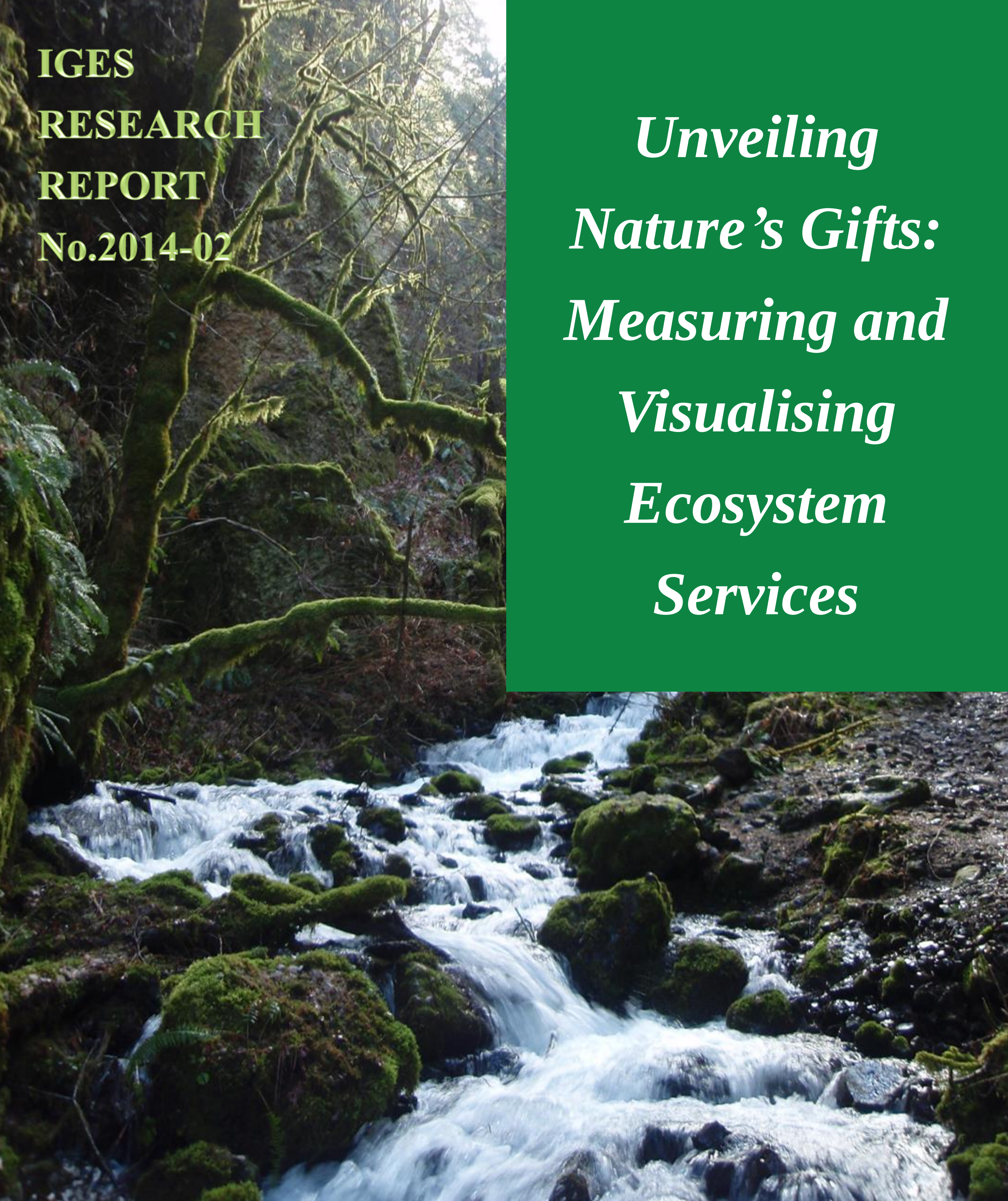
IGES RESEARCH REPORT No.2014-02

Unveiling Nature's Gifts: Measuring and Visualising Ecosystem Services



Institute for Global Environmental Strategies

July, 2014

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The Institute for Global Environmental Strategies (IGES) is an international research institute conducting practical and innovative research for realising sustainable development in the Asia-Pacific region.

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This research report is based on our trial study on quantification of ecosystem services, which was commissioned by the Ministry of Environment Japan (MOEJ) under the title of “Research on the Quantification of Ecosystem Services.”

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List of Acronyms and Abbreviations

CBD-COP	Conference of the Parties to the Convention on Biological Diversity
IPBES	The Intergovernmental science-policy Platform on Biodiversity and Ecosystem Services
GIS	Geographical Information System
MLIT	Ministry of Land, Infrastructure, Transport and Tourism
MODIS	Moderate Resolution Imaging Spectroradiometer
NLNI	National Land Numerical Information
SEEA	United Nations Satellite System for Integrated Environmental and Economic Accounting
TEEB	The Economics of Ecosystems and Biodiversity

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We sincerely acknowledge two governmental officers and review committee members who enthusiastically supported us and provided valuable comments and advice on our research and analysis. Also, we would like to express our special gratitude to two experts in the Idea Co. Ltd. who substantially contributed to these quantification exercises. Lastly, we thank Prof. Hidefumi Imura, Dr. Mark Elder, Dr. Zhou Xin, Dr. Henry Scheyvens, Dr. Federico Lopez-Casero and Dr. Prabhakar Sivapuram for their review and advice.

Summary

Since the 2000s, an increasing number of initiatives have been undertaken in the attempt to measure the physical quantities or the monetary values of ecosystem services. However, concrete methodologies for the quantification of ecosystem services are still to be developed; even the governmental, corporate and academic initiatives for the development of assessment frameworks on ecosystem services have their limitations.

Following this trend, and in recognition of the need for Japan to actively participate in the assessment of ecosystem services and to contribute useful information to the international discussions on these assessment frameworks, this study has been conducted to implement a trial on the quantification of ecosystem services in Japan. Its aim was to serve as a pilot study to deepen understanding on the pros and cons, as well as the challenges in quantifying ecosystem services.

In developing a framework for the quantitative assessment of ecosystem services under the current study, the various services have been organised into broad categories based on existing research and international discussions. A wide range of ecosystem services has been targeted under provisioning, regulating and supporting services, within diverse ecosystem types including forest, agricultural land, urban area, freshwater and coastal ecosystems.

The table below summarises the evaluated ecosystem services by each ecosystem type, respective indicators to be quantified, and the quantification results in Chiba prefecture, which provide the overview of this study and a sense of the scale of each ecosystem service. As this quantification exercise was at the trial stage, a review of the results through verification of the parameters or comparison with other studies will be an essential next step to improve the credibility of the quantification results.

For more comprehensive, reliable and meaningful measurement of ecosystem services, further technological improvement, especially refine of methodologies, expansion of the scope and development of scenarios, will be required. These can be exemplified with the consideration of trade-offs (e.g. provisioning versus regulating) and synergies (e.g. water regulation and flood control) between ecosystem services, the evaluation of biological resources and biological control as well as cultural services, and the development of future land scenarios affecting the level of ecosystem services provision.

Summary of the quantification results (compilation of Table 2-5, 3-8, 4-14)

Ecosystem services			Forest	Agricultural land	Urban area	Freshwater	Coastal zone
Supporting	Biodiversity and habitats	Habitat and nursery provision (ha)	Total surface area 187×10^3	Total surface area 181×10^3	Total surface area 135×10^3	Total surface area 13×10^3	Total surface area 2.7×10^3
Supporting	Biodiversity and habitats	Maintenance of species and genes (species)	Endangered plant species 57	Endangered plant species 18		Endangered plant species 74 Endangered freshwater fish species 20	Endangered plant species 9 Endangered marine fish species 13s
Provisioning	Food (t/year)		Chestnut production capacity 71×10^3 Bamboo shoots production capacity 3.5×10^3	Rice production capacity 577×10^3 Soy bean production capacity 59×10^3 Asian pear production capacity 104×10^3		Fisheries capacity in lakes/ponds 80	Rockfish catch capacity >0 Flatfish catch capacity >0
Provisioning	Freshwater (m^3)					Tap-water provision from natural streams 6.1×10^6 Irrigation water from natural streams 878×10^6	
Provisioning	Materials (forest: m^3/year) (agriculture: t/year)		Wood production capacity 82×10^3	Fodder production capacity 1.9×10^6		Reed production capacity (DD*)	

Note: Grey colour indicates exclusion from the analysis in light of respective natural functions
*: DD denotes data deficient.

Ecosystem services			Forest	Agricultural land	Urban area	Freshwater	Coastal zone
Regulating	Climate regulation	GHGs sequestration ($t\text{-}CO_2$/year)	CO_2 sequestration capacity 558×10^3		CO_2 sequestration capacity 113×10^3	CO_2 sequestration capacity 2.9×10^3	CO_2 sequestration capacity 1.5×10^3
		Heat latent effect (m^3/year)	Evapotrans-piration 1.1×10^9	Evapotrans-piration 802×10^6	Evapotrans-piration 589×10^6	Evapotrans-piration 72×10^6	Evapotrans-piration 18×10^6
	Air quality control (t/year)		SO_2 absorption capacity 25 NO_2 absorption capacity 708	SO_2 absorption capacity 235 NO_2 absorption capacity 707	SO_2 absorption capacity 193 NO_2 absorption capacity 672	SO_2 absorption capacity 3.0 NO_2 absorption capacity 7.0	
	Water regulation	Water flow regulation (m^3/year)	Groundwater recharge 594×10^6	Groundwater recharge 1.0×10^9	Groundwater recharge 583×10^6	Groundwater recharge 65×10^6	
		Water purification (t/year)	Nitrogen removal 5.0×10^3 Phosphorus removal 75	Nitrogen removal by paddy fields 10×10^3	Nitrogen removal 1.5×10^3 Phosphorus removal 22	Nitrogen removal by reed bed 82 Phosphorus removal by reed bed 74	Nitrogen removal by seagrass bed and tidal marsh 1.2×10^3 Phosphorus removal by seagrass bed and tidal marsh 513
	Soil conservation	Soil erosion prevention (t/year)	Soil runoff mitigation 2.4×10^6	Soil runoff mitigation 328×10^3			
		Soil fertility maintenance (t/year)	Nitrogen retention 222 Phosphorus retention 2.5×10^3	Nitrogen retention 37 Phosphorus retention 239			
	Natural hazard mitigation	Flood control	Peak runoff mitigation (calculation of total amount irrelevant to analysis)				
		Landslide mitigation	Increase in safety factor (idem)				
		Wave mitigation	Wave speed reduction (idem)				

Note: Grey colour indicates exclusion from the analysis in the light of respective natural functions

1. Introduction

1.1. Background

The trends in the state of ecosystem services were assessed qualitatively in the Millennium Ecosystem Assessment (MA 2005), demonstrating that 60% of them have been degraded over the last decades. Faced with this urgency, the Tenth Meeting of the Conference of the Parties to the Convention on Biological Diversity (CBD-COP10), held in October 2010 in Japan served as a pivotal event in the development of international discussions on ecosystem services. At COP10, The Economics of Ecosystems and Biodiversity (TEEB) launched a report on its global study on the economic value of ecosystem services, and highlighted the economic losses that would be incurred from their degradation. In line with this approach, many supporting studies have since been produced, with increasing global attention on the monetary valuation of ecosystem services.

At COP10, alongside developments on the economic valuation of ecosystem services, there have been other developments pushing for a wider consideration of ecosystem services. The World Bank launched its project on Wealth Accounting and Valuation of Ecosystem Services (WAVES) for the integration of ecosystem services into National Accounts frameworks for improved decision-making based on the values of biodiversity. It aims to support the development of environmental accounts in 6~10 countries by 2015, and to adopt an international guideline on ecosystem accounting (World Bank, 2013). Furthermore, at the Rio+20 held in June 2012, the World Bank launched the 50/50 Campaign for the integration of natural capital accounting into corporate and national accounts worldwide.

Other international processes relevant to the quantification of ecosystem services include the United Nations Satellite System for Integrated Environmental and Economic Accounting (SEEA), which in 2013 adopted the framework for experimental ecosystem accounts (SEEA-EA) as an international guideline. In parallel to the SEEA-EA development, the European Environmental Agency (EEA) has been developing the Simplified Ecosystem Capital Accounts (SECA), and aims to integrate past efforts on the accounting of environmental conservation and management expenditures, physical flow accounts, and industrial input/output analyses, based on the collection of comparable data from across the region (EEA, 2011). Also in line with the SEEA-EA, at the national scale, the United Kingdom has committed to integrating natural capital accounts into its environmental accounts by 2020. Elsewhere, the State of Victoria in Australia has been developing its data infrastructure on ecosystem status, associated geographical information, models on ecosystem change, and on the influence of management on ecosystem service flows, contributing significantly to the SEEA-EA development process (Eigenraam et al., 2013).

In the private sector, the World Business Council for Sustainable Development (WBCSD) has advanced corporate recognition on ecosystems services through the development of the Corporate Ecosystem Services Review (ESR)[1], and the Guide to Corporate Ecosystem Valuation[2]. At the individual company level, Trucost was established in 2000 as a consulting firm on the evaluation of corporate reliance on natural capital and on the management of associated environmental risks, contributing to the development of reporting guidelines[3] and company rankings (Trucost and TEEB for Business Coalition, 2013). Pricewaterhouse Coopers (PwC) has also been developing a tool called Escher (Efficient Supply Chain Emissions Reporting) for the quantitative assessment of company impacts and risk management along its supply chain[4] with a focus on water resource depletion, land use change, and greenhouse gas emissions.

Among the many initiatives led by academia and NGOs, the Natural Capital Project by Stanford University, The Nature Conservancy, WWF and Minnesota University[5], has developed a spatial analysis tool called InVEST (Integrated Valuation of Environmental Services and Tradeoffs), allowing the analysis of trade-offs between ecosystem services and future land use changes by integrating their demand and supply. Another initiative is Co$ting Nature, a web-based assessment tool launched in 2009 by King's College London, AmbioTEK and the UNEP World Conservation Monitoring Centre (WCMC)[6] for appropriate conservation planning.

1.2. Rationale of the Study[7]

This pilot study aims to conduct a trial on the quantification of ecosystem services in Chiba prefecture, Japan. It seeks to address the gaps in the development of methodologies for the assessment of ecosystem services, in response to the shortcomings of the existing economic valuation approach, as well as the currently limited approaches for the quantitative measurement of ecosystem services (some of which are explained below). The study is a first step in exploring a more comprehensive means for measuring the benefits received from nature, which should be the basis for their sustainable management.

Monetary valuation of ecosystem services is expected to be of particular use when the gains and losses of different ecosystem services need to be compared or aggregated with the same unit.

1 WRI website "The Corporate Ecosystem Services Review" http://www.wri.org/publication/corporate-ecosystem-services-review
2 WBCSD website "CEV, Road testers" http://www.wbcsd.org/work-program/ecosystems/cev/roadtesters.aspx
3 Trucost website "Our History" http://www.trucost.com/our-history
4 PwC website "supply-chain environmental risk and opportunity assessment service" http://www.pwc.com/jp/ja/japan-service/sustainability/supply-chain-risk-opportunity.jhtml
5 Natural Capital Project website "About The Natural Capital Project" http://www.naturalcapitalproject.org/about.html#mission
6 Policy Support Systems website "Co$ting Nature" http://www.policysupport.org/costingnature
7 This section is added by the authors to better explain the importance of quantifying ecosystem services, hence it does not reflect the views and opinions of MOEJ.

Demonstrating the value of ecosystem services in monetary units can also be a useful indicator to promote decision-making among various stakeholders who each have their own economic interest. Monetary information is also essential when policy makers attempt to develop new taxation or subsidisation schemes in relation to ecosystem conservation.

However, when considering existing assessment methodologies, an important step is often missed out between the qualitative assessment and the economic valuation of ecosystem services, which is the quantitative measurement of ecosystem services in biophysical units. This is particularly important, as monetary valuation can have some intrinsic shortcomings, such as the following:

- Many of the valuation methodologies face credibility issues, for instance, the replacement cost approach may result in an overestimation of ecosystem service values depending on the alternative goods selected for the calculation and the related assumptions. The contingent valuation method may show inaccurate willingness to pay if there are considerable uncertainties in hypothetical scenarios on ecosystem restoration and the resulting ecosystem services (Barbier, 2007).
- The monetary value of ecosystem services does not necessarily inform of their current status. Based on the nature of pricing, scarce resources and services will be valued higher and therefore it is possible that the total value of ecosystem services in one area may not appropriately reflect their degradation in biophysical terms.
- Monetary valuation of ecosystem services may lead to the interpretation that ecosystem services are tradable with money regardless of their non-substitutability. This may entail the criticism that valuation practices are aiming for the capitalisation or commodification of nature and ecosystems in biodiversity-rich countries.

