Chapter 2
Groundwater as a Key of Adaptation to Climate Change

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Abstract Sustainable groundwater use is discussed in terms of the balance between risks and services, including adaptation to climate change. Groundwater, with its longer residence time of water circulation, can be an alternative water resource and environment under climate change. Assessments of groundwater services and benefit as well as risk are important for sustainable groundwater use under climate change conditions. Groundwater, which is one of the keys of adaptation to climate change, should be treated as a common resource and environment beyond the tragedy of the commons and the dilemma of boundaries.

Keywords Climate change • Commons • Public and private waters • Resource and circulation • Risk and service • Sustainable groundwater use

2.1 Introduction

Global environmental problems are the consequence of the quandary of striking a balance between humans and nature amidst dynamic natural and societal change so as to build a more functional society. In the case of water problems, it may also be said that the negative aspects of floods and disasters also rest upon balancing them against the benefits and services derived from water resources and water circulation.

Figure 2.1 shows the relationships of various components within three models related to global environmental problems (Moss et al. 2010). Atmospheric, oceanic, snow–ice, and continental carbon circulation are the subjects of the climate model, and energy, economics, health, agriculture, and forestry are central to the integrated model. Rise in sea level, the ecosystem, human dwellings, infrastructure, and other aspects are focused upon in the influence–fragility and risk assessment model.

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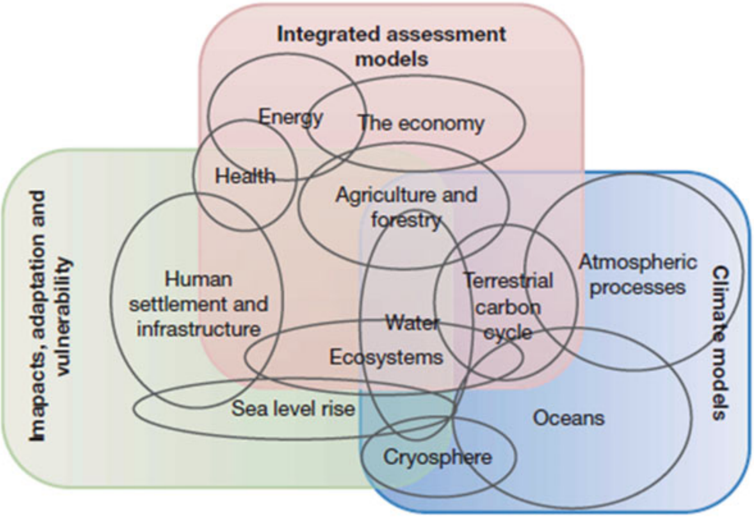

Fig. 2.1 Framework of the models on global environmental problems (Moss et al. 2010)

"Water" is central in all three models: thus, when global environmental problems are broadly separated into the three categories of tangible things, society, and living beings (including humans), the "problem of water" is central to all their relationships.

Among them, the water problems considered up to this point, namely, there being either "too much water" or "too little water," were based on the unbalanced distribution of people and water. However, water problems are not limited to these concerns and are problems spanning space and time. Figure 2.2 depicts the spatial positional relationships (from close to distant) of people and water on the horizontal axis and the circulation time/movement speed of water (from fast to slow) on the vertical axis. From early times in the past, fast-flowing water that was nearby, such as rainwater and river water, and that from ponds and shallow groundwater was used; however, the increase in demand for water together with the need for supplemental water resources at a distance led to the building of dams and waterworks facilities and the transport of water from these structures. Moreover, recently "far-away water" that crosses national borders and watershed areas has come into use, as can be seen from the use of bottled water. Meanwhile, slower groundwater from greater depths is currently being used even when the same water sources are nearby. The virtual water in imports of agricultural and livestock products derived from the use of deep aquifers such as America's Ogallala (High Plains) Aquifer and groundwater under the North China Plain illustrates the current situation wherein water that is even slower and more distant is being used. "Far water" presents the problem of difficulties in administration that extends beyond human awareness, and "slower water" is problematic because of the time needed for it to recover. Both these are problems that creep up unawares and will have a great influence on the future.

