.4.1 Human communities

Climate change affects people and nature in countless ways, and it often exacerbates threats that have already put pressure on the environment. Climate change does not occur overnight, and scientists first alerted the world to the dangers of climate change over thirty years ago. How much longer are we going to allow climate change to continue? Seeboonruang U (2016) analyzed the impact of climate change on groundwater and vulnerability in the drought-prone areas of eastern Thailand and found that many of the sub-districts are highly vulnerable to climate change and will face drought because of the higher sensitivity of groundwater systems to climate change. A change in rainfall patterns in the Upper Chao Phraya Basin will reduce the mean annual groundwater recharge (storage) by 12.9% (1.46 km^3), 9.7% (1.35 km^3), 13.9% (1.49 km^3), and 10.7% (1.38 km^3, Pratoomchai W *et al*. 2014). Suthidhummajit C and Koontanakulvong S (2011) evaluated the climate change impacts on groundwater at the Wang Bua Irrigation Project in Kampheng Phet Province and found that additional fluctuations in the rainfall patterns, reduced rainfall in the wet season and more rainfall in the dry season will occur. Groundwater level fluctuations are sensitive to the pumping scheme and seasonal factors.

3.4.2 Agriculture and industry

Saraphirom P *et al.* (2013a, b) investigated the potential impacts of climate change on the groundwater of the Huai Kamrian sub-watershed located in Khon Kaen Province, where the hydrogeological, saline soil and saline water conditions have been well defined, and they subsequently modeled the climate changes within the research area. These authors found that climate change at the end of this century will have significant impacts on the distribution of saline soils and water logging will reach values that are approximately 23% higher than the current conditions.

4 Adaptation to climate changes

4.1 Policies and management for the protection of water resources under climate change

According to the master plan of groundwater management and development, the Department of Groundwater Resources (DGR, 2009) developed several strategies, programs and project ideas for the next 20 years as follows.

Strategy No. 1: Accelerate the integrated groundwater resources development and management activities in the country as follows:

1) Study and evaluate the groundwater potential and evaluate groundwater demands;
2) Establish a groundwater resources development program;
3) Establish networks for integrated groundwater resource management;
4) Promote the socioeconomic aspect of groundwater management;
5) Establish units to provide technical and commercial consultations to business sectors;
6) Establish a program to provide technical assistance to neighboring countries.

Strategy No. 2: Revise the department's administrative and organizational structures to be consistent with future proactive groundwater management as follows:

1) Improve the organizational structures and public services;
2) Develop plans for critical situation response;
3) Develop the technical skills and capabilities of groundwater personnel.

Strategy No. 3: Revise and expand scope of the groundwater acts to develop national policies and plans and groundwater-related regulations and develop effective enforcement procedures as follows:

1) Establish a program to revise Groundwater Acts for protection and conservation of groundwater resources;
2) Establish a program to develop mechanisms for Groundwater Acts enforcement.

Strategy No. 4: Strengthen the Department's capabilities in monitoring, conservation, and restoration of groundwater resources as follows:
1) Conserve and establish groundwater monitoring systems;
2) Restore groundwater resources;
3) Establish effective management of the Groundwater Development Foundation.

Strategy No. 5: Improve and revise the hydrogeological database to better manage national groundwater resources and promote the public awareness and understanding of groundwater resources.

The Master Plan also provides guidelines for the development of appropriate action plans commensurate with the groundwater development potential and socioeconomic conditions in Thailand over the next 20 years (2007-2026) and establishment of adaptive capacities for groundwater management.

The Thailand Ministry of Natural Resources and Environment and the Ministry of Science and Technology should emphasize adaptation methods according to the impacts of climate change (HAII, 2016). Integrated Water Resources Management (IWRM) for sustainable water management should be applied for surface water and groundwater basins and trans-boundary water management (surface and trans-boundary aquifers). ASEAN members must organize a convention to decide upon international regulations on trans-boundary aquifers. Furthermore, a national development plan should add climate change as one of considerations at both the provincial and local level.

4.2 Technical measures to protect water resources under climate change

Several major programs have been implemented to ensure the future balance of groundwater resources and groundwater storage for agriculture. From 2009-2011, the DGR and Khon Kaen University formulated a research project for Managed Aquifer Recharge by establishing a Pilot Study and Experiment on Managed Aquifer Recharge Using a Ponding System in the Lower North Region River Basin in Phitsanulok, Sukhothai, and Pichit Provinces to test the feasibility of using artificial groundwater recharge to reverse the declining trend. The project duration was between April 2009 and April 2011 and the objectives were to 1) study and investigate artificial groundwater recharge using a recharge pond system or other artificial recharge methods; 2) study the physical processes, hydraulic characteristics, and chemical processes associated with artificial recharge; 3) provide guidelines for integrated mitigation measures for drought and flood hazards; 4) apply the research results to provide guidelines for the project operation; and 5) generate a body of knowledge and provide for technology transfer (DGR, 2011; Srisuk K *et al.* 2012; Srisuk K *et al.* 2014; Uppasit S *et al.* 2012; Nadee S *et al.* 2010). The results of the study showed that the large shallow aquifers in the Lower North Region River Basin consist of layers of sands and gravel from the Yom and Nan rivers. Farmers extract shallow groundwater from shallow aquifers that range 10-15 m in depths for rice production of approximately 7 500 MCM per year, which generates incomes of approximately 25 000 million baht per year. Over the last decade, groundwater levels have been continuously declining at the rates of approximately 10-25 cm/yr, which has resulted in approximately 10 560 km^2 (6.6 million rais) of critical groundwater areas with groundwater levels deeper than 8 m from the surface. If groundwater pumping continues at the same rate without the introduction of mitigation measures, then the critical groundwater areas will increase by approximately 160 km^2 (100 000 rais) and the groundwater levels will be 1.0-2.5 m deeper than the initial levels within the next 10 years. In addition, the Department of Groundwater Resources should increase the awareness and establish knowledge and values for groundwater resources and artificial groundwater recharge along with the development of groundwater recharge master plans as part of the national water resources management program.

5 Challenges and problems

The groundwater research challenges include a lack of knowledge of groundwater recharge mechanisms that are directly related and sensitive to climate variations over short and long-term periods under climate change. Therefore, groundwater-dependent ecological systems in important watersheds should be a focus of research. Moreover, the impact of climate change on groundwater exploitation will involve various communities. As mentioned by the Hydro and Agro Informatics Institute: "Climate change studies currently focus on the scientific approach and do not consider the social dimension. It is time to change. The social dimension must be included to find the best and most suitable answers to safeguard human beings" (HAII, 2016). Collaborations among ASEAN countries and the sharing of information, knowledge, and experiences are inevitable. Furthermore, highly regarded international organizations are the main drivers for promoting the awareness of climate change issues in developing countries, and they include the Mekong River Commission (MRC) and the United Nations Educational, Scientific, and Cultural Organization (UNESCO).

6 Conclusions

Exploiting the scale difference between climate and groundwater models is a crucial strategy for analyzing the data uncertainty. For example, groundwater research usually focuses on local and small scales while climate change research focuses on global, regional, and national levels. Previous groundwater modeling studies should be re-simulated to assess climate change impacts. Therefore, long-term observations and monitoring data are necessary to increase the accuracy of predictions. HAII (2016) stated that "Climate change adaptations should be initiated from the grassroots society. The Department of Local Administration in Thailand should have measurements or regulations to support community adaptations. Furthermore, climate change knowledge should be disseminated to each sector".

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