Although the economic valuation of ecosystem services aims to demonstrate the importance of ecosystems to society, valuation practices are time and resource intensive, whereas the presentation of biophysical quantities may be sufficient to communicate the benefits received from nature with stakeholders (de Groot et al., 2012).

Furthermore, some of the advantages of the quantification of ecosystem services can be enumerated as follows:

- Biophysical quantification can serve to visualise the current status and trends of ecosystem services more directly than their monetary valuation.
- This will also enable us to understand the current balance between supply and demand of certain ecosystem services, for instance, the ecosystem capacity of nutrient removal (service supply) can be compared with the actual amount of nutrient emission (service demand) to

assess the sustainability of this regulating service.

- Quantification can also demonstrate the synergies and trade-offs between different ecosystem services. Given that resource extraction causes land use changes (e.g. clear cutting of forests), trade-offs between different ecosystem services, such as timber production and flood control, can be compared in a quantitative manner.
- The above would serve as a basis to develop future strategies and plans, especially for ecosystem-related decision-makers such as land use planners, environmental managers and primary industry producers.

Despite these advantages in theory, the concrete methodologies for the quantification of ecosystem services are still to be developed. Even the governmental, corporate and academic initiatives for the development of assessment frameworks on ecosystem services, as described in the background of this study, have their limitations. An overall framework for the accounting of ecosystem services has been developed at the international level by SEEA-EA, but lacks concrete methodologies for the calculation of each ecosystem service. Countries are faced with difficulties in using limited data to conduct the actual calculations. The corporate approaches either have a limited coverage of ecosystem services, or are more focused on the impact of corporate activities rather than the services relied on. The methods developed in academia also have a limited coverage of ecosystem and land use types, and there are few studies encompassing diverse ecosystem services.

Following this trend, and in recognition of the need for Japan to actively participate in the assessment of ecosystem services and to contribute useful information to the international discussions on assessment frameworks, this study has been conducted to implement a trial on the quantification of ecosystem services in Chiba prefecture, Japan. Its aim was to serve as a pilot study to deepen understanding on the pros and cons, as well as the challenges in quantifying ecosystem services.

1.3. General Approach of the Study

In developing a framework for the quantitative assessment of ecosystem services under the current study, the various services have been organised into broad categories based on existing research and international discussions. A wide range of ecosystem services has been targeted under provisioning, regulating and supporting services, within diverse ecosystem types including forest, farmland, urban green spaces, freshwater ecosystems and coastal ecosystems. As this study focuses on assessing the physical quantities of ecosystem services, services such as cultural services do not fit well with this perspective and thus have been excluded, with the exception of elements such as tourism and recreation. Furthermore, regarding the quantities of biological materials and the effects of species interactions on the maintenance and control of ecosystem services, these have not been considered in the calculations, as the methodologies are still underdeveloped.

In the present trial, Chiba has been selected as the pilot area, taking into account its balanced inclusion of forest, agriculture, freshwater and coastal ecosystems, the prefecture's efforts to develop a GIS data infrastructure, as well as the future prospects for promoting the quantitative assessment of ecosystem services among subnational governments. The current land cover data of Chiba has been used as the baseline for calculating the various ecosystem services obtained within the prefecture.

2. Measuring Supporting Services

For the measurement of supporting services, which are considered as the foundation of other ecosystem services, the assessment focuses on the types of habitats that are available in Chiba prefecture, as well as the diversity of species that inhabit each type of ecosystem. In this section, the surface areas of each ecosystem, vegetation type, land cover type, as well as the endangered and endemic plant species and fish species are measured as indicators of the stock of biodiversity.

1. Biodiversity – Habitat Provision
2. Biodiversity – Maintenance of Species and Genetic Diversity

Urban areas have been excluded from the assessment of the contributions to the maintenance of species and genetic diversity, as their role in the conservation of endangered and endemic species is considered negligible.

2.1. Biodiversity – Habitat Provision

Biodiversity is regarded here as the foundation of other ecosystem services such as provisioning

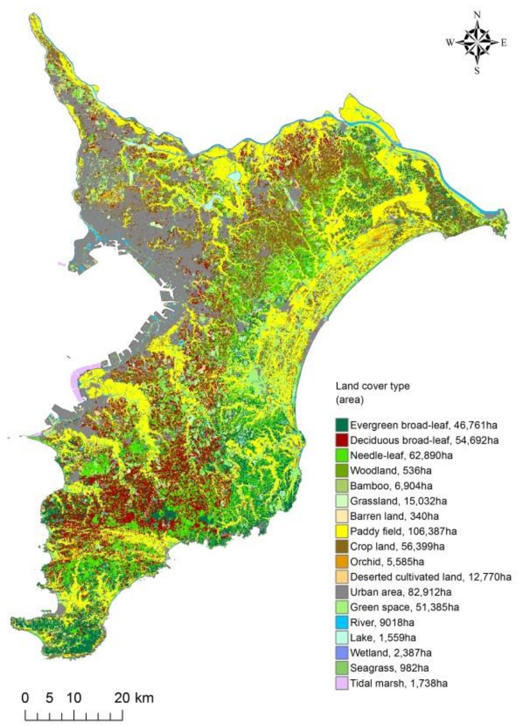


Figure 2-1. Land cover in Chiba prefecture (by authors)

and regulating services, as well as the areas which species can inhabit. Thus the surface area of each ecosystem, vegetation type and land cover type, has been assessed as an indicator of the stock of biodiversity. The data for these measurements has been obtained from maps and official statistics.

A challenge in the assessment of this supporting service was the availability of data. For instance, other indicators such as species richness or abundance by vegetation type or by ecosystems could have been taken as an alternative indicator, but it was not feasible to obtain a comprehensive set of data. Therefore biodiversity and habitats are discussed here as the foundation of provisioning and regulating services, and as the area in which wild fauna and flora can reside. They are measured as the stock of each type of ecosystem, vegetation and land cover.

For the application of this analysis to Chiba, the GIS data provided by the Biodiversity Centre[8] for its second to fifth vegetation survey has been used to calculate the surface of each vegetation category (Table 2-1).

Among these, for the open waters, lake and marsh data from the National Land Numerical Information (NLNI)[9] were used to calculate the surface area of the lakes and marshes using GIS (Table 2-2). These lake and marsh area data were then subtracted with other vegetation data from the vegetation map to obtain the data on the remaining river areas. The 20 thousandth scale topographic classification map from the land classification survey of the Ministry of Land, Infrastructure and Transport (MLIT) was then superposed using GIS to calculate the river areas per habitat type. The surface of seagrass beds and tidal marshes were calculated based on the GIS data obtained from the Biodiversity Centre's past seagrass bed and tidal marsh surveys.

[8] Japanese website can be accessed from http://www.biodic.go.jp/ne_research.html.
[9] It can be accessed from: http://nlftp.mlit.go.jp/ksj-e/index.html.

Table 2-1. Areas of vegetation types according to the vegetation map

Vegetation category	Vegetation sub-category	Area (ha)	Land cover type in this study
Evergreen broad-leaf forest	Evergreen oak community	25	evergreen broad-leaf
	Marlberry - Castanopsis community	243	evergreen broad-leaf
	Arachniodes - Castanopsis community	201	evergreen broad-leaf
	Giant Holly Fern - Persea community	73	evergreen broad-leaf
Warm-temperate coniferous forest	Japanese star anise - fir community	835	needle-leaf
Rock/coastal cliff coniferous forest	Japanese black pine community (VI)	14	needle-leaf
Deciduous broad-leaf forest	Japanese maple - zelkova community	15	deciduous broad-leaf
	Aphananthe oriental elm - Japanese hackberry community	3	deciduous broad-leaf
Swamp forest	Alder community (VI)	19	deciduous broad-leaf
Riparian forest	Tall willow community (VI)	139	deciduous broad-leaf
	Willow shrubs (VI)	128	woodland
	Hydrangea involucrata - Eupteleaceae community	185	deciduous broad-leaf
Coastal dwarf forest community	Spindle tree - cheesewood community	123	woodland
	Cheesewood - holm oak community	4	evergreen broad-leaf
Secondary evergreen broad-leaf forest	Secondary beech/oak forest	43,001	evergreen broad-leaf
	Zelkova - evergreen oak community	573	evergreen broad-leaf
	Evergreen oak residential stand	32	evergreen broad-leaf
	Secondary Japanese cinnamon - Persea forest	119	evergreen broad-leaf
Secondary deciduous broad-leaf forest	Chestnut - Quercus serrata community	15,485	deciduous broad-leaf
	Oak - Quercus serrata community	26,946	deciduous broad-leaf
	Daphne pseudomezereum - Quercus serrata community	11,844	deciduous broad-leaf
	Loose-flowered hornbeam - Chonowski's hornbeam community (VII)	1	deciduous broad-leaf
Secondary evergreen coniferous forest	Japanese red pine community (VII)	8	needle-leaf
Bamboo community	Bamboo and Sasa community	4	grassland
	Simon bamboo community	1,601	grassland
	Pleioblastus chino community	498	grassland
Scrub community	Shrubs	276	woodland
Secondary grassland	Miscanthus group (VII)	626	grassland
	Pleioblastus chino - Miscanthus sinensis community	616	grassland
	Cogon - Miscanthus sinensis community	808	grassland
Post clear-cutting plant community	Former logging site plant community (VII)	345	barren land

Table 2-1 (*Continue*). Areas of vegetation types according to the vegetation map

Vegetation category	Vegetation sub-category	Area (ha)	Land cover type in this study
Moorland, rivers, ponds, and marshland vegetation	Low nutrient soil small plant community	5	wetland
	Phragmite	2,184	wetland
	Miscanthus sacchariflorus community	266	grassland
	Pondweed class	142	wetland
	Alien aquatic plant community	40	wetland
Salt marsh vegetation	Salt marsh vegetation	60	wetland
Sand dune vegetation	Dune vegetation	300	grassland
	Lyme grass - Japanese sedge community	2	grassland
	Wedelia - Japanese sedge community	30	grassland
Coastal cliff vegetation	Miscanthus condensatus community	4	grassland
	Chrysanthemum pacificum - Miscanthus condensatus community	130	grassland
Tree plantation	Cedar, hinoki cypress, sawara cypress plantation	59,868	needle-leaf
	Japanese red pine plantation	599	needle-leaf
	Japanese black pine plantation	1,296	needle-leaf
	Black locust community	2	needle-leaf
	Other plantations	242	needle-leaf
	Edulis plantation	2,501	evergreen broad-leaf
Bamboo	Bamboo forest	6,806	bamboo
	Moso bamboo forest	24	bamboo
	Phyllostachys-Lophatherum gracile forest	42	bamboo
Pastures, golf courses, lawns	Golf court and lawn	9,082	grassland
	Pasture	1,056	grassland
Arable land	Open space, roadside weed community	9,222	deserted cultivated land
	Abandoned farmland weed community	517	deserted cultivated land
	Orchard	5,621	orchid
	Farmland weed community	56,230	crop land
	Paddy field weed community	106,356	paddy field
	Abandoned paddy field weed community	2,957	deserted cultivated land
Urban areas	Urban area	64,700	urban area
	Residential area with greenery	49,745	green space
	Parks and cemeteries with a residual planted vegetation	1,564	green space
	Industrial area	11,604	urban area
	Developed land	5,539	urban area
	Open water	10,475	Freshwaters
	Natural barren land	1,124	urban area
	Residual planted vegetation	388	green space
Total		515,513	

Source: developed by the authors based on the data obtained from Biodiversity Centre

Table 2-2. Areas of lakes, rivers, seagrass beds, and tidal marshes

Category	Name or type	Area (ha)
Lakes and marshes	Sotonasakaura	13
	Hachimanko	5
	Inbanuma	947
	Hakkakuko	3
	Teganuma	371
	Takatakiko	105
	Shiduko	56
	Toyofusako	25
	Mishimako	41
	Kameyamako	67
	Douteiko	3
	Total	1,637
Rivers	Mountains	226
	Plateaus and hills	2,266
	Lowlands	3,604
	Others*	2,891
	Total	8,986
Seagrass beds and tidal marshes	Seagrass bed	986
	Tidal marsh	1,736
	Total	2,722

Source: developed by the authors based on the data obtained from NLNI and Biodiversity Centre

2.2. Biodiversity – Maintenance of Species and Genetic Diversity

Under the assumption that endemic and endangered species cannot survive without their respective habitat ecosystems, the number of endemic and endangered plant and fish species hosted by each ecosystem type was assessed. For terrestrial ecosystems (forests and farmland), the number of endemic and endangered plant species were assessed as the indicators. For aquatic ecosystems (terrestrial and coastal), in addition to plant species, fish species numbers were also assessed. Official statistics and survey records were used to extract, among the known plant and fish species, the number of species which are endemic or nationally endangered per ecosystem type.

The challenge for this assessment lies in the fact that the reliance of each species to its habitat is determined based the general ecology of each species. For any future assessments, it would be ideal to have a clear knowledge of the relationship between species and ecosystem characteristics (types) based on expert knowledge. This would also allow for comparison between regions. Furthermore, some ecosystem categories and taxonomic groups lacked data on endangered species, so it would be necessary to consider which taxa to focus on in the future.

(1) Assessment on Plant Species in Chiba Prefecture

Based on Chiba prefecture’s Red Data (2009a), the presence of nationally endangered plant species (registered under the third Red List of the Ministry of the Environment) in the prefecture was

Table 2-3. Nationally endangered plant species and their presence in Chiba Prefecture

	Nationally endangered species*[1]	Species present in Chiba prefecture*[2]
Vascular plants	1,977 (2113)	158
Bryophytes	284 (283)	11
Algae	187 (197)	26
Fungi	135 (133)	9
Total	2,583 (2726)	204

NB: ( ) represents the number of species listed in the Fourth Red List
*1: Sum of species in Category I (CR+EN), Category II (VU), Near Threatened, and No Data.
*2: Excluding extinct or unknown species within those listed in the Chiba Red Data Book
Source: Chiba Prefecture (2009) and MOEJ announcement on the publication of the Fourth Red List (brackish and freshwater fish)[10]

verified. The result showed that at least 204 species rely on Chiba 's supporting services for habitat provision (Table 2-3).

For the 158 endangered seed plants and fern species among them, the supporting services were analysed by indicating the number of species by habitat type, categorised based on habitat characteristics established in the Red Data Book.

Chiba has many species relying on forest ecosystems and freshwater ecosystems (57 and 74, respectively). In particular, the "woods" category within the forest ecosystem (35 species) and the "moorlands/wetlands" within the freshwater ecosystem (39 species) have a particularly high number of species relying on them (Table 2-4). These results show that the woods and moorlands/wetlands habitat types play an important role in the provision of supporting services for the forests and freshwater species in the prefecture. Furthermore, the number of species relying on the category of "grasslands/meadows" is also high in both forest and aquatic ecosystems. It was also found that many of the species relying on these are currently threatened by the reduction in the amount of natural disturbance by flooding as well as the artificial disturbance from grass cutting for maintenance. Based on this it can be understood that a certain level of disturbance in these ecosystems also plays an important role in the provision of supporting services for biodiversity. Finally, in Chiba, farmlands are home to 18 endangered species, and coastal ecosystems are home to 9.

Regarding endemic species, Chiba hosts several which have adapted to the characteristics of the Boso Peninsula, including the *Orchis graminifolia var.suzukiana*, but the data is incomplete. According to the prefecture (2009), there are an estimated 1,998 species of native plants.

10 MOEJ "Announcement on the publication of the Fourth Red List for brackish and fresh water fish species" http://www.env.go.jp/press/press.php?serial=16264.

Table 2-4. Number of species present by habitat type within each ecosystem

Ecosystem	Habitat type	Number of species present
Forest	Woods	35
	Rocks	2
	Grassland/meadow	17
	Bare land	3
	Cliff	4
	Wetland	2
	Forest edge, roadside	2
	Total	57
Agricultural land	Paddy	12
	Storage reservoir	3
	Waterway	1
	Ponds	11
	Grassland	1
	Wetland/floodplain	3
	Total	18
Freshwater	Mountain stream	2
	Pond/waterfront	18
	Grassland/meadow	18
	Moorland/wetland	39
	Waterway	3
	Forest	1
	Total	74
Coastal	Salt marsh/brackish water	5
	Beach/sand	2
	Tidal marsh/coastline	1
	Rocky shore	1
	Total	9

Note: Species overlap between habitat types, but the total indicates the number of species present within the corresponding ecosystem type.

