Graduate School of Frontier Sciences, the University of Tokyo

Graduate Program in Sustainability Science

2009-2010

Master's Thesis

Land Use/Cover and Surface Water Quality at Multiple Spatial Scales in the Kanto Region

Submitted in February 2010

Supervisor: Professor Takashi Oguchi

Advisor: Professor Makoto Yokohari

(47-086823 Andy Darmawan)

Abstract

Previous research has shown that water quality in a river basin is affected by its land use/cover. However, more research is needed because findings so far vary from one river basin to another. This research assesses relationships between land use/cover and water quality in river basins of the Kanto region, Japan.

First, land use/cover changes during 1983–1986, 1989–1992, and 1995–1999 were analyzed. It was found that the changes were decreased in number with time, but increased in average size. Their spatial distribution also extended from urban and agricultural areas to forest in the upper reaches. A larger percentage of forest was converted into land constructed for residence/factories and cultivated meadows. Agricultural areas including paddy fields were also converted, especially into land constructed for residence/factories.

Second, temporal trends of water quality were analyzed. The results show overall improvement of water quality in most river basins since the 1970s, which can be attributed to the enforcement of the Environmental Pollution Prevention Law. However, degradation of water quality due to nutrient concentration was observed in some river basins. Spatially, lower water quality occurs in areas dominated by urban and agricultural land use/covers. Therefore, pollution controls applied to these areas will improve water quality.

Correlation and multiple regression analyses indicate that, for the spatial scale of the whole Kanto region, water quality is mainly related to percentages of factory/industrial areas, those of urban districts with a few trees, and those of urban/residential districts with many trees. This indicates that despite the presences of sewage systems and wastewater treatment plants, anthropogenic activities associated with land use/cover remain affecting water quality. Weed communities including those on the roadside and in both cultivated and uncultivated paddy fields play a significant role in determining water quality in the spatial scale of river basins. This suggests that resuming agriculture in areas with unmanaged weed communities will improve water quality.

Altering spatial scales used in the correlation analysis of land use/cover and water quality including multiple regression led to different results. This indicates the importance of spatial scales in analyzing relationships between land use/cover and water quality. Therefore, plannings of sustainable development should consider the use of multiple spatial scale approaches to protect water quality in an appropriate manner.

Keywords: Land use/cover, Water quality, Kanto region, River basin

Declaration

This thesis is a presentation of my original research work. Wherever contributions of others are involved, every effort is made to indicate them clearly, with due reference to the literature, and acknowledgement of collaborative research and discussion.

Date: ……………………………...

Acknowledgments

First, I offer my sincerest gratitude to my supervisor, Professor Takashi Oguchi, who has supported me throughout my thesis with his patience and knowledge whilst allowing me the room to work independently. I attributed my Master's degree to his encouragement and effort and without him, this thesis would not have been completed or written. One simply could not wish for a better or friendlier advisor.

I would also like to express my deepest gratitude to my advisor Professor Makoto Yokohari for his patient guidance, critical comments, and excellent suggestions throughout this research project. I appreciate his vast knowledge and skills in many areas. I would also like to thank the other professors in the Graduate Program of Sustainability Science for sharing their knowledge throughout my study and for building a better understanding in sustainability science.

I would like to thank Jiro Kogi for sharing me his knowledge on water quality and for helping me obtain GIS data for the Kanto region. I am indebted to Erwin Hardika Putra for his advices on water quality and river basins, and Leony Olivia Unsulagi for her assistance in reviewing my thesis draft.

I recognize that this study would not have been possible without the financial assistance from The University of Tokyo's President Scholarship. I am also indebted to my colleagues in the Graduate Program of Sustainability Science for their help, valuable advices and being great friends during my study. Finally, I take this opportunity to express my profound gratitude to my beloved family for their moral support and patience during my study.