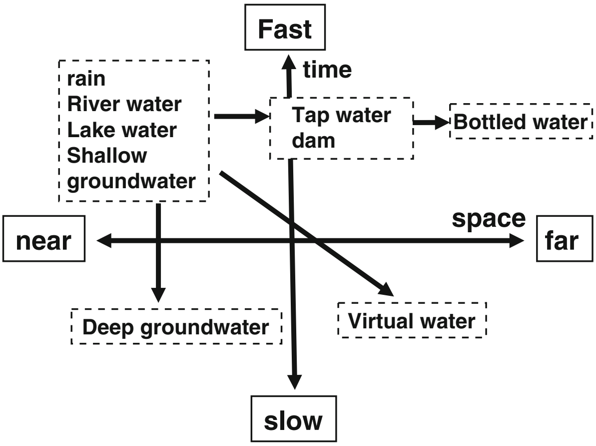

Fig. 2.2 Water uses in time and space

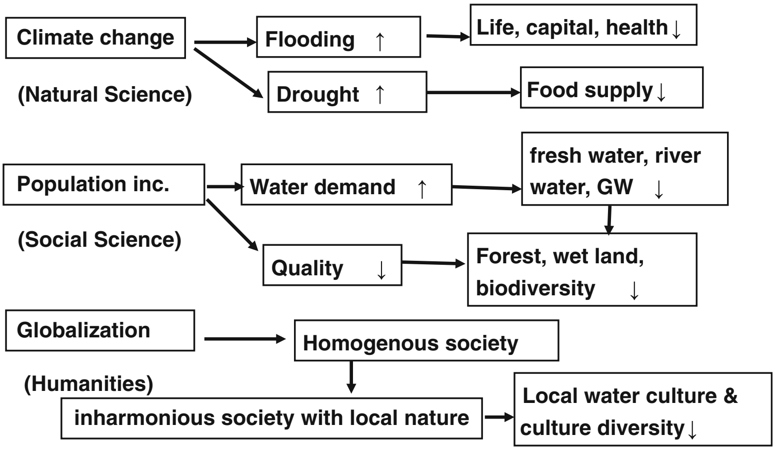

Fig. 2.3 Causes of water problems. *GW*, groundwater

Three factors involved in creating the water problem that is central within the global environmental problem can be posited in a broad sense (Fig. 2.3). One of these is the natural science factor of climate change. Climate change, which includes global warming, changes the patterns of rainfall and greatly increases the risks of floods as well as the frequency and severity of droughts. The former is linked to loss of life, health, and property whereas the latter is a serious global environmental problem that puts pressure on the supply and demand for food. The second is the societal factor of the increase and concentration of the human population. The escalation in the withdrawal of water resources stemming from increased water demand causes a reduction in stored groundwater and the blockage of rivers as well as a reduction of freshwater areas, which in turn results in worsening of the environments of forests, farmlands, marshes, and coastal water areas coupled with declining biodiversity. In addition, the excessive material load created by increased human activities invites the worsening of water quality and diminishes the qualitative factor in each of the freshwater resources just mentioned. The third factor is the globalization of society, which is a human cause. It has been pointed out that the uniform concept of values spreading across the globe forms societies that are not in harmony with a particular region, which may lead to the loss of the region's water culture and its cultural diversity. The current state of affairs views these three factors respectively as interrelating with each other to cause various global environmental problems.

2.2 Difference Between Groundwater and Surface Water in Relationship to Adaptation to Climate Change

When comparing surface water and groundwater in terms of water resources used by humans, their greatest hydrological differences lie in their residence times and replacement times. Table 2.1 shows the respective storage volumes, transport volumes (flux), and residence times within global water circulation. The residence (or replacement) time can be derived from the storage volume and flux (groundwater recharge rate); however, the differences between arid and humid regions as well as disparities in residence times arising from depth in the case of groundwater or other factors will create great differences among each factor (Table 2.2).