(2) Assessment on Fish Species in Chiba Prefecture

Similarly to the assessment on plant species, having verified the number of nationally endangered freshwater and brackish water fish species (registered under the fourth Red List of the Ministry of the Environment) in Chiba, there are at least 20 species relying on the freshwater and coastal ecosystems of the prefecture. Of the freshwater and brackish water fish species, 79 are native to Chiba prefecture (104 species identified if including the 25 alien and introduced species) (Biological Society of Chiba, 1999). There are species that may be considered as endemic, such as the Tokyo Bitterling (*Tanakia tanago*), but there are no records of its range being limited to Chiba. According to the Fourth Red List of the MOEJ, there are 234 nationally endangered fish species. As there is currently no Red List for marine fish species[11], the results of an expert questionnaire survey of

[11] The Fisheries Agency has published in 1998 the “Data book on rare Japanese aquatic species”, but it has been criticised to have included insufficient number of species

members of the Ichthyological Society of Japan conducted by Shigeta et al. (2011) have been used to identify possibly endangered species, and to verify their presence in the prefecture. As a result, among the 32 commercial species indicated as possibly endangered in Japan, at least 13 species have been found to be present in Chiba (Chiba prefecture, 2002).

Among the fish fauna present in the seas of Chiba, the prefecture's periodical on nature has recorded a total of 542 species, consisting of 58 species of Chondrichthyes and 483 species of Osteichthyes. This includes not only shallow-sea species living along the coastline but also deep-sea fish, commercial offshore species such as pacific saury, and migratory species riding the Kuroshio Current from tropical regions. These species reflect the diversity of Chiba prefecture's coastal ecosystems, including those facing the open ocean with sandy beaches and rocky coastlines, as well as those facing the inner bay areas with seagrass beds, tidal marshes, brackish waters, and deep offshore areas. As a reference point, 663 species have been identified in the inner Tokyo Bay.

2.3. Conclusion

As a result of this assessment, the supporting services provided by ecosystems in Chiba can be summarised as in Table 2-5. Although this is a simplified view of the stock of ecosystems available and the biodiversity inhabiting them, it is nevertheless an important baseline on the overall land use of the target area.

Table 2-5. Summary of Chiba prefecture's supporting services

<table>
<tr><th colspan="3">Ecosystem services</th><th>Forest</th><th>Agricultural land</th><th>Urban area</th><th>Freshwater</th><th>Coastal zone</th></tr>
<tr><td rowspan="2">Supporting</td><td rowspan="2">Biodiversity and habitats</td><td>Habitat and nursery provision (ha)</td><td>Total surface area 187×10^3</td><td>Total surface area 181×10^3</td><td>Total surface area 135×10^3</td><td>Total surface area 13×10^3</td><td>Total surface area 2.7×10^3</td></tr>
<tr><td>Maintenance of species and genes (species)</td><td>Endangered plant species 57</td><td>Endangered plant species 18</td><td></td><td>Endangered plant species 74

Endangered freshwater fish species 20</td><td>Endangered plant species 9

Endangered marine fish species 13</td></tr>
</table>

3. Calculating Provisioning Services

For the assessment of provisioning services, the study focuses on the calculation of three components, namely food, water, and materials, provided by ecosystems in Chiba. The study thus targets the flow of agricultural and fisheries production, freshwater resource distribution, and production of non-food materials such as timber. For all of these components, data on the amount of yearly provision is available to some extent from official statistics, although artisanal or recreational harvests from each type of resource are not included in the calculations due to data deficiency.

1. Food provision – Agricultural and Fisheries Production
2. Freshwater provision – Distribution of Water Use Rights
3. Material provision – Production of non-food materials

In this section, urban areas are excluded from the assessment, as they are not considered as a source of provisioning services, and the quantities of materials such as reeds produced from freshwater ecosystems could not be identified. Although coastal areas are also possibly a source of materials such as algal products, they have been excluded due to the lack of concrete numerical data on their production rates.

3.1. Food provision – Agricultural and Fisheries Production

For the assessment of food provisioning services, the per unit area capacity for food production has been calculated based on the current flow of agricultural products from terrestrial and aquatic ecosystems. This approach has been chosen bearing in mind the possible use of results in future land use scenario analyses.

For forest ecosystems, the annual harvest of forest food products such as chestnuts and bamboo shoots has been extracted from official statistics (in t/year). For farmlands, three indicators have been chosen, corresponding to the types of agricultural land use, namely the annual rice production for paddy fields, the annual soy and other production from vegetable farms, and the annual fruit production from orchards (in t/year). For freshwater ecosystems the amount of annual fish catch has been extracted from the available statistics. Finally, for coastal ecosystems, the annual fish catch statistics have been extracted, distinguishing the types of fish corresponding to different habitats, namely seagrass beds, tidal marshes, coral reefs, and mangrove forests. These annual production statistics are then divided by the surface area of each of these ecosystem types identified through GIS, to obtain the per unit area production capacity of each land use.

In these analyses, the current production is assumed to be at the maximum production capacity due to data constraints, but if based on a more sustainable production method with lower fertilizer inputs, a lower per unit area production rate may be more likely.

The statistical information on Chiba's forest products, agricultural products and fisheries products are presented in the following tables (Table 3-1 - Table 3-3).

As a point of reference, according to the 2011 Food Balance Sheet (Ministry of Agriculture, Forestry and Fisheries, 2011), the average citizen in Japan consumes 57.8kg/year of rice, which, multiplied by Chiba's population of 6,190,000, amounts to 357,782t of rice. If all paddy fields in the prefecture were used to produce rice, the potential production would amount to 160% of the prefectural consumption. Furthermore, if all farmland in Chiba were used to produce soy beans, the total harvest would equal 56,200t/year and if all orchards were used to produce Asian pears, the production would be of 103,485t/year. However, it is important to bear in mind that these

Table 3-1. Annual production of forest food products

Product	Production (t)	Production area (ha)	Production per unit area (t/ha)	Remarks
Chestnut	397	312.0	1.3	2009 data
Bamboo shoots	230	436.0	0.5	2011 data
Raw wood shiitake	298	3.6	83.4	2011 data
Fungal bed shiitake	477	1.9	254.9	2011 data

Note: This list includes only products for which the production surface area data were available.
Source: Chiba Prefecture (2011c)

Table 3-2. Annual production of agricultural products

Product	Production (t)	Production area (ha)	Production per unit area (t/ha)	Remarks
Rice	332,800	61,400	5.4	2012 data
Japanese radish	163,500	3,110	52.6	2012 data
Cabbage	128,100	3,000	42.7	2012 data
Carrot	113,200	3,280	34.5	2012 data
Sweet potato	100,600	4,700	21.4	2012 data
Leek	67,100	2,460	27.3	2012 data
Watermelon	45,900	1,250	36.7	2012 data
Tomato	44,100	859	51.3	2012 data
Turnip	41,800	1,080	38.7	2011 data
Spinach	39,000	2,350	16.6	2012 data
Cucumber	32,600	516	63.2	2012 data
Asian pear	31,600	1,710	18.5	2012 data
Potato	31,100	1,380	22.5	2012 data
Taro	22,400	1,790	12.5	2012 data
Sweet corn	16,900	1,720	9.8	2012 data
Peanut	12,300	5,690	2.2	2012 data
Burdock root	11,600	581	20.0	2012 data
Eggplant	10,200	370	27.6	2012 data
Soy bean	927	900	1.0	2012 data

Note: This list includes only products exceeding an annual production of 10,000t.
Source : Chiba Annual Statistics (2012a)

Table 3-3. Annual fisheries production from rivers, lakes and coastal areas

Product	Production (t)	Production area (ha)	Production per unit area (t/ha)	Source	Remarks
Lake fisheries	97	1,805	53.7	A	2010 data
Rockfish	11	46,600[*1]	0.2	B	2005 data
Flatfish	591	46,600[*2]	12.7	C	2010 data

Note: The assumption has been made that rockfish and flatfish catch originate from shallow seas, thus the surface area of shallow seas identified through the Ocean Survey of the National Survey on the Natural Environment has been applied to calculate the per unit area production capacity.
Source A: Chiba Annual Statistics (2012b)
Source B: Keiyo Bank (2006)
Source C: Chiba Annual Statistics (2012c)

would not only be limited by the amount of land, but also by the amount of freshwater provided by the surrounding ecosystems. When considering the potential production under the limits of agricultural water provision, the amount of available freshwater for agriculture originating from natural streams, as indicated in the following section on water provision, is 878 billion m^3/year. If all of this were to be used for rice production, as the virtual water necessary for rice production is 3,700m^3 per tonne of production according to the virtual water calculator of the Ministry of the Environment of Japan (MOEJ)[12], the rice production capacity would be 237,235t, below the current amount of production. It can be understood that by making use of artificially developed water sources such as dams and pumped groundwater, we have been able to exceed the limits of water provision by the ecosystem. If all of the freshwater from natural sources allocated to agriculture were applied to soy bean production, as the virtual water required is 2,500m^3 per tonne of soy bean, the total production capacity would be 351,108t. However, this would require a land area larger than the current area of farmland; therefore it would require changes in land use from other uses. Furthermore, if all natural stream water for agriculture were applied to the production of Asian pears, as this requires 356m^3 of virtual water per tonne of fruit, the production capacity would be 2,465,649t. Similarly to soy bean production, this would also require a bigger area of cultivation than the current orchards.

Based on these assumptions, it can be understood that current rice production capacity is limited by current water availability, whereas soy and Asian pear production capacity are limited by the available area of farmlands and orchards (Table 3-4).

[12] Japanese website can be accessed from: http://www.env.go.jp/water/virtual_water/kyouzai.html.

Table 3-4. Annual production potential under land area and water resource limitations

Product	Current		Under land area limitations		
	Production (t)	Production area (ha)	Land area (ha)	Production potential (t)	Water needs (1000m3)
Rice	332,800	61,400	106,400	576,709	2,133,823
Soy bean	927	900	56,200	57,886	144,715
Asian pear	31,600	1,710	5,600	103,485	36,841

Product	Current		Under water resource limitations		
	Production (t)	Production area (ha)	Virtual water (m3/t)	Production potential (t)	Land needs (ha)
Rice	332,800	61,400	3,700	237,235	43,769
Soy bean	927	900	2,500	351,108	340,882
Asian pear	31,600	1,710	356	2,465,649	133,426

3.2. Freshwater provision – Distribution of Water Use Rights

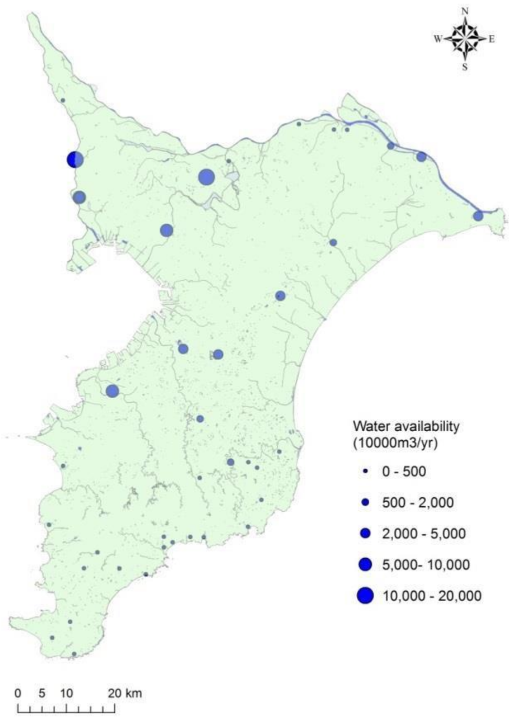
In the assessment of freshwater provisioning services, the amount of water use licensed by current water use rights at each intake point (in m^3/year) has been considered as the maximum amount of freshwater available for human use. However, water use rights listed in the official statistics include freshwater secured through human interventions such as river development and dam constructions. Therefore, where possible, the water use rights originating from artificially developed sources have been excluded, taking into account only the water use rights issued for natural streams. The data has been gathered from official statistics. The challenge for this assessment is the lack of linkage between the amount of freshwater provisioning services obtained, and the surrounding land use type. Establishing the relationship with regulating services such as the regulation of water runoff is also a challenge for further consideration.

For Chiba prefecture, the maximum water intake authorised for the 40 intake points according to the water use license allocations as of March 2012 (Chiba prefecture, 2011) has been mapped in Figure 3-1. The total water intake capacity of Chiba prefecture amounts to 807.5 million m^3, which largely exceeds the actual intake amount of 566.9 million m^3 (Chiba prefecture, 2011). However, when distinguishing between different sources, the natural streams which constitute ecosystem services provide 6.1 million m^3, amounting to only 8% of current water use (Table 3-5). Based on this it can be understood that the largest share of current water use relies on sources secured through dams and other development.

Regarding agriculture irrigation waters, a long-term water balance survey by the prefecture (2008) indicates that it is difficult to determine the total water use capacity due to complicated institutional structures, thus the amount of irrigation is assessed based on the amount of irrigation licenses issued. Therefore, this assessment also calculated the irrigation capacity based on the issued licenses (Table 3-6). Of these, the amount of irrigation waters sourced from natural streams equals

877.8 million m^3, which is 77% of the total irrigation water use including groundwater consumption.

As there is no allocation from natural streams, industrial water consumption has been excluded from this assessment.



Source: based on Chiba prefecture (2011a)

Figure 3-1. Maximum water intake authorised for Chiba prefecture's intake points

Table 3-5. Maximum water intake by source type

Source type	Water purification facilities	Water use license (m^3/s)	Annual intake (1000m^3)	Portion (%)
Dams	26	9.6	303,871	38
Waterway	6	7.3	231,159	29
Barrage	3	3.6	113,530	14
River development	7	2.1	67,456	8
Natural streams	15	1.9	61,186	8
Flood control basin	1	0.5	15,926	2
Rationalization of agricultural irrigation	1	0.5	14,822	2
Total	59	25.6	807,949	100

Source: based on Chiba prefecture (2011a)

Table 3-6. Breakdown of agricultural irrigation licenses by source type

Source type	Annual water use license (1000m3/year)	Portion (%)
Natural streams	877,771	77
Dams	171,840	15
Groundwater	86,003	8
Total	1,135,614	100

Source: Chiba Prefecture (2008)

3.3. Material provision – Production of non-food materials

For the assessment of material provisioning services, the actual flow of materials produced was identified and calculated as the per unit area production capacity of each ecosystem type. Here, rather than the total stock of materials, the production capacity was estimated based on the current production level due to limited availability of data.

For forest ecosystems, the amount of annual timber and bamboo production were considered. For farmlands, the production of fodder was considered as a form of non-food material production. Finally for freshwater ecosystems, the production of reeds was considered. Coastal ecosystems were excluded due to lack of data on the quantities of marine products used as materials. Similarly to agricultural production, this assessment regards current production levels as the maximum production capacity of each ecosystem type, but further integration of the perspective of sustainability would be required.

In the case of Chiba prefecture, the per unit area production of forest products and fodder have been included in the following table (Table 3-7). For freshwater ecosystems, the data on reed production in Chiba were not available[13].

3.4. Conclusion

The results of the calculations on Chiba's yearly amount of provisioning services are summarised in Table 3-8 below. They have been estimated based on the per unit production capacity of each ecosystem issued from this section, and the surface area of each type of ecosystem obtained from land use maps.

In terms of estimating the provisioning capacity of the various ecosystems, it is debatable whether to base calculations on the current production amount, the potential production amount, or a more conservative estimate from a sustainability perspective (for instance, by placing limitations on water resource availability). Here, due to data constraints the current production quantities have been

[13] Although studies on a reed bed of 45 ha in the Banzu tidal marsh have suggested an availability of 200-1,100g of dry reed material per square metre (Shimizu et al., 2002), this does not necessarily equal the production capacity.

Table 3-7. Annual production of materials

Product	Production	Production area (ha)	Production per unit area (kg/ha)	Source	Remarks
Wood	72,000 (m3)	137,021*	0.5 (m3/ha)	A, B	2011 data
Bamboo	15,000 (bundles)	127	118.1 (bundles/ha)	A, C	2008 data
Fodder	38,400 (t)	1,120	34.3 (t/ha)	D, E	2011 data
Corn	64,300 (t)	1,120	57.4 (t/ha)	D, E	2011 data
Sorgo	34,600 (t)	521	66.4 (t/ha)	D, E	2011 data

Note*: Applied the area of the forest planning target zone obtained from the 2005 Forestry Census
Source A: Chiba Prefecture (2011c)
Source B: MGA (2011a)
Source C: Chiba Prefecture (2011b)
Source D: MGA (2011b)
Source E: MAFF (2012)

regarded as the provisioning capacity, but there are considerable interlinkages between the provisioning of freshwater and agricultural products which could not be indicated in a quantitative manner. Also, this assessment has illustrated that current water use largely relies on man-made sources, and a challenge for future assessments would be to establish linkages between land use types, the amount of freshwater provisioning services, and the amount of other provisioning services such as food production.