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Chapter 1 Introduction

1.1. Background

Interactions between human and the environment vary from place to place. However, motives and driving force behind the interactions are generally the same: to provide goods and services for human needs. Inevitable population growth has been increasing the scale and intensity of human–environment interactions into an unsustainable level (Foley et al., 2005; Lambin et al., 2001; Vitousek et al., 1997). Human adversely modifies the earth surface and considerably affects natural processes. However, evaluation and quantification of human activities' impacts on the natural environment are a daunting task. It requires an integration of social, economic, cultural, and political aspects, and knowledge on their effects on the characteristics and functions of the environment (Munroe et al., 2002; Vitousek et al., 1997). In many cases, however, the absences of data and methodology to describe the complex human–environment interactions hamper the efforts to quantify human activities' impacts on the environment (Veldkamp & Lambin, 2001).

Land use/cover patterns are recognized as a result of interactions between biophysical and socio-economical aspects of human activities (Lambin et al., 2000). It has been regarded as one of the most important driving forces in global environmental changes, and is essential in the debate of sustainable development (Lambin et al., 2001; Lepers et al., 2005). Therefore, land use/cover is intensively used as a proxy to evaluate the effects of human activities.

In the field of hydrological science, relationships between human activities and changes in hydrological processes have been a main interest of many scientists. Studies indicate that land use/cover holds an important role in determining the quantity and quality of surface water. For example, land use/cover affects the generation of storm runoff (Bhaduri et al., 2000; Niehoff et al., 2002; Vieux, 1991), and the distribution of agricultural areas affects the concentration of nutrients (nitrogen and phosphorus) in surface water (Hayakawa et al., 2006; Nagumo & Hatano, 2001; Woli et al., 2002). Urbanization also affects surface water quality. Environmental problems such as eutrophication and red tide in Japan are attributed to the increasing use of detergents and fertilizers. Siakeu et al. (2004) observes a general temporal decrease in suspended sediment concentration (SSC) in major rivers in central Japan, but also indicates that human activities, especially urbanization limits the decrease in some area. Bhaduri et al. (2000) observes the effect of urban areas on heavy metal (lead, copper, and zinc) concentrations in the surface water of Little Eagle Creek, USA.

This research assesses the effects of land use/cover on surface water quality in the Kanto region at three different spatial scales: the whole Kanto region, each of major river basins, and each monitoring site. It uses spatial and statistical analyses on land use/cover and hydrological data collected by the Japanese government.

1.2. Literature review

1.2.1. Land use/cover and its change in Japan

In many cases, the concept of land use and that of land cover are used interchangeably and cannot be clearly defined due to their similarity. Multiple, simultaneous uses of a land parcel also contribute to the obscured differentiation of land use and land cover. In general, land use refers to results of human activities, while land cover refers to the attribute of natural cover including vegetation, soil, topography, surface, and groundwater, as well as artificial construction covering the earth surface (Anderson et al., 1976; Lambin et al., 2000).

The multidisciplinary nature of land use/cover change that involves complex processes including social and ecological ones is studied widely in the past few decades (Argawal et al., 2002). It is one of the most important information required for decision making, especially to control various aspects of development and avoid its unfavorable impacts on the environment (Anderson et al., 1976). Its recognition as the driver of global environmental change makes land use/cover change as central in the debate of sustainable development (Lambin et al., 2001; Lepers et al., 2005).

While it is a nearly impossible task, the debate encourages the creation of land use/cover change that improves the current and future environmental conditions (Opdam et al., 2006).

In Japan, studies on land use/cover increased in the 1950s due to the limited habitable space for post-war rehabilitation (Himiyama, 2001). In the 1960s, Japan's economic growth brought land use/cover studies into a further level. Urbanization and industrialization issues in big cities like Tokyo, Osaka, and Nagoya fostered uncontrolled urban sprawl and uncertainties on land designation (Saizen et al., 2006). The New City Planning Law to revise the older City Planning Law (passed in 1919) was enacted in 1968 as part of efforts in controlling urban sprawl in the urban fringe area. The law consists of five different aspects. First, introduce the City Planning Area that consists of urbanization promotion area (UPA) and urbanization control area (UCA). Second, introduce the Development Permission System to provide a standard for public facilities and to regulate development in UCA. Third, introduce a reformed zoning system. Fourth, introduce public participation in urban planning. Fifth, delegate urban planning to prefectural and municipal governments (Sorensen, 2000).