Looking at the amount available from the standpoint of storage volume, it appears that groundwater provides the largest source of usable freshwater resources; however, when considering it from the aspect of usage or flow in terms of flux, it becomes evident that the amount of river water overwhelmingly exceeds that of groundwater. About 435 mm of the 670 mm of rain that annually falls on land evaporates and the remaining 235 mm runs off as surface water. This 235 mm becomes a part of rivers and underground water and flows into the sea. The worldwide average groundwater recharge volume has been estimated to be 137 mm/year (Fig. 2.4; Doll et al. 2002). In the case of Japan, about 600–700 mm of an annual precipitation volume of 1,400 mm, is returned to the atmosphere through evapotranspiration and about 300 mm of the remaining 700–800 mm goes to groundwater recharge (Yamamoto 1983). The value

Table 2.1 Residence time of various waters

Seawater	2,500 years
Snow and ice	1,600–9,700 years
Permaforest	10,000 years
Groundwater	900–1,400 years
Soil water	1 year
Lake water	17 years
Wetland	5 years
River water	17 days
Vapor	8 days

Table 2.2 Causality of groundwater problem; D: Driving force, P: Pressure, S: State, I: Impact

D	P	S	I
Population increase	Increase in water demand	Increase in groundwater pumping	Decrease in groundwater storage
Climate change	Change in precipitation pattern	Decrease in groundwater recharge	
Urbanization	Land cover change		
Population increase in coastal zone	Increase in water demand	Saltwater intrusion	Groundwater salinization
Global warming	Sea level rise	Saltwater intrusion	
Increase in population	Increase in material loads	Improper water management	Groundwater contamination
Urbanization	Heat island	Subsurface warming	Effects on ecosystem?
Globalization	Capitalism	Water transfer with more energy consumption	Unsustainable groundwater uses

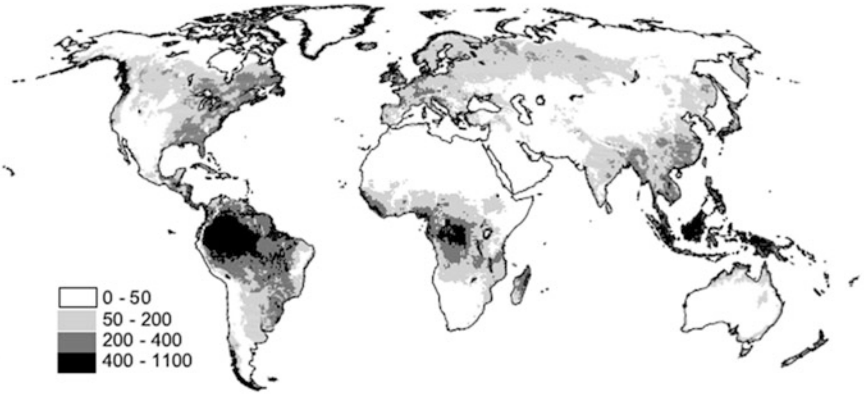

Fig. 2.4 Estimated groundwater recharge rate (mm/year) (Doll et al. 2002)

of the groundwater recharge rate (R) in relationship to the evapotranspiration (E) subtracted from the precipitation (P) indicates that $R/(P-E)$ in Japan has a smaller value than the worldwide average.

It has been pointed out that the change in precipitation patterns accompanying climate change bears the possibility of reducing groundwater recharge rates through an increase in surface runoff volume. In contrast, it has also been noted that there are examples where climate changes such as global warming have been related to the change in water resources.