Table 3-8. Summary of provisioning services obtained in Chiba prefecture

Ecosystem services		Forest	Agricultural land	Urban area	Freshwater	Coastal zone
Provisioning	Food (t/year)	Chestnut production capacity 71×10^3 Bamboo shoots production capacity 3.5×10^3	Rice production capacity 577×10^3 Soy bean production capacity 59×10^3 Asian pear production capacity 104×10^3		Fisheries capacity in lakes/ponds 80	Rockfish catch capacity >0 Flatfish catch capacity >0
	Freshwater (m^3)				Tap-water provision from natural streams 6.1×10^6 Irrigation water from natural streams 878×10^6	
	Materials (forest: m^3/year) (agriculture: t/year)	Wood production capacity 82×10^3	Fodder production capacity 1.9×10^6		Reed production capacity (DD*)	

4. Estimating and Mapping Regulating Services

Quantification of regulating services attracts global attention from the wider stakeholders for the purpose of academic researches and real policy making (e.g. InVEST model introduced in the Section 1.1). In this chapter, we will quantify 10 regulating services with the respective estimation methodologies and the GIS techniques, which enable us to visibly understand where we can benefit from regulating services more substantially. Those regulating services include:

1. Climate Regulation – Greenhouse Gases Sequestration
2. Climate Regulation – Heat Latent Effect
3. Air Quality Control
4. Water Regulation – Water Flow Regulation
5. Water Regulation – Water Purification
6. Soil Conservation – Soil Erosion Prevention
7. Soil Conservation – Soil Fertility Maintenance
8. Natural Hazard Mitigation – Flood Control
9. Natural Hazard Mitigation – Landslide Mitigation
10. Natural Hazard Mitigation – Wave Mitigation

Since some regulating services are generated from a particular type of ecosystem, those inappropriate for evaluation in the light of the nature of the ecosystem functions will be excluded from this quantification exercises (e.g. soil erosion prevention cannot be expected in freshwater ecosystems and coastal zones). This information is summarised in Table 4.1.

The following sections introduce the existing methodologies which are frequently used for estimating the respective ecosystem functions or the possible approaches to quantify the ecosystem services which have not been sufficiently addressed so far. Followed by clarification of the data sources, quantification results will be shown on the geographical maps and the total volume over the prefecture will be presented if appropriate.

Table 4-1. Evaluated ecosystem services by each ecosystem type

Ecosystem services		Forest							Agricultural land				Urban		Freshwater			Coastal zone	
		evergreen broad-leaf	deciduous broad-leaf	needle-leaf	woodland	bamboo	grassland	barren land	paddy field	crop land	orchid	deserted cultivated land	urban area	green space	river	lake	wetland	seagrass bed	tidal marsh
Climate regulation	GHGs sequestration	√	√	√	√	-	-	-						√	-	-	√	√	-
	Heat latent effect	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√
Air quality control		√	√	√	√	√	√	√	√	√	√	√	√	√	-	-	√		
Water regulation	Water flow regulation	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√		
	Water purification	√	√	√	√	-	-	-	√					√	-	√	√	√	√
Soil conservation	Soil erosion prevention	√	√	√	√	√	√	√	√	√	√	√							
	Soil fertility maintenance	√	√	√	√	√	√	√	√	√	√	√							
Natural hazard mitigation	Flood control	√	√	√	√	√	√	√	√	√	√	√	√	√					
	Landslide mitigation	√	√	√	√	√	√	√	√	√	√	√	√	√					
	Wave mitigation	√	√	√	√	-	-	-											

Note: Grey colour indicates exclusion from the analysis in the light of respective natural functions, while “-” stands for data deficient.

4.1. Climate Regulation – Greenhouse Gases Sequestration

The amount of carbon dioxide (CO_2) sequestration by each land cover type is estimated with the respective unit values and geographical areas. As the net CO_2 emissions from agricultural areas are generally considered to be positive, they are excluded from the assessment.

Forest age is taken into account to estimate the unit CO_2 sequestration by forests. First of all, the respective forest areas by forest types (i.e. natural/planted, broad-leaf/needle-leaf) and age classes were obtained from the agriculture and forestry census in 2005 (MIC, 2008). Planted forests are further broken down into the specific species level. Adopting the middle value of each age class, the average forest age weighted by respective areas was calculated (Table 4-2). Subsequently, unit CO2 sequestration indicated in Chiba prefecture (2009b) was averaged by forest types and forest age[14].

The forest type of natural or planted is not considered in the common classification of this research, therefore the values of natural broad-leaf (2.2 t-CO2/ha/year) and planted needle-leaf (5.3 t-CO2/ha/year) were applied for the parameters of broad-leaf and needle-leaf forests, judging from the respective area sizes. Although deciduous and evergreen broad-leaf forests are separated out in the common classification, the same value was applied for these two types of forests. This can be justified by the result that the same CO_2 sequestration value was estimated for both Sawtooth Oak and Oak. While we also apply this broad-leaf unit value to the woodland and forested parks due to the data limitation, bamboo and grasslands were not evaluated herein since their CO_2 sequestration values are considered zero (MOE, 2006).

As for the parameters of wetlands and seagrass bed, 1.2t-CO2/ha/year and 1.5t-CO2/ha/year were applied, respectively (Nagata, 2006; Ito and Nakano, 2006). The unit values of CO_2

Table 4-2. Average forest age and CO2 sequestration by each forest type

Forest type / species	Area (ha)	Average age	CO2 sequestration (t-CO2/ha/yr)
Natural broad-leaf	74,872	42.7	2.2
Planted broad-leaf	1,047	46.0	2.2
Sawtooth Oak (*Quercus acutissima*)	712	42.2	2.4
Oak (*Quercus*)	13	44.3	2.4
Others	322	54.5	1.9
Natural needle-leaf	195	66.3	2.5
Planted needle-leaf	60,906	43.1	5.3
Japanese cedar (*Cryptomeria japonica*)	49,269	43.4	5.1
Japanese cypress (*Chamaecyparis obtusa*)	8,322	38.6	6.3
Pine (*Pinus*)	3,304	49.4	6.2
Others	12	43.4	—

Source: calculated from MIC (2008) and Chiba Prefecture (2009b)

14 The values of planted forests are area-weighted average values of respective species.

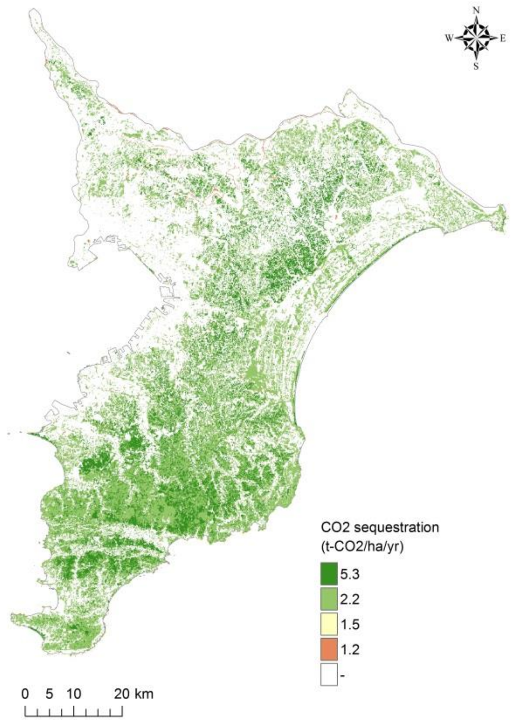


Figure 4-1. CO2 sequestration

sequestration by respective land cover types are summarised in the Annex and are visualised on the geographical map (Figure 4-1). The total amount of CO_2 sequestration in the prefecture was estimated 675 thousand t-CO2/ha/year.

Although we applied the above approach to estimate CO_2 sequestration, it would be far preferable to use the equation function which includes CO_2 concentration as one of the parameters, considering the further predictable increase in CO_2 in the atmosphere. We also note that methane emissions from the wetland muds and CO_2 emissions through decomposition of organic matters and CO_2 assimilation by phytoplankton in the coastal areas have not been quantified in the assessment.

4.2. Climate Regulation – Heat Latent Effect

Evapotranspiration from terrestrial vegetation and evaporation from surface water are evaluated as proxies of heat latent effects. Potential evapotranspiration is estimated with the Hamon equation, and subsequently adjusted by the evapotranspiration coefficient which is attributed to each land cover type, in order to obtain actual evapotranspiration (Tallis et al., 2011, pp.261). Meanwhile, potential evapotranspiration is perceived as actual evaporation in the case of surface water (Fujita et al., 2006)[15]. The Hamon equation is expressed as follows:

[15] Air temperature, not water temperature, is used for estimating evaporation from surface water in

$$ET_0 = 13.97dD^2W_t$$

where ET_o denotes potential evapotranspiration, d is the number of days in a month, D is the mean monthly daylight hours calculated for each year (in units of 12 hours), and W_t is a saturated water vapour density (g/m^3) calculated by:

$$W_t = 4.95 \times exp(0.062T)/100$$

where T stands for the mean temperature in degrees Celsius. The annual mean monthly daylight hours D was calculated based on the latitude of each point in the prefecture (CERI, 2012). The annual mean temperature T was obtained from the NLNI.

Then, evapotranspiration coefficient is estimated by:

$$ET_k = \begin{cases} LAI/3, \ when\ LAI \leq 3 \\ 1, when\ LAI > 3 \end{cases}$$

where ET_k is evapotranspiration coefficient and *LAI* is the leaf area index (Tallis et al., 2011, pp.263). Focusing on Chiba, the annual mean *LAI* by each land cover type is calculated from the datasets in 2013 downloaded from the Moderate Resolution Imaging Spectroradiometer (MODIS)[16] provided by the Land Processes Distributed Active Archive Centre, and modified into evapotranspiration coefficient ET_k (see Annex). Considering the fact that the evapotranspiration coefficient also relates to the soil moisture content and the vapour pressure deficit (Ota et al., 2006), they should be also taken into account to estimate the evapotranspiration coefficient as long as relevant datasets are available.

Figure 4-2 shows the estimated potential and actual evapotranspiration, demonstrating that the larger potential evapotranspiration was expected around the coastal areas because of higher mean temperatures while the larger actual evapotranspiration could be observed in the inland forested areas with a higher leaf area index. The total actual evapotranspiration throughout the prefecture was estimated at 2.65 billion m^3/year, which is equivalent to 31.6% of the annual precipitation (i.e. 8.37 billion m^3/year according to the datasets obtained from the NLNI).

this analysis, referring to Fujita et al. (2006).

[16] It can be accessed from: http://modis.gsfc.nasa.gov/.

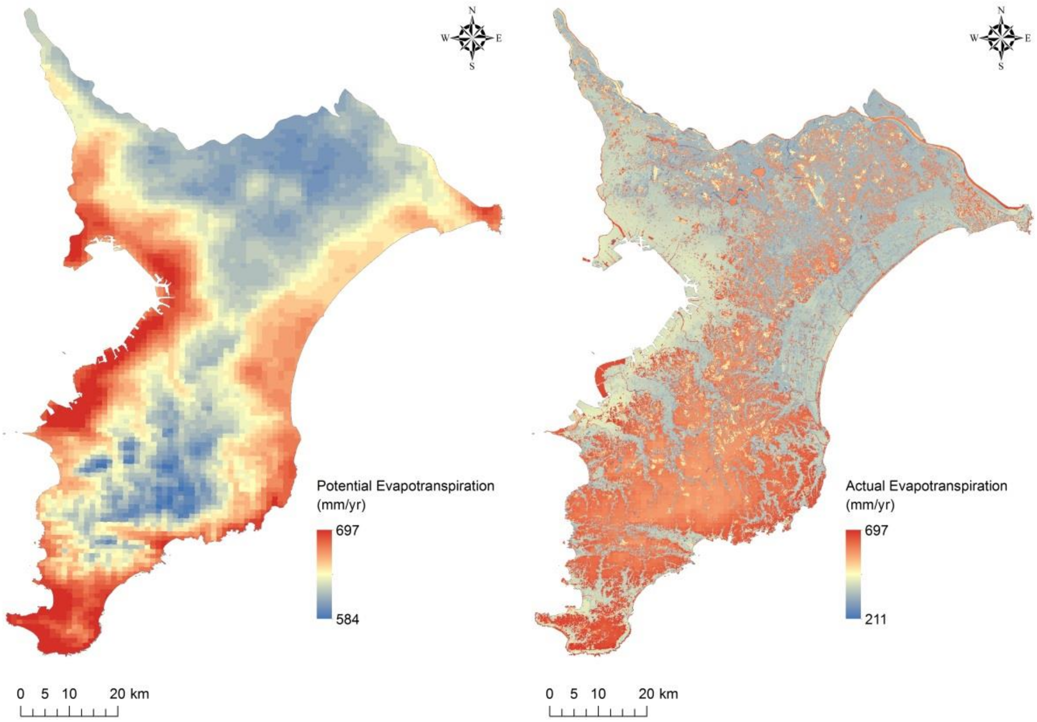


Figure 4-2. Potential and actual evapotranspiration

4.3. Air Quality Control

The amounts of sulfur dioxide (SO_2) and nitrogen dioxide (NO_2) removed from the atmosphere through plants' respiration activity are evaluated with the following equations indicated in PREC Institute (2011, pp.34):

$$U_{SO2} = 18.6 \times \mathrm{C}_{SO2} \times P_g$$
$$U_{NO2} = 13.9 \times \mathrm{C}_{NO2} \times P_g$$

where *C* denotes pollutants concentration in the atmosphere (µg/cm^3) and P_g is the gross primary product (t-C⁄ha⁄year). Note that CO_2 concentration is assumed 390ppm in this equation, and the upper limit of removal volume is not presumed as is clear from its linear form.

Air pollutants concentration at 91 observed points in Chiba in 2011 were obtained from the Database for Environment Related Values provided by the National Institute for Environmental Studies[17], which were converted from ppm to µg/cm^3 with the above temperature data and then spatially interpolated throughout the prefecture using the spline method (Figure 4-3).The gross primary products in 2013 were obtained from the MODIS and averaged by land cover types (see

[17] Japanese website can be accessed from: http://www.nies.go.jp/igreen/index.html.

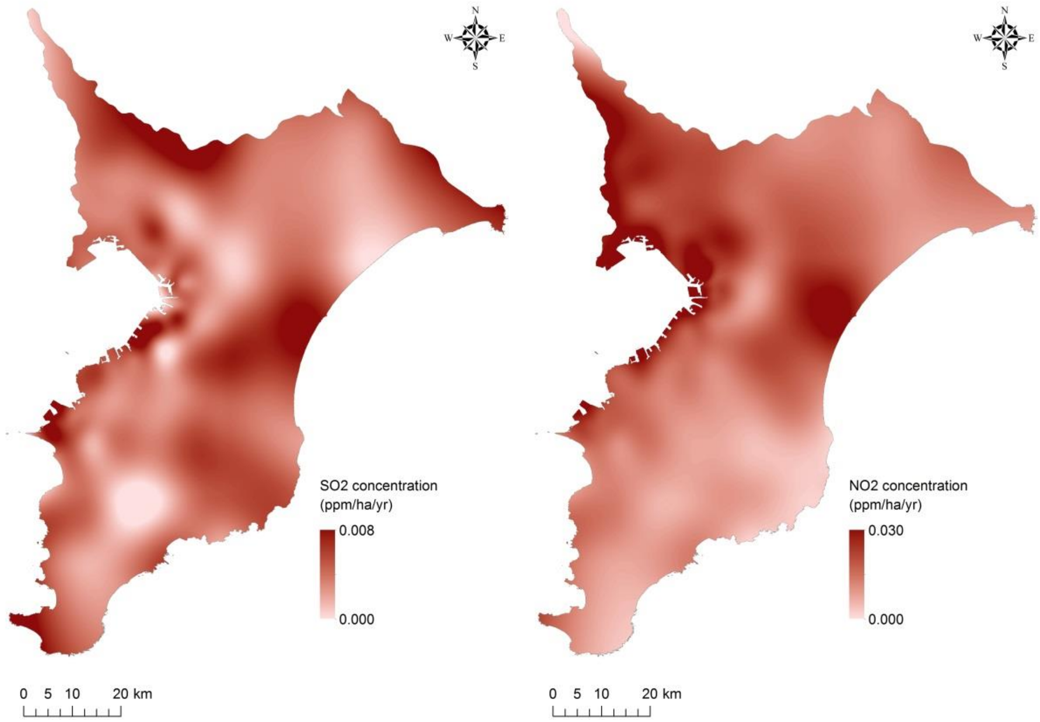


Figure 4-3. SO_2 and NO_2 concentration

Annex).