As implied by its original name, UPA was designed to promote urbanization and its utilization for commerce, residence, etc. UPA includes the existing urban area, as well as the area where development is planned within the next 10 years (Sorensen, 2002). Supporting infrastructures such as roads, tap water, and sewage networks need to be developed as the requirement of development in UPA (Saizen et al., 2006). On the other hand, UCA limits the development by prohibiting new development or construction work of new facilities, except in the area where residences already exist (Rural Development Planning Commission, 1981). The law continues to provide the basis of the city planning system in Japan (Sorensen, 2002). To some extent, it successfully reduced the impacts of low density development and local ecosystem damage due to the urban sprawl, and dealt with the impacts of declining population in Japan (Noda & Yamaguchi, 2008).

1.2.2. Water quality and land use/cover

The term water quality defines an integrated index of chemical, physical, and microbiological characteristics of water. Surface water quality is affected by natural processes and anthropogenic activities within a drainage basin. Natural processes that affect water quality includes the deposition of solutes and gases from the atmosphere, weathering and erosion of rocks and soils near the land surface, and reaction of percolated water in the soil (Hem, 1985). In many river basins, water quality is also altered by numerous anthropogenic activities. Diversion and impoundment of water for human use affect the hydrological cycle (Vitousek et al., 1997). Pollution substances are introduced to a water system from both point and non-point sources (Gove et al., 2001).

Because controlling point pollution sources is relatively easy, many early water pollution programs focused on reducing the pollution load from point sources (Karr & Dudley, 1981). This was also the case with Japan, where environmental problems due to pollutant from point sources have been identified since the Meiji era (Environment Agency, 1972). Okada & Peterson (2000) observe that water pollution problems in Japan are associated with its rapid economic growth since the 1950s. Industry shifted to a heavy, chemical one that degraded the environmental quality, especially water quality across industrial areas.

In 1958, the Japanese government introduced the Water Quality Conservation Law and the Factory Effluent Control Law to deal with water pollution (Okada & Peterson, 2000). This was followed by the establishment of water quality standards for several major rivers such as the Edo, Yodo, Kiso, Ishikari, and Ara. Ever since, the government passed several laws including the Basic Law for Environmental Pollution Control, the Water Pollution Control Law and other related legislations to provide comprehensive measures against various environmental pollutions including water pollution (Environment Agency, 1972).

While the regulation and control of effluents successfully reduce pollution due to point sources, controlling pollution due to non-point sources is still a problem. Education, promotion of appropriate management practices, and modification of land use/cover are among of the methods that reduce the non-point source pollution (Ongley, 1996). pH, dissolved oxygen (DO), biochemical oxygen demand (BOD), chemical oxygen demand (COD), suspended solids (SSC), total coliform (coliform), total nitrogen (TN), and total phosphorus (TP) are considered to be affected by human activities (Jain & Singh, 2003; Shrestha & Kazama, 2007; Siakeu et al., 2004; Wang et al., 2007; Woli et al., 2002, 2008). Adversely living environment values also affect human activities, mainly agricultural activities and fisheries industries, leading to change in water quality.

One of the most basic water quality parameters is hydrogen ion or pH. It represents the solubility and biological activities of chemical constituents such as nutrient and heavy metals (Jain & Singh, 2003). Water with low pH (less than 6) can be harmful for fish, since it could dissolve more ions in the water including heavy metals (Duh et al., 2008). Pure water at 25ºC has a pH value of 7, while unpolluted surface water generally has a range between 6.5 to 8.5 (Hem, 1985). This variation highly depends on the buffering of carbonate systems of surface water (Jain & Singh, 2003). For example, dissolved bicarbonates from the carbonate bedrock might increase pH values of surface water (Duh et al., 2008).