Figure 2.5 shows the interannual changes in the number of days of precipitation for Taiwan (Taniguchi 2011). There has been little change in annual precipitation volumes for the past 100 years; however, a reduction in the days of precipitation throughout Taiwan is evident. It can be said that the rainfall patterns

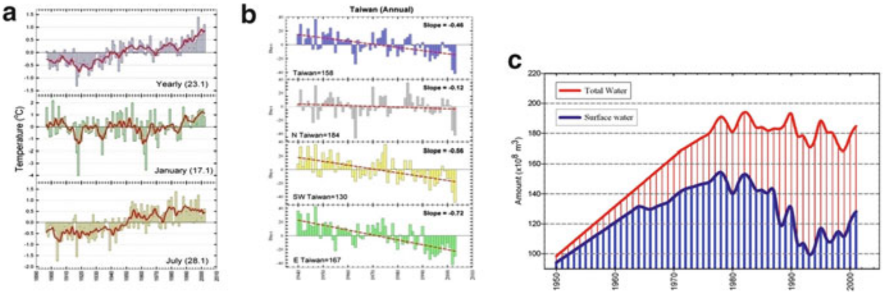

Fig. 2.5 Changes in water resources in Taiwan. (**a**) Increase in air temperature caused by global warming. (**b**) Decrease in precipitation date. (**c**) Change of water resources from surface water to groundwater

are drawing closer to those of a tropical rainfall pattern, with greater differences in the days with no rainfall and those with heavy rainfall. The reliability of water usage wherein surface water is stored in dams for use has been slightly shaken in conjunction with this, and there are indications of a trend toward the use of groundwater.

The case of Taiwan is an example of the water resource being switched as a consequence of climate change; however, the differences of residence time between groundwater and surface water were strongly related in this instance. Greater changes in the precipitation that makes up the base flow of the river water flow also mean that there will be larger changes in the short retention times for surface water. The magnitude of these changes in precipitation volume makes water administration even more difficult and increases the role of the relatively long groundwater retention time in its capacity as a natural low-pass filter.

2.3 Groundwater as a Natural Resource

When groundwater is viewed as a natural resource, the problem of where water is stored (retained) and who owns it becomes very important. Figure 2.6 shows a structural outline of the water problem in Saijo City in Ehime Prefecture. The problem is that surplus water from a dam constructed for the specific purpose of water for industrial use is planned to be transported (but this is not yet implemented) beyond the boundaries of the watershed. The Kamo River flowing through Saijo City becomes a raised riverbed and its river water recharges the groundwater. In Saijo, the groundwater derived from water recharged by the Kamo River creates an artesian well, the so-called “Uchinuki.” These “Uchinuki” wells have been used since ancient times. Although the waterworks facilities is considerably less than the national average, it may be said that this has been caused by the use of groundwater

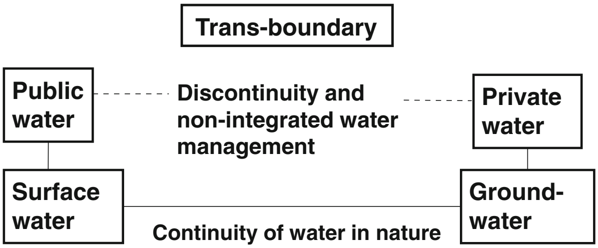

Fig. 2.6 Driving force, pressure, state, and impacts on groundwater problems

at every home. It is clear that a change in river discharge from the dam into the Kamo River would not only result in changes to the recharge volume for the groundwater, but that the change in groundwater flow volume on the coast would also alter the location the saltwater boundary, leading to saltwater intrusion. Two problems are involved: whether to use the water as surface water or as groundwater and the transboundary water predicament. The former problem includes the incommensurate dilemma wherein, under the Japanese system of water administration, surface water is handled as "public water," which means it is managed by public government, etc., whereas groundwater is associated with the property and considered to be "private water." This is a problem stemming from the scientifically contiguity of surface water and groundwater and its disconnectedness under the social system.

On the one hand, in the latter transboundary water problem, there is the public and private water issue, that is, who owns the water and how to overcome Hardin's "Tragedy of the Commons" (Hardin 1968), all concluding in the dilemma of how to administer groundwater as a moving common resource, capital, and asset.