The total volumes of SO_2 and NO_2 removal in the prefecture were estimated at 690t/year and 2,093t/year, respectively. Figure 4-4 demonstrates that the removal performance was substantially affected by the atmospheric concentration of the air pollutant. To investigate the contribution of vegetation more precisely, the removal volumes were re-estimated under the condition that mean concentrations were applied to the whole areas uniformly. As a consequence, the southern part of the peninsula with higher gross primary products showed higher potentials for air quality control (Figure 4-5).

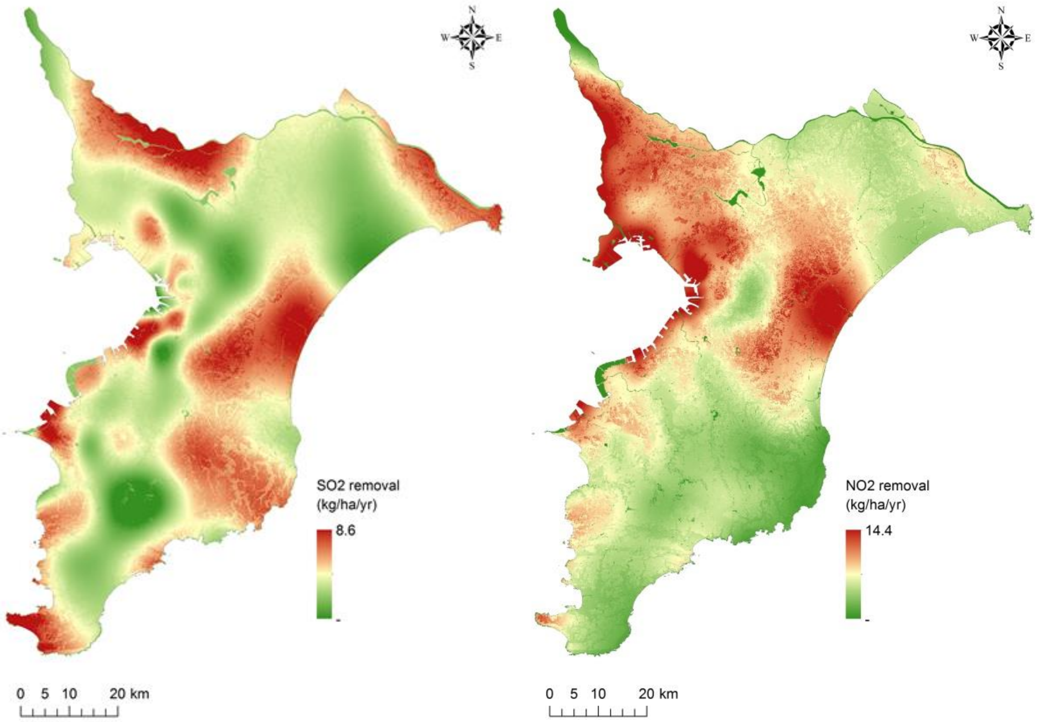


Figure 4-4. SO_2 and NO_2 removal

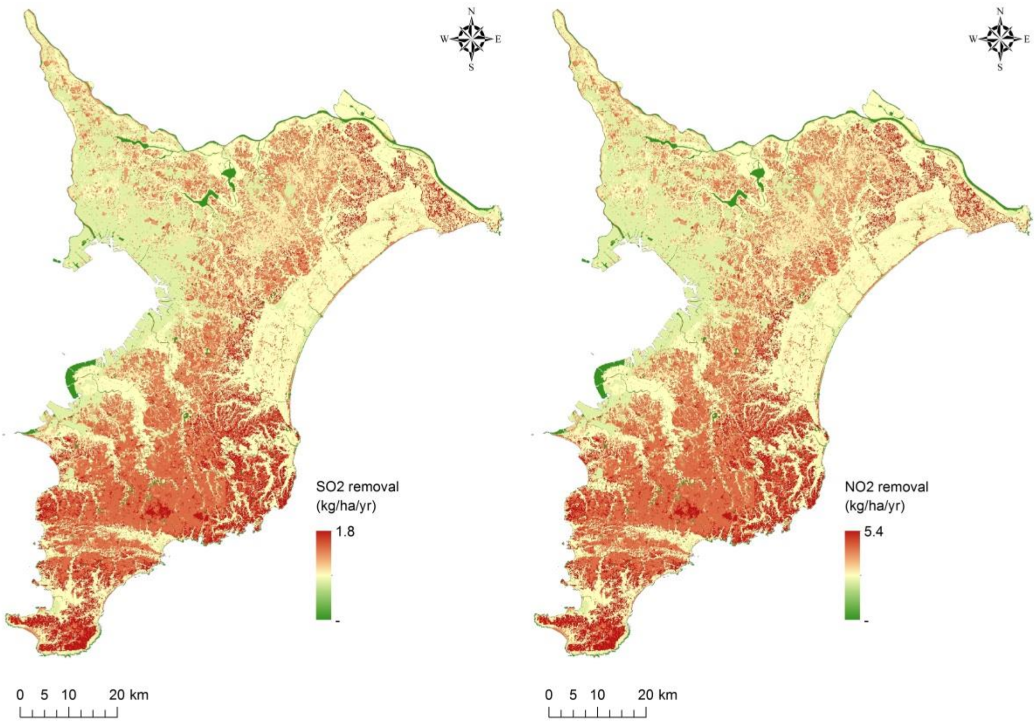


Figure 4-5. SO_2 and NO_2 removal under the mean concentration

4.4. Water Regulation – Water Flow Regulation

Since infiltration of rainfall underground can contribute to a slow-down of water flow, groundwater recharge in the terrestrial areas is evaluated as an indicator of water flow regulation. The water balance method introduced in MLIT (2010) is applied in this analysis:

$$Gr = P - ET - R_{surf} - R_{sub}$$
$$ET = a_1 \times e^{b_1(\alpha \times P \times T)}$$
$$a_1 = 53.057 \times e^{0.0003P}$$
$$b_1 = 1.2143 \times P^{-1.2741}$$
$$R_{surf} = a_2 \times e^{b_2(1-\alpha)}$$
$$a_2 = 0.0727 \times P - 31.894$$
$$b_2 = 7.4201 \times P^{-0.0304}$$
$$R_{sub} = a_3 \times (\alpha \times \beta)^{-b_3}$$
$$a_3 = 0.723 \times P - 51.895$$
$$b_3 = 1.507 \times P^{-0.113}$$

where Gr is groundwater recharge (mm/year), P is precipitation (mm/year), ET is evapotranspiration (mm/year), T is annual mean temperature in degrees Celsius, R_{surf} is surface runoff (mm/year), R_{sub} is subsurface runoff (mm/year), α is pervious surface rate (%), and β is the ratio of horizontal distance to the vertical height. The parameters of this model are dependent on saturated hydraulic conductivity of each top soil type; however, the order of 10^{-4} cm/sec is uniformly applied regardless of the soil types for the simplification purpose here in this analysis.

Precipitation data was obtained from the NLNI. The pervious surface rates referred to the values indicated in Takagi et al. (2001), reclassified into the land cover classification in this research as shown in Table 4-3. The ratio of horizontal distance to the vertical height was calculated with elevation and slope degree of each mesh (250m resolution), which were acquired from the NLNI.

Evapotranspiration was estimated first by the above equation (Figure 4-6). Its value range was considerably larger than that estimated in Section 4.2., but the value distributions resembled each other. Followed by the estimates of surface flows and subsurface flows (Figure 4-7), groundwater recharge was calculated (Figure 4-8), resulting in negative values in some areas mainly around urban areas. As this is clearly against our understanding and can be perceived as the weakness of this model, the negative values were adjusted to zero for descriptive purposes (Figure 4-8). The total adjusted groundwater recharge in the whole prefecture was estimated at 22.8 billion m^3/year, which is equivalent to 27.3% of the annual precipitation.

Table 4-3. Pervious surface rate of each land cover

Original land cover type	Pervious surface rate	Land cover type in this study*
Mountainous forests and barren lands	0.93	evergreen broad-leaf, deciduous broad-leaf, needle-leaf, woodland, bamboo, grassland
Paddy fields	0.90	paddy fields
Crop lands	0.86	crop land, orchid, deserted cultivated land
Developing area	0.88	
Open space	0.75	barren land
Industrial area	0.63	
Low-rise apartment house	0.62	
Closely-spaced low-rise apartment house	0.50	
Mid-to-high-rise apartment house	0.67	
Commercial area	0.58	
Road	0.49	
Parks and green space	0.87	green space
Other public space	0.79	
River and lakes	0.95	river, lake, wetland
Others	0.85	

Note*: The mean value of developing area, industrial area, low-rise apartment house, closely-spaced low-rise apartment house, mid-to-high-rise apartment house, commercial area, road, and other public space is applied to the urban area.
Source: Takagi et al. (2001)

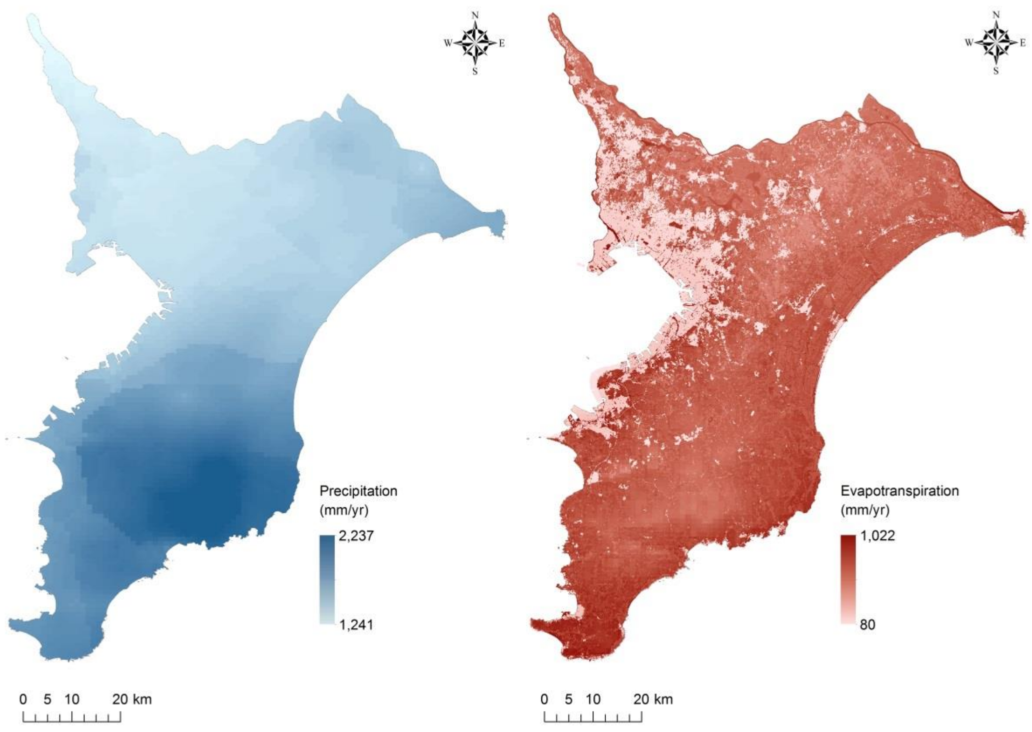


Figure 4-6. Precipitation and evapotranspiration

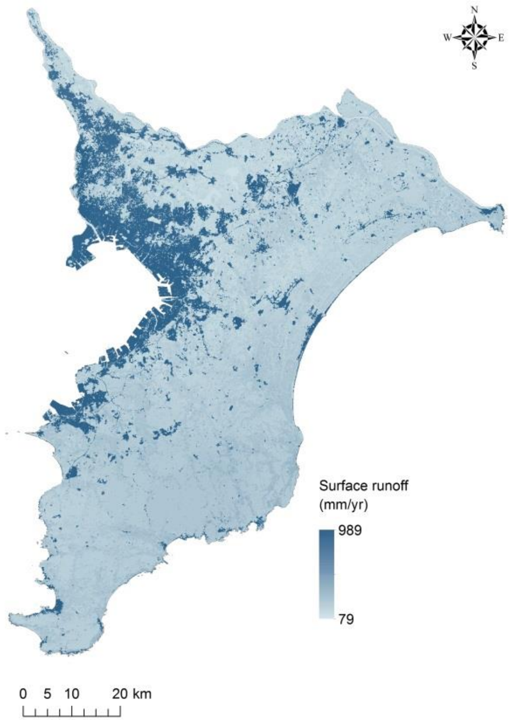


Figure 4-7. Surface runoff and subsurface runoff

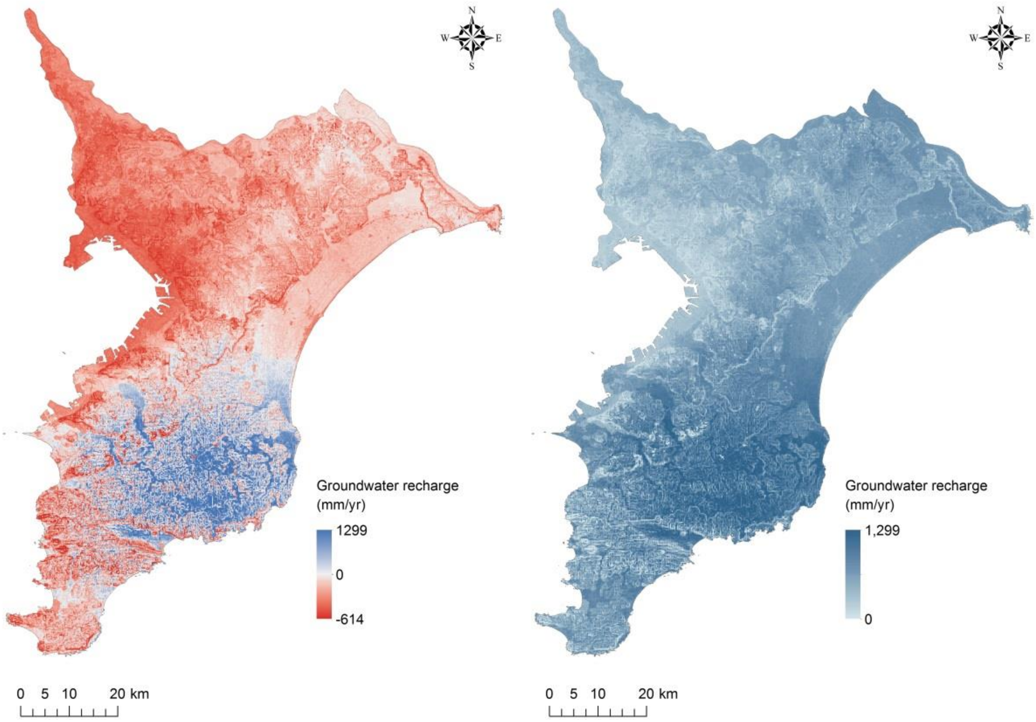


Figure 4-8. Estimated and adjusted groundwater recharge

4.5. Water Regulation – Water Purification

Removal of both total nitrogen (T-N) and total phosphorus (T-P) contained in the water is evaluated for forest ecosystems, wetlands, seagrass bed and tidal marsh, while removal of only T-N is evaluated for paddy fields and lakes due to their low capacities to remove T-P. To do this, the unit values are estimated from the existing information. The potential source of nutrients such as crop lands and urban areas are excluded from the analysis.

The unit values of T-N and T-P removal in forests are estimated by subtracting nutrient exports from nutrient inputs attributed to rainfall. The T-N concentration in the rainfall around the Kanto region (where Chiba prefecture is located) was obtained from Aoi et al. (2002). Multiplied by the average annual rainfall in the prefecture (i.e. 1,813mm), the T-N input was estimated 39.7kg-N/ha/year. As for the T-N export from forests, 242 case studies across the nation were collected from academic journals and conservation plans for lake water quality, classified into broad-leaf, needle-leaf and mixed forests. Obtaining the T-P concentration in the rainfall on national average from Tabuchi (1985), the T-P input was also estimated 0.73kg-P/ha/year in the same way. These values are summarised in Table 4-4.

Removal capacity of T-N in the paddy fields is estimated by subtracting exports from inputs through irrigation. 78 case studies on T-N inputs were collected from academic journals and conservation plans for lake water quality, resulted in 95.1kg-N/ha/year on average (Table 4-5). As it was revealed that the T-P exports exceed inputs by 3.0kg-P/ha/year, exclusion of T-P removal in the paddy field from this assessment can be justified.