Surface water temperature also affects pH, where at higher temperature pH is smaller (Hem, 1985). Contrast finding is reported by Swank & Bolstad (1993), where gradual increment in temperature along the stream increases pH. A long-term observation by Iwashita & Shimamura (2003) in the Sagami River indicates no correlation between seasonality and pH, suggesting that temperature hardly affects surface water. Furthermore, Ryu et al. (2007) attribute seasonal variations of pH in the Han River basin, Korea, to the effect aquatic plankton blooms during the warm season.

Another important parameter of water quality is Dissolved Oxygen (DO) that represents the amount of gaseous oxygen (O_2) in water, which is essential for aquatic organism. Low DO concentrations in surface water indicate a degraded aquatic ecosystem (Wang et al., 2007). According to Hem (1985), the concentration of DO in water reflects temperature and atmospheric pressure. Warmer surface water is known to have less DO due to oxygen saturation (Shrestha & Kazama, 2007). Hem (1985) provides an example of the effect of temperature on

DO. At 5ºC, DO in equilibrium is 12.75 mg/l, while an increase in the temperature to 30ºC will decrease DO into 7.54 mg/l.

Processes that consume organic matter and photosynthesis activities of aquatic biota such as algae are known to alter DO in surface water (Hem, 1985; Hooda et al., 2000). Physical conditions of streams also create small variations in DO in surface water. For example, shading from riparian vegetation reduces the intensity of light and affects photosynthesis activities of aquatic biota in surface water, resulting in the alteration of DO (Williams et al., 2000). Anbumozhi et al. (2005) note that DO is 1.25 higher in an area with riparian zones. Wang et al. (2007) observe higher DO for rivers in a hilly area, which likely due to the enhanced re-aeration of surface water.

The third major parameter of water quality is biochemical oxygen demand (BOD), that represents the amount of oxygen require by microorganisms to degrade organic matter under aerobic conditions (Jain & Singh, 2003). Thus, it has been used as an indirect measure of organic matter concentration in surface water, and in general it is negatively correlated with DO (Ferrier et al., 2001). While BOD is mainly determined by the concentration of organic matter, nitrification from highly dissolved ammonia and the presence of algae also affect BOD (Even et al., 2004; Jain & Singh, 2003).

Chemical oxygen demand (COD) is also a major water quality parameter. It has been used to measure organic and inorganic matter susceptibilities to oxidation (Jain & Singh, 2003). Thus, a strong correlation between BOD and COD is generally observed (Vega et al., 1998). Shrestha & Kazama (2007) note that the temporal variation in COD in the Fuji River basin is small. They also observe that decayed organic matter from forest and soil erosion in agricultural areas affect COD. However, in Tokyo Bay, a contrasting observation is reported, where COD varies seasonally (Kawabe & Kawabe, 1997).

Suspended sediment concentration (SSC) has also been regarded as a parameter representing generalized water quality. Suspended sediment refers to fines, mostly silts and clays that have size less than 0.062 mm (Packman, 2004). It is generally supplied to surface water through soil erosion processes (Shrestha & Kazama, 2007). Higher SSC can be observed with higher runoff, especially in agricultural areas where soil can be easily eroded (Ahearn et al., 2005; Braskerud, 2002). However, Johnson et al. (1997) indicate that variations in SSC do not reflect seasonal differences in runoff, indicating sources of SSC other than soil erosion. Oguchi et al. (2000) and Wang et al. (2007) observe that industrial and domestic sewages discharged into surface water in urban areas lead to higher SSC than that in rural areas.