Furthermore, the transboundary water problem leads to the "Dilemma of the Boundaries" when it is generalized (Taniguchi and Shiraiwa 2012). Borders such as national borders and regional administrative boundaries are necessary bounds for administration as they serve as the primary units of governments/administrations and their existence ensures cultural unity and clear administration. On the other hand, clear boundaries also mean that contiguous natural phenomena become disjointed for administration, leading to various inconveniences. As examples, a regional water administration system that differs with the watershed, which is a hydrological unit, the discontinuity of a system for continents and oceans, and differences in administrative water systems (the public water–private water problem) for the aboveground (surface water) and underground (groundwater), all indicate the various problem points inherent in boundaries. Although the importance of various sectors and the cooperation and coordination between interested parties has been pointed out in integrated water administration, an effective method for the rectification of differences in boundaries has yet to be found.

2.4 Services and Benefits of Circulating Groundwater

The groundwater in arid and semiarid regions may be somewhat considered only as a "resource" in its value and assessment; however, in humid regions, "circulation," which is another important aspect of groundwater, also comes into focus in value and assessment. In particular, it is necessary to weigh the risk assessments for floods, droughts, and other disasters with regard to the service provided by "circulation" and to evaluate them equally.

The millennium assessment for ecosystem services (Millennium Ecosystem Assessment 2005) shows the 16 services forming the basic services span a wide range and that it would be difficult to assess each individually in most cases. These services can be separated as "water" and classifying the services into those that do not mediate living organisms, or in other words, as things in an "environment system service"; and "ecosystem service," which mediates living organisms to a limited extent; and a "human service" in which humans are involved through city functions and so on. The "river maintenance water" used in the case of river water is close to the concept of environmental flow; however, its usage is diverse and dependent on which sections are to be included in the service. In the case of groundwater, the maintenance of the ecosystem at the stage where it reaches the surface as a spring, in river water, and in the riparian zone border (wetland) has drawn much attention.

The service of groundwater toward human society in its interim stage as it flows by is mainly as a water resource service; however, a part of it bears limited groundwater service assessment in its storage function use with the cool temperature of water in wells and in its emergency use for disaster control.

An example of the ecosystem service provided by groundwater discharged in coastal regions may be seen in habitats such as those of the *Crassostrea nippona* oyster in the shoreline area of the Chokai Mountain foothills. In Yuza Town at the Chokai Mountain foothills near the border between Akita and Yamagata Prefectures, *C. nippona* oysters, which live in a brackish water environment, can be found even in bays without river outflow, indicating the relationship between groundwater flow and the oysters (Fig. 2.7). The relationship can be seen in the annual precipitation in the watershed water balance and in the annual production of *C. nippona* oysters, which asserts the importance of groundwater as the freshwater component in the composition of the brackish water. In addition, isotope ratios analogous to those in the groundwater composition have been verified in the strontium isotope ratios that make up the *C. nippona* oyster shells, thereby providing evidence indicative of the involvement of the groundwater in the oyster habitat. This observation indicates that it is not only rivers which connect the land and the sea but that groundwater also exists as a mediator. In precipitous terrain such as that in Japan, it can be said that the volcanic geologic conditions with their good water permeability and the hydrometeorological conditions of plentiful precipitation maintain the shoreline habitat in relationship to the land and ocean via groundwater.

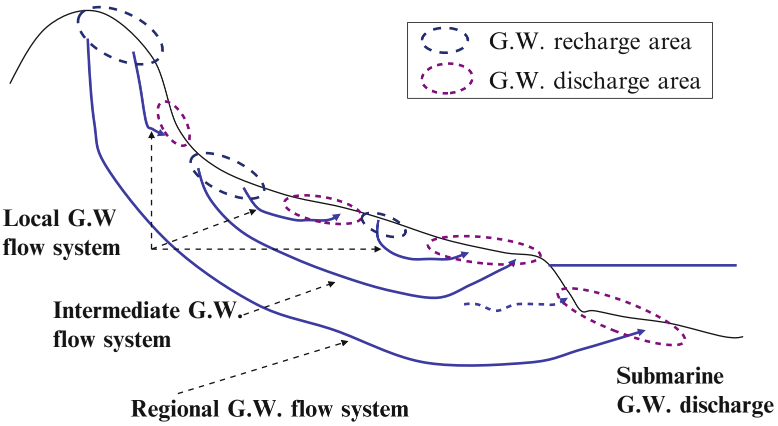

Fig. 2.7 Groundwater flow systems in humid regions

In this way, the assessment of the services provided by groundwater in maintaining the coastal habitat and other services, and the "service assessment" as an antithesis of "risk assessment" for disasters and such as they relate to groundwater, will continue to be important into the future.