The following equation is applied to estimate denitrification capacity of T-N in the Tega Marsh, which encompasses an area of 6,500ha (Ueda and Ogura, 1989):

$$R_n = 5.8Tw^{1.2}$$

where R_n is the removal capacity (kg-N/day) and *Tw* is the water temperature in degrees Celsius. Assuming that *Tw* is 15.0 degrees Celsius constantly, the denitrification capacity was estimated at

Table 4-4. Unit values related to T-N and T-P in the forest ecosystems

(kg/ha/year)

Forest type	T-N		T-P		Land cover type in this study
	Export	Removal capacity	Export	Removal capacity	
Broad-leaf	10.9	28.8	0.30	0.43	evergreen broad-leaf, deciduous broad-leaf, green space
Needle-leaf	7.1	32.6	0.24	0.49	needle-leaf
Mixed	6.7	33.0	0.31	0.42	woodland

Source: multiple documents

Table 4-5. Unit values related to T-N and T-P in paddy fields

（kg/ha/年）

	Gross export		Net export*	
	T-N	T-P	T-N	T-P
Max	70.0	31.000	368.7	32.850
Min	-15.1	0.023	-1,164.4	-10.950
Mean	16.5	1.830	-95.1	3.011
Median	10.9	0.770	5.6	0.550

Note*: This is the value subtracting inputs from gross exports: the negative values indicate removal potentials of paddy fields.
Source: multiple documents

Table 4-6. Removal capacity of T-N and T-P in reed bed, seagrass bed and tidal marsh

Land cover type	Nutrient	Removal capacity (as shown in the document)	Removal capacity (kg/ha/year)	Literature
Reed bed	T-N	80.0mgN/m^2/day	292.0	Kusuda (1994)
Reed bed	T-P	8.5mgP/m^2/day	31.0	Kusuda (1994)
Seagrass bed	T-N	44.0mgN/m^2/day	160.6	Sasaki (1989)
Seagrass bed	T-P	4.4mgP/m^2/day	16.1*	Sasaki (1989)
Tidal marsh	T-N	493.5μmolN/m^2/h	605.2	Kuwae et al. (2000)
Tidal marsh	T-P	217.7μmolP/m^2/h	286.1	Kuwae et al. (2000)

Note*: This is estimated by the authors based on Sasaki (1989), which considers the phosphorus content of eelgrass is approximately one-tenth of the nitrogen content.
Source: multiple documents

84.0kg-N/ha/year[18]. Since the annual inputs of T-N are estimated 70.8kg-N/ha/year in 2010 (Chiba prefecture, 2012), the denitrification capacity exceeds the inputs under the above assumption. The values of reed bed (wetland), seagrass bed and tidal marsh are obtained from the respective literatures shown in the Table 4-6.

The summary of the water purification evaluation is indicated in Annex and Figure 4-9. The total T-N and T-P removal in the prefecture were estimated 18.6 thousand t-N/year and 684t-P/year, respectively.

[18] Yoshida et al. (1979) estimated the denitrification capacity of Kasumigaura Lake at 1.4 – 34.1t-N/ha/year, which largely differs from this result, hence, verification of the information will be needed.

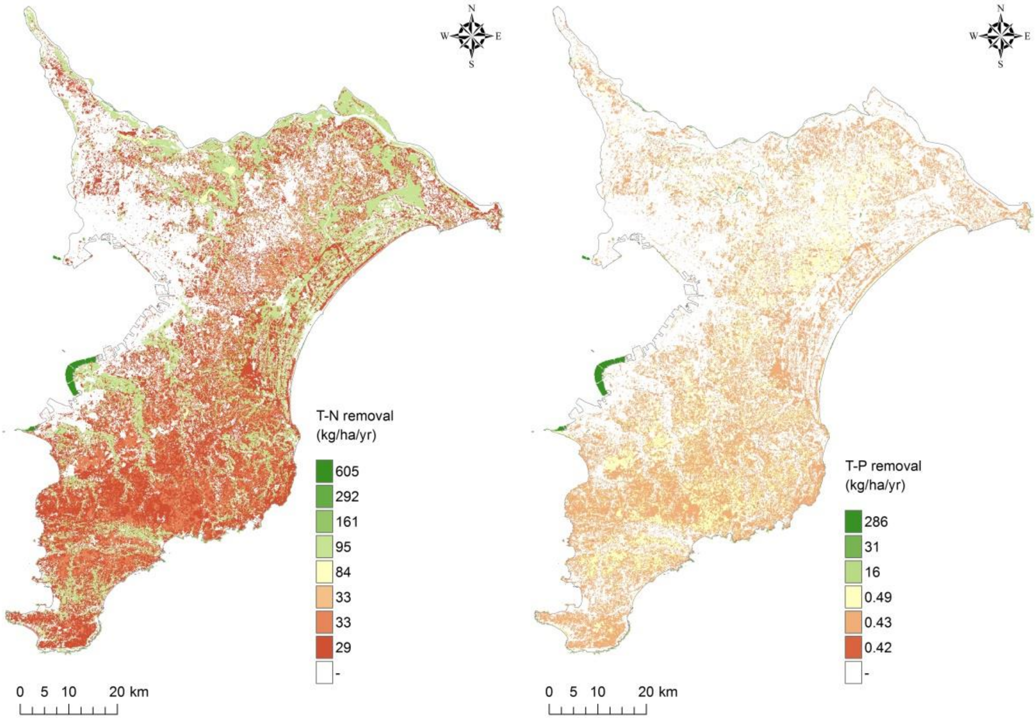


Figure 4-9. T-N and T-P removal

4.6. Soil Conservation – Soil Erosion Prevention

The level of prevention is quantified by estimating the soil erosion volume with and without vegetation using the Universal Soil Loss Equation (USLE):

$$E = R \times K \times L \times S \times C \times P$$

where *E* is soil loss (t/year), *R* is the rainfall and runoff factor, *K* is the soil erodibility factor, *L* is the slope length factor, *S* is the gradient factor, *C* is the crop factor, and *P* is the practice factor. Although the USLE has been developed for the analysis on the soil loss in agricultural lands in the U.S., it can be applied to the mountainous forests in Japan (Kitahara, 2002).

Since complex datasets (e.g. the number of rainfall events in a year and maximum rainfall intensity in 30 minutes for each rainfall event) are required to estimate the rainfall and runoff factor *R*, it was simply obtained from Imai and Ishiwatari (2006a) (R = 377.3). The mean values of soil erodibility factor *K* by soil class were also obtained from Imai and Ishiwatari (2006b), then applied to the soil map provided by the Ministry of Land, Infrastructure, Transport and Tourism (MLIT)[19] (Table 4-7).

[19] Japanese website can be accessed from: http://nrb-www.mlit.go.jp/kokjo/inspect/landclassification/download/index.html.

Table 4-7. Soil erodibility factor by soil class

Soil class	Soil erodibility factor (K)	Soil type in this study
Lithosols		
Sand-dune Regosols	0.019	Sand-dune Regosols
Humic Andosols	0.012	Humic Andosols
Andosols	0.021	
Gleyed Andosols	0.042	
Brown Forest soils	0.028	Brown Forest soils
Gray Upland soils	0.041	
Gley Upland soils	0.034	
Red soils	0.039	
Yellow soils	0.037	
Dark Red soils	0.026	Dark Red soils
Brown Lowland soils	0.051	Brown Lowland soils
Gray Lowland soils	0.047	Gray Lowland soils
Gley soils	0.043	Gley soils
Muck soils	0.030	
Peat soils	0.019	Peat soils

Note: The value of 0.001 was applied to rocks, surface water and undefined area, which are included in the soil map.
Source: Imai and Ishiwatari (2006b)

The slope length factor *L* and the gradient factor *S* are estimated by the following equations which can be applied to the steep slopes (Renard, 2011):

$$L = (l/72.6)^{0.5}$$

$$S = \begin{cases} 10.8 sin\theta + 0.03, if\ slope \leq 9\% \\ 16.8 sin\theta - 0.50, if\ slope > 9\% \end{cases}$$

where *l* is the slope length (m), and θ is the slope degree. The elevation mesh by 1m resolution was acquired from the Base Map Information operated by the Geospatial Information Authority of Japan[20]. The slope length is calculated on the assumption that the horizontal length is 5m everywhere, subsequently resized into 100m resolution with the bi-linear interpolation method (Figure 4-10).

As for the crop factor *C* and the practice factor *P*, they were obtained from Japan Wildlife Research Center (2006) (Table 4-8).

Conversion from forests to barren lands and from agricultural lands to deserted cultivated lands were assumed to estimate the soil erosion volume without vegetation. As a result of analysis, the soil loss in the current state was estimated 0 – 72t/ha/year, and that after conversion was estimated 0 – 114t/ha/year (Figure 4-11). Subtracting the former from the latter (Figure 4-12), the

20 Japanese website can be accessed from: http://fgd.gsi.go.jp/download/.

total soil erosion prevention in the prefecture was estimated 2.7 million t/year.

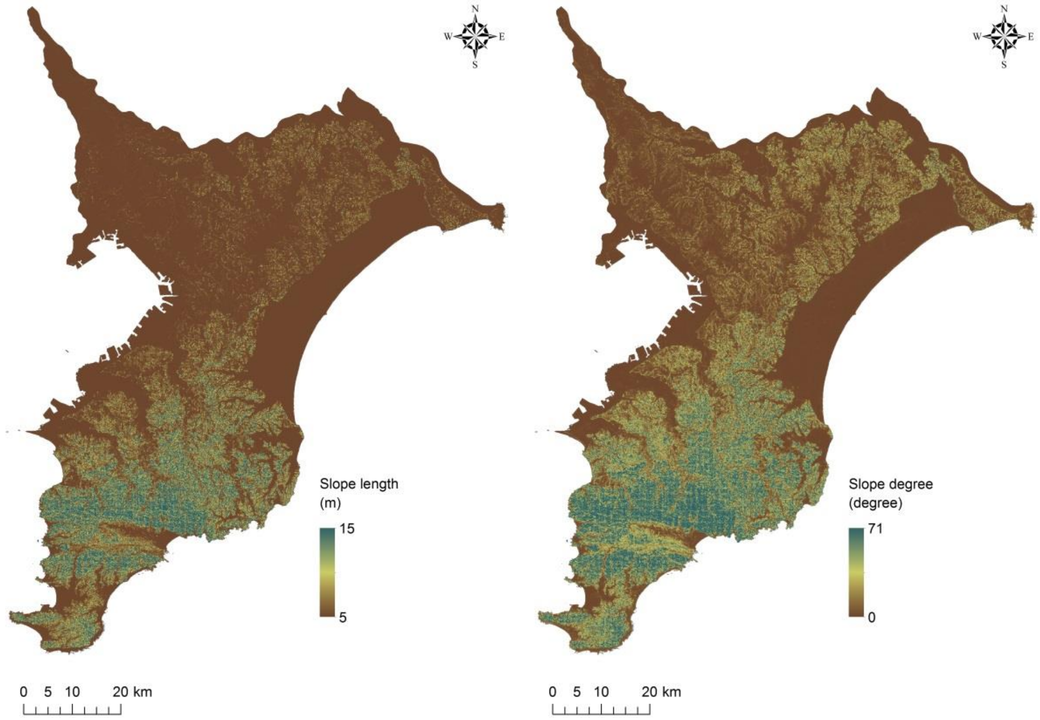


Figure 4-10. Slope length and degree

Table 4-8. Crop factor and practice factor by land cover type

Original land cover type	Crop factor (C)	Practice factor (P)	Land cover type in this study
Paddy field	0.30	0.10	paddy fields
Crop land	0.40	0.40	crop land, orchid
Forest (understory vegetation coverage rate higher than 10%)	0.01	0.10	evergreen broad-leaf, deciduous broad-leaf, woodland, bamboo forest
Forest (understory vegetation coverage rate lower than 10%)	0.01	0.40	
Barren land	1.00	1.00	barren land, deserted cultivated land
Urban area	0.00	0.10	
Main roads	0.00	0.10	
Other developed lands	0.00	0.10	
River	0.00	0.00	
Golf course	0.02	0.30	grassland

Source: Japan Wildlife Research Center (2006)

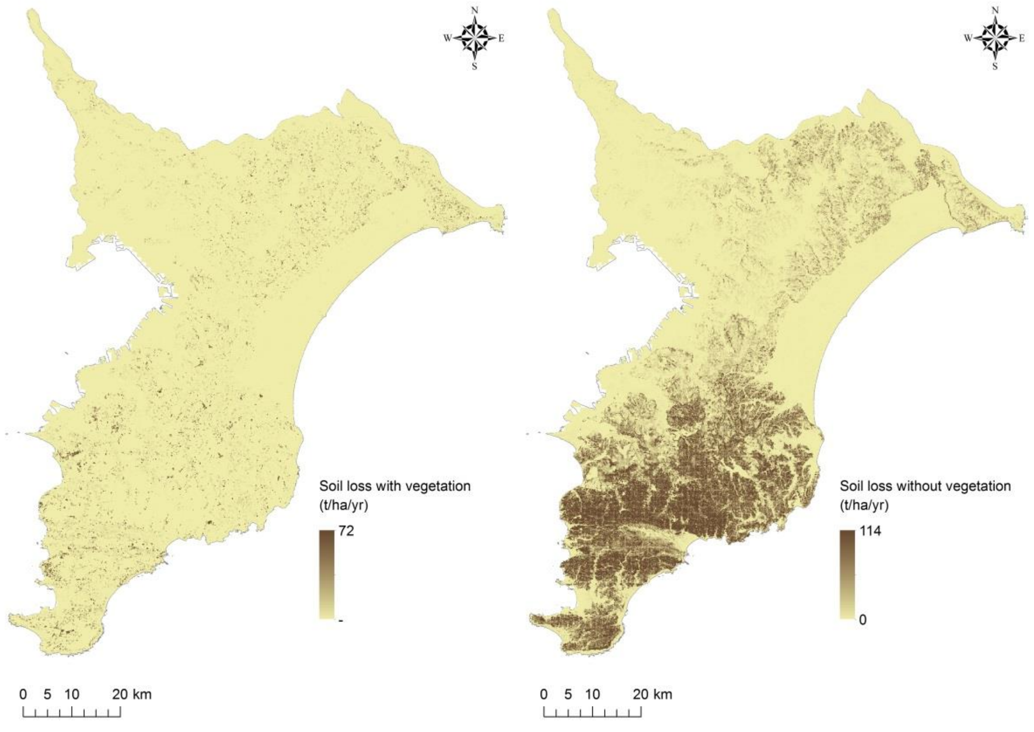


Figure 4-11. Soil loss with and without vegetation

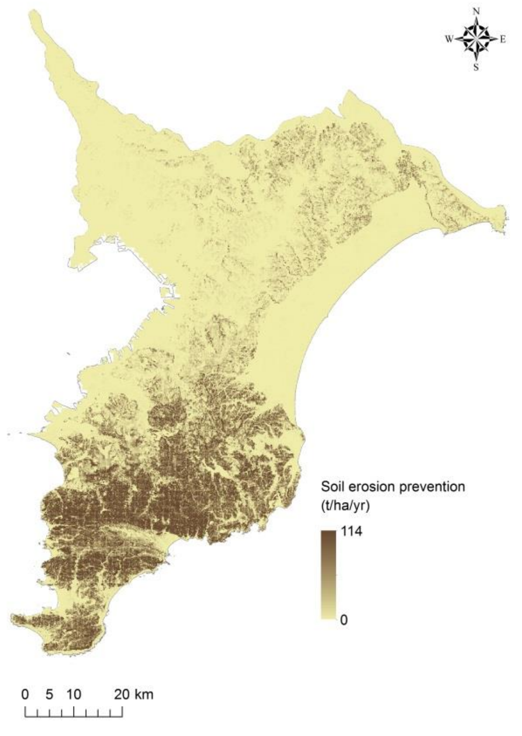


Figure 4-12. Soil erosion prevention

4.7. Soil Conservation – Soil Fertility Maintenance

The amount of nutrients, i.e. nitrogen and phosphorus, maintained owing to soil erosion prevention is evaluated by simply multiplying prevented soil loss by each concentration in the top soil. The nutrient concentration data were obtained from the Soil Information Viewing Systems developed by the National Institute for Agro-Environmental Science[21], averaged by soil class and reclassified into the soil classification applied in this research (Table 4-9). The total nitrogen and phosphorus maintenance in the prefecture were estimated 259t/year and 2,749t/year, respectively.