In water quality assessment, the concentration of coliform bacteria, particularly *Escherichia coli* has been used to indicate the potential impact of pathogenic organisms. High concentrations of *E. coli* in surface water might indicate pollution due to bad sanitation of human and animal fecal (Gallagher & Spino, 1968); they are also observed in drainage basins with livestock grazing activities (Hooda et al., 2000). However, the concentration of coliform can be originated from other sources such as soil, decaying vegetation, and industrial activities (Kuhn et al., 1997).

Total nitrogen (TN) and total phosphorus (TP) are common identifiers of nutrient in water. Nitrogen is a vital element required for plant and animal growth. Nitrate and ammonia are the two key forms of nitrogen in water. In normal conditions the concentration of nitrate in water is 0.5 to 3 mg/l, while the concentration of ammonia is around 3 mg/l (Jain & Singh, 2003). Nitrogen in surface water comes through several means; agricultural areas and grasslands are the major contributors (Ahearn et al., 2005). The release of geological nitrogen (mainly from meta sedimentary and meta volcanic bedrock) in the Mokelumne River, USA, accounts for its water's high nitrate concentrations (Holloway et al., 1998). Discharged wastewater from a treatment plant also contributes to nitrogen concentrations in surface water (Ahearn et al., 2005). As a natural process, nitrogen fixation by planktonic organisms also contributes to the nitrogen concentration in surface water (Howarth et al., 1988; Smith et al., 1997). On the contrary, denitrification in wetlands, riparian forests, and grasslands could reduce the nitrogen concentration of surface water (Hayakawa et al., 2006).

Although phosphorus is abundant in sediment, its concentration in the soluble form in surface water is relatively low (Hem, 1985). A common concentration of phosphorus in surface water is around 0.05 mg/l (Jain & Singh, 2003). Both its lower mobility and strong association with SSC account for this situation (Woli et al., 2008). In North America and Europe, as much as 90% of TP is associated with suspended sediment transport (Ongley, 1996). The importance of sediment transport in determining TP implies that land use/cover near the stream correlates more with TP, in comparison to the whole river basin (Sharpley et al., 1999). A model by Allan et al. (1997) shows that nutrient concentrations in surface water respond to increased runoff associated with increased urban and agricultural areas. In contrast, their model shows a reduction in nutrient concentration if forest expands. However, Woli et al. (2008) suggest that the concentration of phosphorus in surface water is not necessarily related to agricultural land use/cover but more to the proportion of urban areas.

1.3. Research objectives

Many studies including those reviewed above indicate that certain land use/cover types affect water quality. However, the outcomes of the research in this field are various. Each catchment tends to be unique in terms of the combination, spatial pattern, and management of land use/cover that could bring different impacts on the observed water quality parameters (Sliva & Williams, 2001). In Japan, research in this field tends to concentrate on agricultural areas (Feng et al., 2004; Woli et al., 2004), riparian forest (Anbumozhi et al., 2005; Nagasaka & Nakamura, 1999), and grassland (Hayakawa et al., 2006). Additionally, the research involves limited water quality parameters mainly nitrogen and phosphorus (Hayakawa et al., 2006; Nagumo & Hatano, 2001; Woli et al., 2008). Although the Japanese government has been constantly monitoring water quality related to the living environment, little is done to assess the effect of land use/cover on water quality parameters other than nitrogen and phosphorus.

Research in assessing relationships between land use/cover and water quality tends to focus on a single catchment over a short period (Gove et al., 2001). In recent years, however, relationships for multiple catchments at different scales have been observed (Delong & Brusven, 1991; Jarvie et al., 2002; Sliva & Williams, 2001). However, we still have limited knowledge about regional variability in the effects of land use/cover on water quality.

Therefore, the main objective of this research is to assess the effects of land use/cover on surface water quality in Japan at multiple spatial scales. The Kanto region was selected for the research because it is the most populated and socially dynamic region in Japan, and characterized by various catchment conditions from mountains to plains. Three different spatial scales are considered: the whole Kanto region, each of major river basins, and each monitoring site. The research is expected to provide the following outcomes:

1. Description of land use/cover changes in the Kanto region in the late 20th and 21st centuries,
2. Description of water quality trends in major river basins in the Kanto region in the late 20th and 21st centuries
3. Description of relationships between land use/cover and water quality at multiple spatial scales

The information above will not only give a scientific generalization of the impacts of land use/cover on water quality in the Kanto region, but also a useful guideline to planners for appropriate future land use/cover changes.