2.5 Groundwater in Humid Regions

In humid regions such as Japan, the evaluation of not only the role played by groundwater as a "resource" but its assessment from the aspect of "circulation" and the "services" it provides is an important point. The key is to understand the intrinsic "volume permitted by nature (natural resource capacity)" in terms of the groundwater storage and recharge rates for groundwater while attempting to increase the capabilities of each respective regional society to their maximum using the latest technology, traditional wisdom, and the knowledge of international society such as late-comer's benefit.

Groundwater has the salient feature of having a longer residence time compared to surface water, so it functions as a "key" with respect to climate change and a changing society. Groundwater must be grasped in terms of its diverse problems with admissibility, adaptation, capability, and capacity, and proposals for a consortium to increase governance capabilities through legal systems and regulations and such have begun to be put forth (Taniguchi 2011). It will be a structure for discussions by the differing "sectors and stakeholders" who face common similar problems and share knowledge about them on the differences in policies stemming from the differences in the "volume permitted by nature" and the "latecomer's benefits" that differ in each of their countries, regions, and cities. On that occasion three types of components will need to be in place: (1) monitoring/assessment method, (2) modeling/visualization, and (3) policy planning, and it will be important that all these aspects be linked organically.

The subterranean environmental problems that recur in Asian cities are caused by a lack of understanding of the tolerances of the region and by exceeding them. An assessment method for the "volume permitted by nature" (capacity) of the underground environment for groundwater retention volume/groundwater recharge volume, etc., is close to being established. Meanwhile, consortiums and such should be used for education on the "latecomer's benefits," which are a part of the knowledge of international society, and on regional traditional wisdom as they relate to the capabilities of people and society.

Changes in water, materials, and the heat environment in the underground caused by human activities extends from depths ranging from a hundred to several hundreds of meters, and it is clear that groundwater circulation speed has increased more than tenfold in the past 100 years (Taniguchi 2011). In addition, it is also evident that the subterranean heat storage resulting from the heat island phenomenon accompanying urbanization has reached between twofold and sixfold that of the underground heat storage caused by worldwide global warming. Because direct use of the underground environment and human activities above ground influence the underground in this manner, it remains to be seen how far the underground environment can be used as an alternative environment for the surface. With regard to water volume, through the experience of the "Tragedy of the Commons" known as land subsidence, and at the current point of having acquired assessment methods and the limit of the volume permitted by nature, it is possible to have sustained usage through administration that extends beyond "borders." Meanwhile, it is possible to control the "load" with regard to water quality and heat; however, the monitoring of "accumulation" will probably be necessary in the future.

2.6 Conclusion

Under the conditions of increasing population numbers and concentration, as well as globalization, the question becomes one of how to manage the underground environment so as not to damage the future use of the underground environment. It is clear that integrated management is needed to straddle two boundaries: that between the surface and underground, and that between the land and ocean. So long as water continues to circulate in nature, water that has been compartmentalized for societal systems, purposes, and objectives needs to be administered in an integrated and multitiered manner. Another point is the importance of joint management of the underground environment, including switching groundwater from private to public ownership. When undertaken, the perspectives of the "benefits" gained in relationship to those "paid out" will be vital. Last, it is necessary to configure suitable policies that match the capacity/capability of the region and the developmental stage of a city. In humid regions such as Japan in particular, groundwater administration that incorporates not only the concept of it as a "resource" but that of its "circulation" as well, which takes full advantage of the features of groundwater that alleviate change, is necessary.

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