4.8. Natural Hazard Mitigation – Flood Control

While the above water regulation evaluates annual water flow, flood occurrence is considered herein as short-term water movement. The peak flow volumes with and without vegetation are estimated by the rational formula[22,23]:

$$Q = 1/360 \times f \times r \times A$$

Table 4-9. Nutrient concentration by soil class

(mg/100g)

Soil class	Nitrogen concentration	Phosphorus concentration	Soil type in this study
Lithosols	11.6	261.1	Lithosols
Sand-dune Regosols	3.5	139.3	Sand-dune Regosols
Humic Andosols	7.6	67.4	Humic Andosols
Andosols	15.8	38.3	
Gleyed Andosols	17.8	29.6	
Brown Forest soils	7.7	132.9	Brown Forest soils
Gray Upland soils	11.1	52.8	
Gley Upland soils	13.4	28.3	
Red soils	7.3	231.0	
Yellow soils	7.5	137.8	
Dark Red soils	3.6	76.7	Dark Red soils
Brown Lowland soils	5.8	141.7	Brown Lowland soils
Gray Lowland soils	11.0	72.9	Gray Lowland soils
Gley soils	14.7	32.0	Gley soils
Muck soils	15.0	29.3	
Peat soils	13.2	26.7	Peat soils

Source: The Soil Information Viewing Systems, modified by the authors

21 Japanese website can be accessed from http://agrimesh.dc.affrc.go.jp/soil_db/.
22 This equation is frequently used for small to medium size watershed (Chiba Prefecture, 2006).
23 Although the difference of peak flow volume is simply considered as a flood control service in this research, only the case that peak flow exceeds the threshold of flood should be evaluated from the perspective of ecosystem service demand.

Table 4-10. Runoff coefficient

Land cover type	Runoff coefficient*	Land cover type in this study
Forest	0.25 - 0.65	evergreen broad-leaf, deciduous broad-leaf, evergreen needle-leaf
Woodland, cropland	0.35 - 0.75	woodland, bamboo, paddy field, crop land, orchid
Grassland	0.45 - 0.85	grassland
Rock	0.50 - 0.90	barren land, deserted cultivated land
City	0.90 - 0.95	
Residential area	0.70 - 0.80	
Paved road	0.85 - 0.98	
Gravel road	0.60 - 0.75	
Garden	0.45 - 0.55	
Forested area	0.35 - 0.40	
Park	0.55 - 0.65	

Note*: Each middle value is adopted in the analysis. The mean value of city, residential area and paved road is applied to the urban area, and that of forested area and park is applied to green space.
Source: Forestry Agency (year unknown)

where Q is peak flow volume (m^3/sec), f is the runoff coefficient, r is the rainfall intensity within the time of flood concentration (mm/hour), and A is the watershed area size (ha). The runoff coefficients of each land cover type were obtained from Forestry Agency (year unknown) as shown in Table 4-10, and subsequently averaged by each watershed. Then, two maps of watersheds (one represents the small watersheds but at least larger than 200ha and the other symbolises larger basins which contain these small watersheds) were created with the elevation map obtained from the NLNI.

The Kraven's formula is applied to estimate time of flood concentration (MLIT and CERI, year unknown), assuming that inlet time is a part of flow time for simplification purposes:

$$t = 1/3600 \times L/W$$

where t is flow time (hour), L is the flow length (m), and W is the flood propagation velocity (m/sec). Followed by the estimation of the flow length L for each small watershed with the GIS (Figure 4-13), the flood propagation velocity W was calculated with the comparison table below (Table 4-11).

With the estimated flow time t above, the rainfall intensity is calculated by the Fair equation developed by the Civil Engineering Research Institute as follows:

$$r = b \times T^m/(t + 0.5 + a)^n$$

where T is recurrence interval, a, b, m and n are all the parameters calculated in each observation point. These parameters in Chiba were acquired from the same source (Table 4-12), then spatially

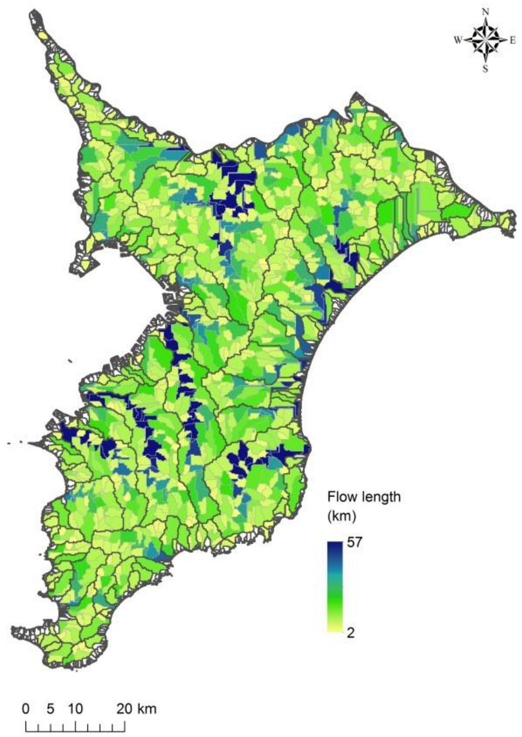


Figure 4-13. Flow length

Table 4-11: the relationship between flow length and flood propagation velocity

*I**	>1/100	1/100 – 1/200	<1/200
W	3.5m/sec	3.0m/sec	2.1m/sec

Note*: *I* is the value calculated as the elevation gap between upstream edge and estuary divided by the flow length *L*.
Source: MLIT and CERI (year unknown)

Table 4-12. Each parameter in the Fair equation

Observation point	Latitude	Longitude	a	b	m	n
Sahara	35.9014	140.4853	2.26	59.7	0.30	0.85
Abiko	35.8681	140.0333	4.76	129.8	0.26	1.00
Tojo	35.8169	140.6850	2.47	71.4	0.28	0.87
Sakura	35.7183	140.2167	3.85	76.1	0.28	0.89
Yokoshiba	35.6506	140.4836	2.61	81.1	0.26	0.92
Mobara	35.4025	140.3022	1.39	54.2	0.23	0.74
Kisarazu	35.3681	139.9175	1.06	41.3	0.26	0.69
Ushiku	35.3853	140.1503	5.58	144.5	0.23	0.95
Sakahata	35.2192	140.1003	3.24	80.9	0.28	0.82
Kurohara	35.2347	140.2350	3.42	86.7	0.25	0.81
Sakuma	35.1022	139.8686	5.28	140.8	0.32	0.98
Kamogawa	35.1017	140.1006	2.36	71.6	0.23	0.82
Katsuura	35.1358	140.3025	2.15	98.2	0.22	0.88
Tateyama	34.9833	139.8669	3.52	107.5	0.22	0.91

Source: AMeDAS Probable Rainfall Analytical Program by Civil Engineering Research Institute, Available at https://www.pwri.go.jp/jpn/seika/amedas/top.htm.

interpolated over the prefecture with the inverse distance weighting method. Setting T as one year[24], mean rainfall intensity in each watershed is estimated as Figure 4-14.

Lastly, the peak flow volumes with and without vegetation were estimated (Figure 4-15). The watersheds located in downstream areas show higher values in both maps, resulting in the similar characteristics of flood control map (Figure 4-16). This consequence may imply that estimation was substantially affected by watershed area size and flow length, and that the elasticity of small land cover change can be considered low.

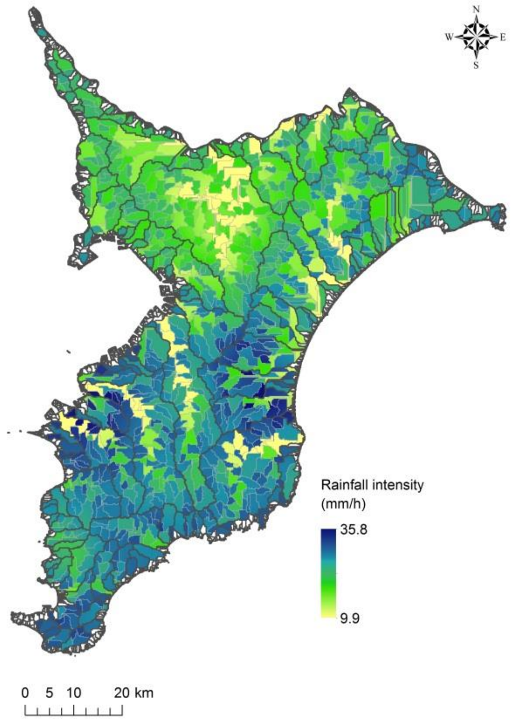


Figure 4-14. Rainfall intensity within the time of flood concentration[25]

[24] Note that this will largely affect the estimated rainfall intensity.

[25] Mean rainfall intensity in an hour becomes relatively small in the watershed having the longer time of flood concentration, because the rainfall volume does not much differ as the flow length does.

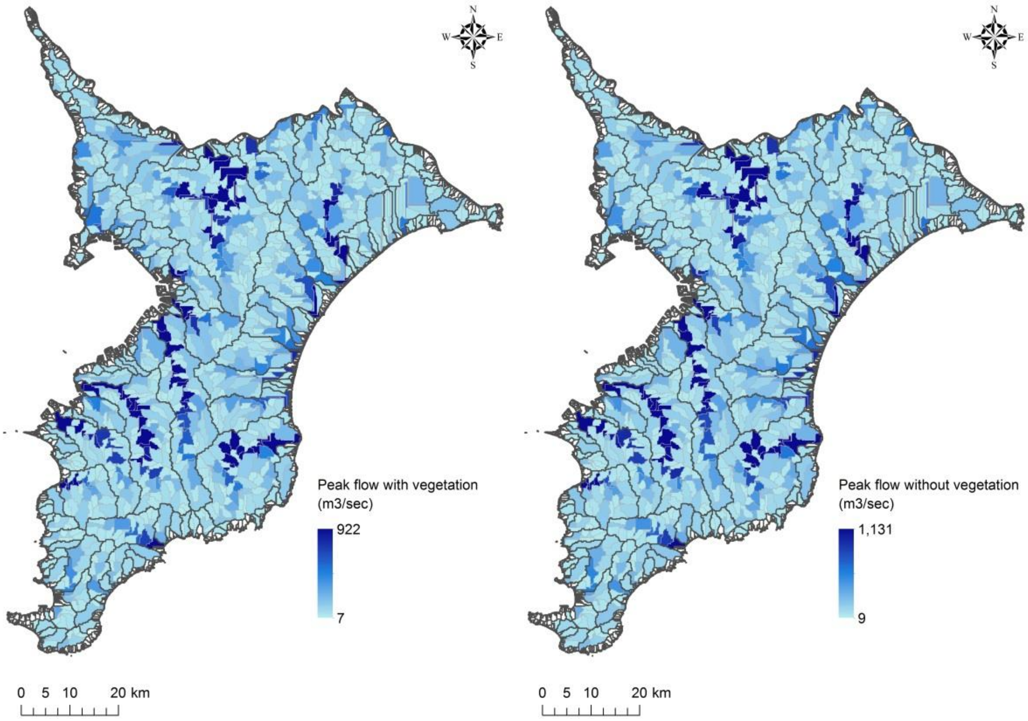


Figure 4-15. Peak flow volume with and without vegetation

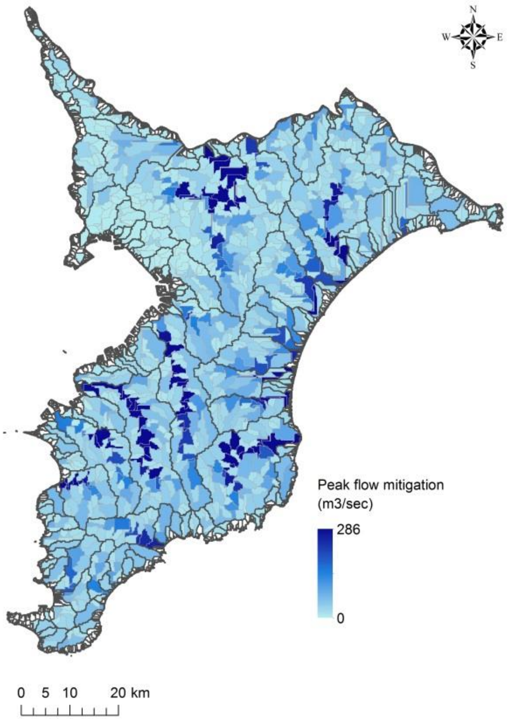


Figure 4-16. Peak flow mitigation

4.9. Natural Hazard Mitigation – Landslide Mitigation

The improvement in safety rate (less than one is judged dangerous) which can be attributed to the existence of vegetation, inter alia, the positive impact of tree roots on shear force resistance of soil, is evaluated[26]. Abe (1997, pp.170) indicates the following estimation formula:

$$\Delta FS = \Delta S/(Hs \times \delta \times sin\theta)$$

where ΔFS is the improvement in safety rate, ΔS is the intensity of reinforcing shear force resistance of soil by tree roots (kgf/m^2), *Hs* is the soil depth (cm), δ is the unit weight of saturated soil (kN/m^3), and θ is the slope degree. This formula satisfies the following equation:

$$FS = (c + \Delta S + Hs * \delta * tan\emptyset cos\theta)/(Hs * \delta * sin\theta)$$

where *c* is the coefficient, and $\emptyset$ is the degree. Abe (1997, pp.170) sets *c* = 200 kgf/cm^2 and $\emptyset$ = 34 degree as default.

The regression function of ΔS was analysed from the table in Abe (1997, pp.170), which explains the relationship among soil depth, forest age and the intensity of reinforcing shear force resistance of soil by tree roots. The regression equation is as follows:

$$\Delta S = 240.95 - 2.00Hs + 5.15Fa$$

where *Fa* is the forest age. The mean forest age of each forest type was calculated in Section 4.1. The soil depth *Hs* by soil type was obtained from the Global Soil Profile Data by ISRIC-WISE,

Table 4-13. Soil depth by soil class

Soil class	Soil depth (cm)
Sand-dune Regosols	90.6
Humic Andosols	123.1
Brown Forest soils	119.9
Gley soils	123.4
Dark Red soils	137.2
Gray Lowland soils	123.4
Brown Lowland soils	123.4
Peat soils	155.3
Rocks	9.9

Source: the Global Soil Profile Data by ISRIC-WISE, available at http://www.isric.org/data/data-download.

[26] As a landslide event hardly ever occurs at a place where the slope degree is less than 25 degrees, only slopes with degrees larger than 25 are evaluated here.

which was then reclassified into the soil class applied in this research (Table 4-13). The unit weight of saturated soil δ was also estimated $18kN/m^3$ from Abe (1997, pp.170 - 171). So as to calculate the slope degree θ, the elevation mesh used for the estimates of soil erosion prevention was reutilised.

The estimation results of the safety rates with and without vegetation and the improvement in safety rate were demonstrated in Figure 4-17 and Figure 4-18. As shown, the safety rate could be improved by 5.6 points at the maximum in the southern part of the peninsula.