Chapter 2 Study Area

The Kanto region is in the central of Honshu Island with an area of 32,385 km^2. It encompasses Tokyo Metropolis and six other prefectures: Chiba, Saitama, Kanagawa, Gunma, Ibaraki, and Tochigi (Figure 1). The landform of the Kanto region consists mainly of mountains, hills, Pleistocene upland terraces, and Holocene alluvial plains (Karan, 2005).

Figure 1. Map of the Kanto region in Honshu Island

The mountainous areas in north and west, as well as the hills in south form the borders of the Kanto region (Figure 2). The mountains includes Mount Fuji (3,776 m.a.s.l.), the highest mountain in Japan. In general the mountains are underlain by Miocene or older rocks, while the hills consist of Pliocene to middle Pleistocene strata (Yoshikawa et al., 1981). Endo (1992) and Karan (2005) state that these hills consist of alternations of gravel, sand, and clay beds with a cover of volcanic ash called Kanto Loam. The Pleistocene terraces made up of gravel, sand, and clay are also covered with a thick layer of Kanto Loam, and extend from Boso Peninsula to the northern and western parts of the Kanto region. Alluvial plains concentrate in the central part of the region and they are underlain by very thick sediment (> 3,000 m) characterized by unconsolidated marine clay deposits covered by alluvial deposits (Endo, 1992; Karan, 2005).