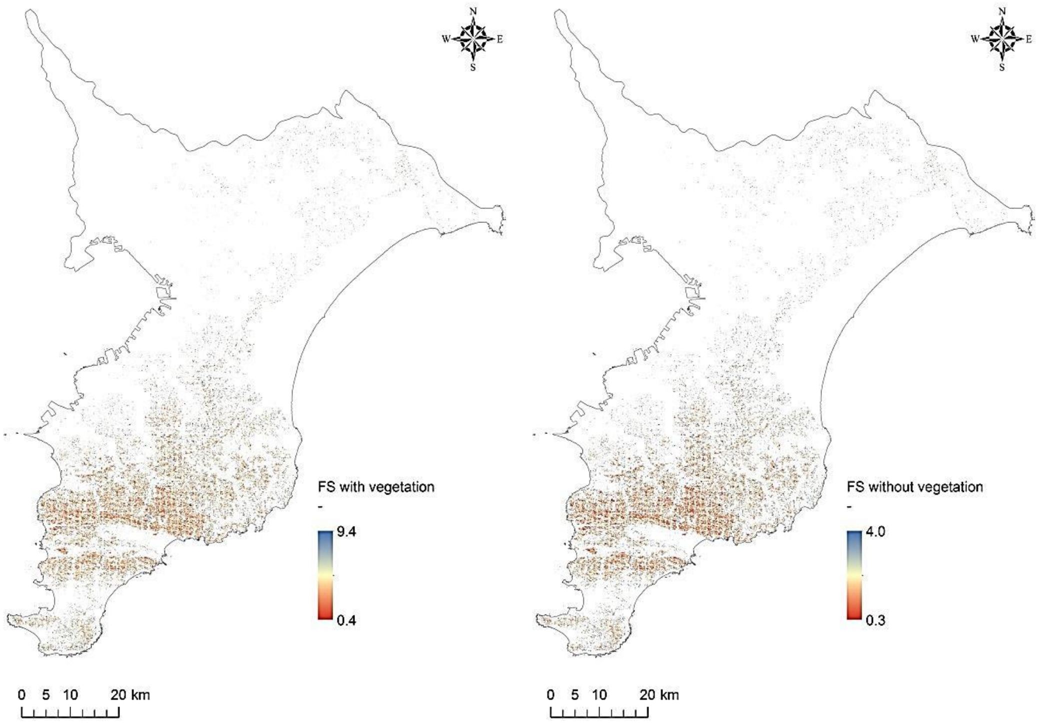


Figure 4-17. Safety rate with and without vegetation

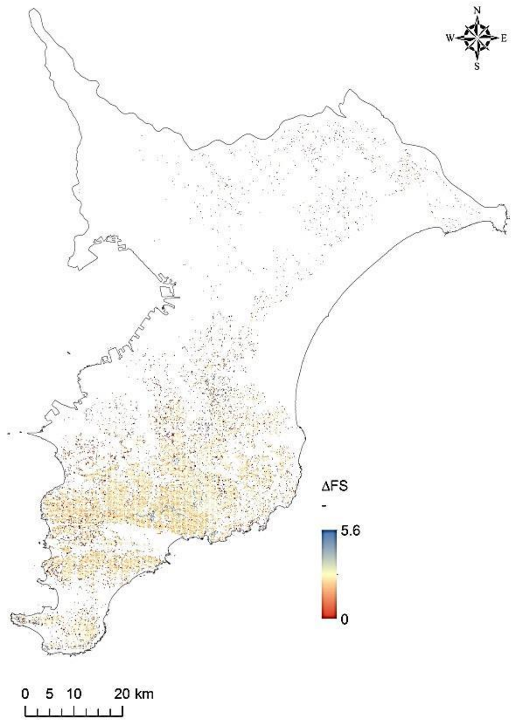


Figure 4-18. Improvement in the safety rate

4.10. Natural Hazard Mitigation – Wave Mitigation

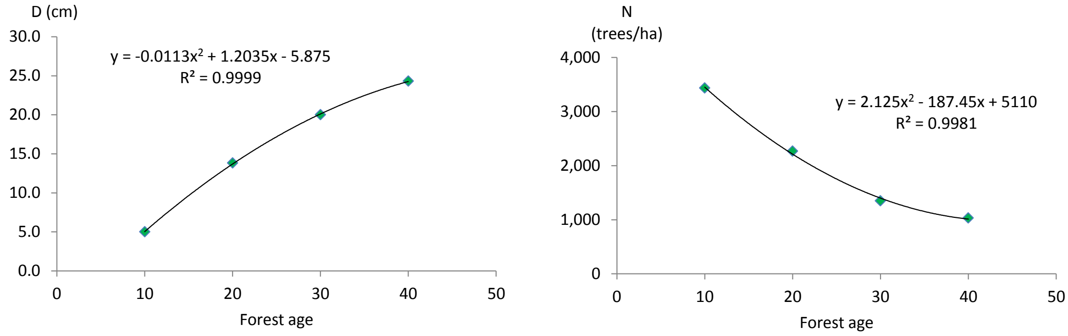
The expected wave mitigation function of forests is evaluated by the equation indicated in Koyama (1948):

$$log_e\left(\frac{V_0}{V}\right) = \frac{L \times C_D \times D \times N}{2 \times 10^4}$$

where V_0 is the wave intrusion velocity (m/sec), V is the wave velocity after passing through forests (m/sec), L is the forest width (m), C_D is the resistance coefficient of trees (assumed 1.0 herein (see Kawai, 2012, pp.10)), D is the diameter at breadth height (cm), N is the tree density (trees/ha).

As it will be difficult to take into account the forest width depending on the wave intrusion direction, all the forests within a distance of 1km from the coastline are simply evaluated by 100m mesh (i.e. the forest width L is always 100m). Based on the simulation conducted in Abe (1997, pp.164), the approximate curve was plotted which explains the relationships of forest age with the diameter at breadth height D and the tree density N (Figure 4-19).

Figure 4-20 shows the estimation result. The forest age has a strong influence in this analysis, but its impacts on the diameter and the density are opposite, resulting in the maximum wave mitigation function of woodlands to which the average forest age was given.



Soucre: Abe (1997, pp.164), revised by the authors

Figure 4-19. Diameter at breadth height and tree density

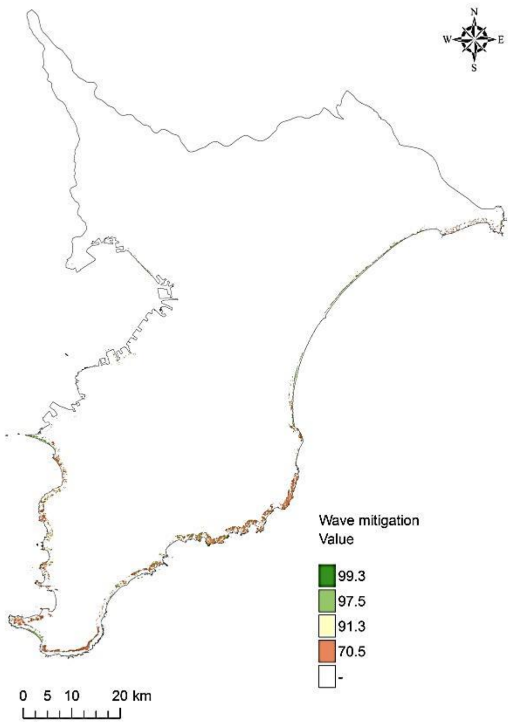


Figure 4-20. Wave mitigation

4.11. Conclusion and Discussion

The quantification results are summarised in Table 4-14, which may present the substantial benefits people can obtain from surrounding ecosystems. We should note, however, that this quantification exercise only focused on the supply side of services, namely, the demand for the services was not taken into consideration in this analysis[27]. In this sense, these results can be understood as the representation of ecosystem functions rather than ecosystem services.

As mentioned in Section 1.1., this analysis is the first step of the quantification exercise. We have not validated the results except for a minor comparison with other indicators (e.g. annual evapotranspiration versus rainfall). An examination of the parameters and calculation results is indispensable in the quantitative analysis of ecosystem services. To do this, ground-truthing may be required, but can be challenging if the target area is large. Where multiple models are available, it would be best to consider the adequacy of estimates based on a comparison of results from various models.

[27] For instance, purification of water under the condition that water quality standard is fulfilled cannot be recognised as a service to the people.

Table 4-14. Summary of the estimation of regulating services

Ecosystem services			Forest	Agricultural land	Urban area	Freshwater	Coastal zone
Regulating	Climate regulation	GHGs sequestration ($t\text{-}CO_2$/year)	CO2 sequestration capacity 558×10^3		CO2 sequestration capacity 113×10^3	CO2 sequestration capacity 2.9×10^3	CO2 sequestration capacity 1.5×10^3
		Heat latent effect (m^3/year)	Evapotrans-piration 1.1×10^9	Evapotrans-piration 802×10^6	Evapotrans-piration 589×10^6	Evapotrans-piration 72×10^6	Evapotrans-piration 18×10^6
	Air quality control (t/year)		SO2 absorption capacity 25 NO2 absorption capacity 708	SO2 absorption capacity 235 NO2 absorption capacity 707	SO2 absorption capacity 193 NO2 absorption capacity 672	SO2 absorption capacity 3.0 NO2 absorption capacity 7.0	
	Water regulation	Water flow regulation (m^3/year)	Groundwater recharge 594×10^6	Groundwater recharge 1.0×10^9	Groundwater recharge 583×10^6	Groundwater recharge 65×10^6	
		Water purification (t/year)	Nitrogen removal 5.0×10^3 Phosphorus removal 75	Nitrogen removal by paddy fields 10×10^3	Nitrogen removal 1.5×10^3 Phosphorus removal 22	Nitrogen removal by reed bed 82 Phosphorus removal by reed bed 74	Nitrogen removal by seagrass bed and tidal marsh 1.2×10^3 Phosphorus removal by seagrass bed and tidal marsh 513
	Soil conservation	Soil erosion prevention (t/year)	Soil runoff mitigation 2.4×10^6	Soil runoff mitigation 328×10^3			
		Soil fertility maintenance (t/year)	Nitrogen retention 222 Phosphorus retention 2.5×10^3	Nitrogen retention 37 Phosphorus retention 239			
	Natural hazard mitigation	Flood control	Peak runoff mitigation (calculation of total amount irrelevant to analysis)				
		Landslide mitigation	Increase in safety factor (idem)				
		Wave mitigation	Wave speed reduction (idem)				

5. Conclusion and the Way Forward[28]

Measuring and mapping ecosystem services is an important first step for their sustainable management. Quantification of ecosystem services, inter alia, regulating services, in biophysical terms with spatial techniques is a relatively new field even in academia, and is gradually attracting policy attention at international conferences (e.g. CBD-COP and IPBES).

This study quantified a wide range of ecosystem services from supporting to provisioning and regulating services in a spatially explicit way in most of its assessments. As no single publication has demonstrated biophysical quantities of such a wide range of ecosystem services focusing on one region (at least in Japan), this could be the first comprehensive report on the spatial quantification of ecosystem services.

Through a series of quantification exercises, on the other hand, we have noted several challenges that need to be tackled in order to improve the biophysical assessment of ecosystem services. Apart from the limitations in the existing methodologies and data availability, critical issues in measuring ecosystem services can be illustrated as follows:

- Supply and demand: based on the understanding that the ultimate aim of quantifying ecosystem services is to achieve its sustainable use by balancing supply and demand, there is a need to measure both the amount of ecosystem services currently available and the amount currently used, and to compare them in order to assess whether current ecosystem service supply is fulfilling the demand of the people. We should note that oversupply can be also expected as discussed in Section 4.11.
- Stock or flow: particularly in calculating provisioning services, it should be clearly determined whether we will measure the potential maximum amount of ecosystem services (i.e. the stock) or the sustainable amount of extraction (i.e. the flow), depending on the purpose of the studies. We should take the former approach when considering future resource availability, while the latter can be used for evaluating current resource balance.
- Man-made ecosystem services: the treatment of ecosystem services derived from man-made structures (e.g. foods from agricultural lands and freshwater from concrete dams) should be clarified. When deciding whether these elements should be included or not, we should bear in mind that there remains the difficulty of distinguishing the purely natural and partially artificial products often mixed up in the natural environment (e.g. freshwater in river streams).

[28] Although most of the discussions in this section were recognised among those who have been involved in this research, these conclusions should be understood to be those of the authors and not attributed to MOEJ.

- Geographical measurement scale: due to the fact that the distribution of ecosystem services does not necessarily coincide with decision-making units such as municipalities or provinces (e.g. CO2 sequestration at the global scale and water regulation in large basins), the scale of the target area would need to be tailored according to the distribution of each ecosystem service, although this may pose the problem of inconsistency of geographical scale in the assessment.

This report did not clearly tackle these challenges; the demand of ecosystem services and the sustainable level of extraction were not necessarily estimated, and the benefits from neighbouring prefectures holding large water sources and carbon sinks were not considered. These issues have to be addressed in future studies.

In addition to the general issues prevailing in an ecosystem service quantification exercise, our study will need further specific enhancement in terms of methodology, scope and simulations as explained below:

- Refining the methodology: the methodology applied in this report requires further improvement in the consistency between various indicators and the temporal uniformity. The former issues are mainly represented by the considerations of synergies, trade-offs and double-counting. Due to the nature of quantitative analyses, it is difficult to add or subtract between different ecosystem services. However, there can be positive and negative relationships between them (e.g. water regulation and flood control, or timber harvest and soil erosion prevention). Since the individual methodologies in this report have been selected in light of their appropriateness for estimating each ecosystem service indicator, the overall framework of quantification and the criteria for selecting methodologies need to be reviewed from these perspectives. Regarding the temporal uniformity, the same data year should be set among parameters, although this is not an easy task when relying on open data sources. It will be far more difficult to collect time-series datasets, inter alia, on annual land cover maps with a certain level of detail in the vegetation classifications, which are essential for analysing the interannual changes of ecosystem services. To do so, data collection in one specific site over the years will be required.
- Expanding the scope: as pointed out earlier, the ecosystem services strongly linked to biodiversity, i.e. biological resources such as medicine and genetic resources, and biological control such as pollination and pest control, could not be evaluated in these quantification exercises. As for the former, it is still controversial whether only resources which have been proven to be beneficial (e.g. medicine originating from natural resources) should be quantified, or whether the probability of living species being beneficial in the future (e.g. predicted number of beneficial species among millions of existing species) should be evaluated. The formulation of indicators and calculation methodologies will be of importance. Similarly, further knowledge

will be required to quantify biological control. Although the role of biodiversity in preventing local pest outbreaks has been reported in some studies, the relationship between diversity and probability of occurrence has not been fully investigated yet. Cultural services have also been excluded from the analysis. Except for recreation and eco-tourism, however, it will be impossible to measure the quantity of cultural services per se (e.g. aesthetic value and sense of place). Alternative approaches, such as development of a relevant index, economic valuation or social valuation, need to be considered for their quantitative evaluation[29].

- Building scenarios: ecosystem services are highly dependent on land use, and future changes can impact on the level of services provided. Therefore in order to benefit sustainably from ecosystem services, it is necessary to conduct quantitative analyses of future land use scenarios. As indicated above, this would require the analysis of trade-offs. For instance should a forest be cleared for agriculture, the benefits of the expected harvest will have to be weighed against the degradation of other ecosystem services. With this in mind, this study has calculated the capacity of food and material provisioning services based on the assumption that current yields are at maximum productivity. However, this is based on current levels of fertilizer and water inputs, and therefore cannot be used to develop scenarios promoting sustainable production activities in hilly areas for example. Depending on the scenario, adjustments of parameters and assumptions will be required.

Measuring ecosystem services in biophysical terms contributes to understanding the current conditions of natural capital, communicating them to a wide range of stakeholders, setting environmental policy targets, formulating landscape plans based on the full potential of ecosystem services, and developing ecosystem accounts. This report has demonstrated the possibility of quantifying ecosystem services in a spatially explicit manner and has also highlighted some of the challenges in improving the robustness and accuracy of the evaluation. Future research on ecosystem services modelling should incorporate these aspects and be expanded towards developing a simulation tool for analysing the impacts of possible scenarios on both our livelihoods and the natural environment.

[29] The definition of social valuation is not clarified, so it was raised as one of the major issues in the IPBES.

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Annex

The parameters attached to the land cover type in this study

Ecosystem services	Parameter	Forest							Agricultural land				Urban		Freshwater			Coastal zone	
		evergreen broad-leaf	deciduous broad-leaf	needle-leaf	woodland	bamboo	grassland	barren land	paddy field	crop land	orchid	deserted cultivated land	urban area	green space	river	lake	wetland	seagrass bed	tidal marsh
Habitat provision	Area (1000ha)	46.8	54.6	62.9	0.5	6.9	15.0	0.3	106.4	56.2	5.6	12.7	83.0	51.7	9.0	1.6	2.4	1.0	1.7
Food	Unit value (t/ha/yr)	-	1.3	-	-	0.5	-	-	5.4	1.0	18.5	-			-	0.05	-	>0.00	0.01
Material	Unit value*[1]	0.5	0.5	0.5	-	118.1	-	-	-	34.3	-	-			-	-	-		
GHGs sequestration	Unit value (t-CO2/ha/yr)	2.2	2.2	5.3	2.2	-	-	-						2.2	-	-	1.2	1.5	-
Heat latent effect	Evapotrans-piration coefficient*[2]	1.00	1.00	1.00	1.00	1.00	0.84	0.49	0.68	0.69	0.67	0.87	0.70	0.64	1.00	1.00	0.35	1.00	1.00
Air quality control	Gross primary product*[2] (t-C/ha/yr)	21.5	19.3	19.2	19.9	18.6	18.0	14.5	15.6	16.1	15.4	17.2	14.8	15.6	-	-	10.5		
Water flow regulation	Pervious surface rate	0.93	0.93	0.93	0.93	0.93	0.93	0.93	0.9	0.86	0.86	0.86	0.61	0.87	0.95	0.95	0.95		
Water purification	T-N removal (kg/ha/yr)	28.8	28.8	32.6	33.0	-	-	-	95.1					28.8	-	84.0	292.0	160.6	605.2
	T-P removal (kg/ha/yr)	0.43	0.43	0.49	0.42	-	-	-						0.43	-	-	31.0	16.1	286.1
Soil erosion prevention	Crop factor	0.01	0.01	0.01	0.01	0.01	0.02	1.00	0.30	0.40	0.40	1.00							
	Practice factor	0.10	0.10	0.10	0.10	0.10	0.30	1.00	0.10	0.40	0.40	1.00							
Flood control	Runoff coefficient	0.7	0.7	0.7	0.7	0.6	0.6	0.6	0.7	0.6	0.6	0.6	0.8	0.8					
Landslide mitigation	Forest age*[2]	42.7	42.7	43.1	42.9	-	-	-											

Note: Grey colour indicates exclusion from the analysis in the light of respective natural functions, while "-" stands for data deficient.
*1: The unit for forest ecosystems is m^3/ha/year (but the unit for bamboo is bundle/ha/year) and for others is t/ha/year.
*2: The area-weighted average value of evergreen and deciduous broad-leaf and needle-leaf is applied for woodland.

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