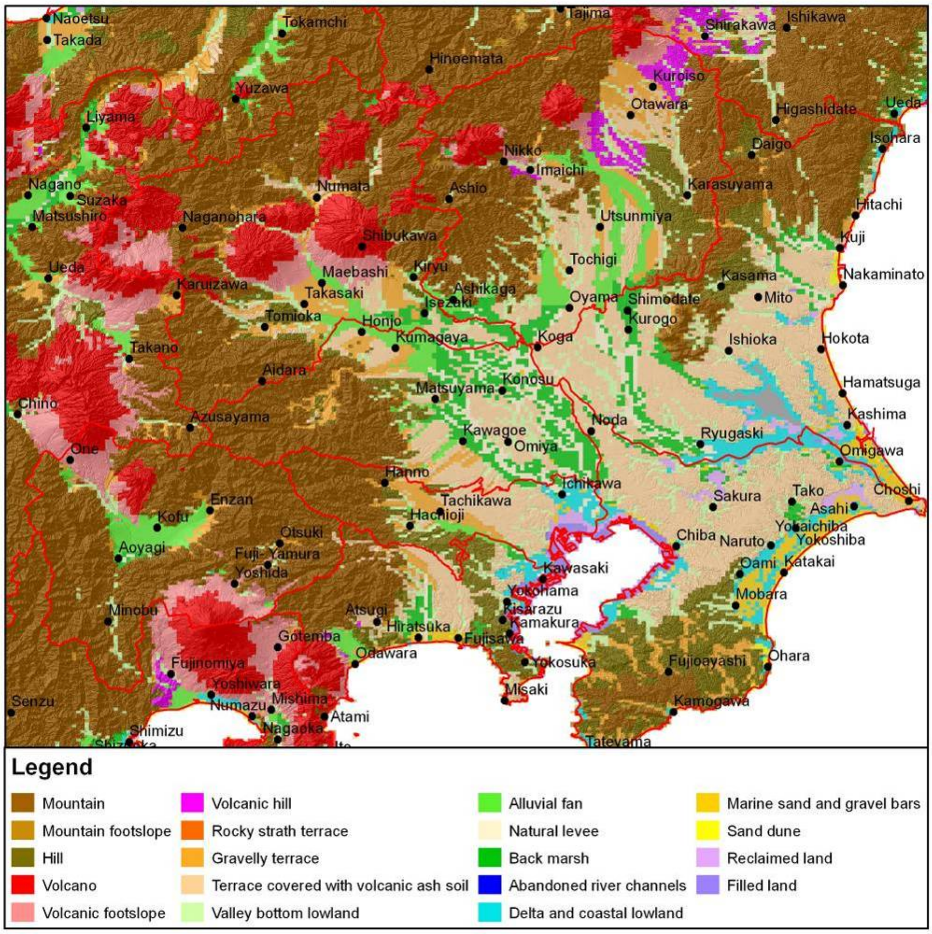


Figure 2. Distribution of landforms in the Kanto region

Eight major rivers (Ara, Edo, Fuji, Kuji, Naka, Sagami, Tama, and Tone) with a total length of 1,549 km flows through the Kanto region and provide water resources for the region (Figure 3) (River Department, 2002a). This study deals with the catchments of these rivers. Their general characteristics are described below. The land use/cover data used for the description are those collected in 1995–1999.

Figure 3. Major rivers and their catchments in the Kanto region

2.1 Ara and Edo Rivers

The Ara River or Arakawa is one of the main rivers in the southern Kanto region, flowing through Tokyo. It originates in Mount Kobushi (2,475 m.a.s.l.) in the Kanto Mountains and flows to Tokyo Bay. The length of its mainstream is 173 km, and its drainage basin covers 2,940 km^2 in Saitama Prefecture and Tokyo Metropolis. The Edo River or Edogawa is another river that flows through Tokyo. With a 200 km^2 drainage basin and a 55 km mainstream, the Edo River flows from the eastern part of Tokyo into Tokyo Bay. In the past, this river was a part of the Tone River; however, in the 17th century, diversion works made the river independent like the present condition. On the other hand, channels connecting the Ara and Edo Rivers, as well as the flat topography in their lower reaches made the exact separation of the two basins impossible. Therefore, the two river basins are treated as one in this paper.

The land use/cover in the Ara/Edo River basin is characterized by forested areas in the upper reach with some agricultural areas along the rivers (Figure 4). In the middle reach, agriculture is the dominant land use/cover. In the 17th century, the lower catchment was designated as an agricultural zone to supply food to Tokyo (Karan, 2005). However, in the past 50 years, rapid urban development of Tokyo resulted in the conversion of this zone into a residential/industrial one. According to River Department (2002a), among the studied river basins, the Ara/Edo River basin has the highest population density that reach 3,164 person/km^2 (Ara) and 17,000 person/km^2 (Edo) (Table 1).

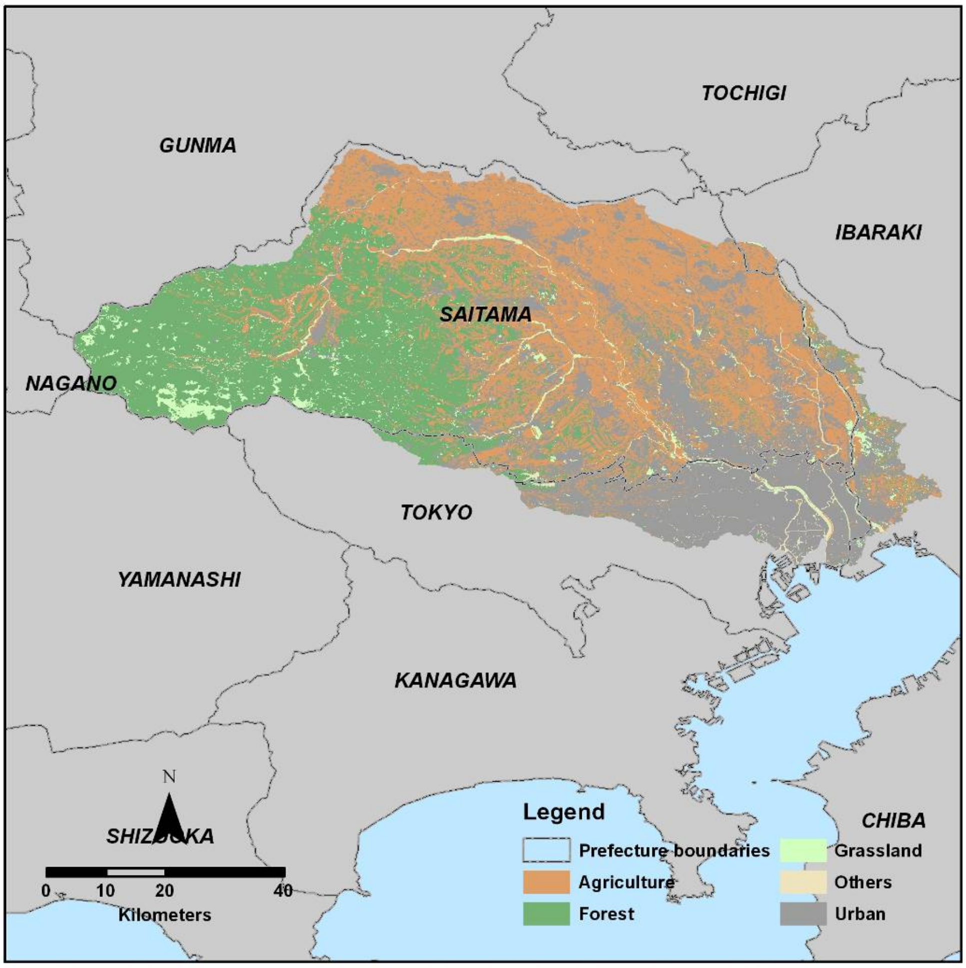


Figure 4. Distribution of general land use/covers in the Ara/Edo River basin in 1995–1999

Table 1. Summary of the studied river basins in the Kanto region

River	Catchment (km^2)	Stream length (km)	Related prefectures	Population (million)	Population density (person/km^2)
Ara	2,940	173	Saitama, Tokyo	9.3	3,164
Edo	200	55	Ibaraki, Chiba, Saitama, Tokyo	3.4	17,000
Fuji	3,564	128	Nagano, Yamanashi, Shizuoka	1.14	320
Kuji	1,484	124	Ibaraki, Fukushima, Tochigi	0.2	135
Naka	3,283	150	Tochigi, Ibaraki, Fukushima	0.91	278
Sagami	1,781	109	Kanagawa, Yamanashi	1.28	718
Tama	1,263	138	Tokyo, Kanagawa, Yamanashi	3.57	2,827
Tone	15,343	322	Ibaraki, Tochigi, Gunma, Saitama, Chiba, Tokyo	12.14	791
Source: Adjusted from River Department (2002a, 2002b)					

2.2. Fuji River

The Fuji River or Fujigawa is located in the west of Mount Fuji in the outskirt of the Kanto region. With total mainstream length of 128 km, the Fuji River originates from two places. The first origin is Mount Kai-Komagatake in the north of the Southern Japanese Alps, and the Kamanashi River flows from there. The second origin is located in the Kanto Mountains at the northern part of Yamanashi Prefecture, and the Fuefuki River flows from there. These two rivers meet in the south of the Kofu Basin to become the Fuji River, and it flows into the Pacific Ocean at Suruga Bay (Shrestha & Kazama, 2007). The total area of the Fuji River basin is 3,564 km^2, which is mostly dominated by forest (68.20%) (Figure 5). Agriculture, the second largest land use/cover in the basin (17.25%), can be found mainly in the middle reach, i.e., the Kofu Basin. As shown in Figure 5, grassland that covers 7.76% of the total basin shows a wide patchy distribution in the basin, while major urban areas are located within the Kofu Basin.

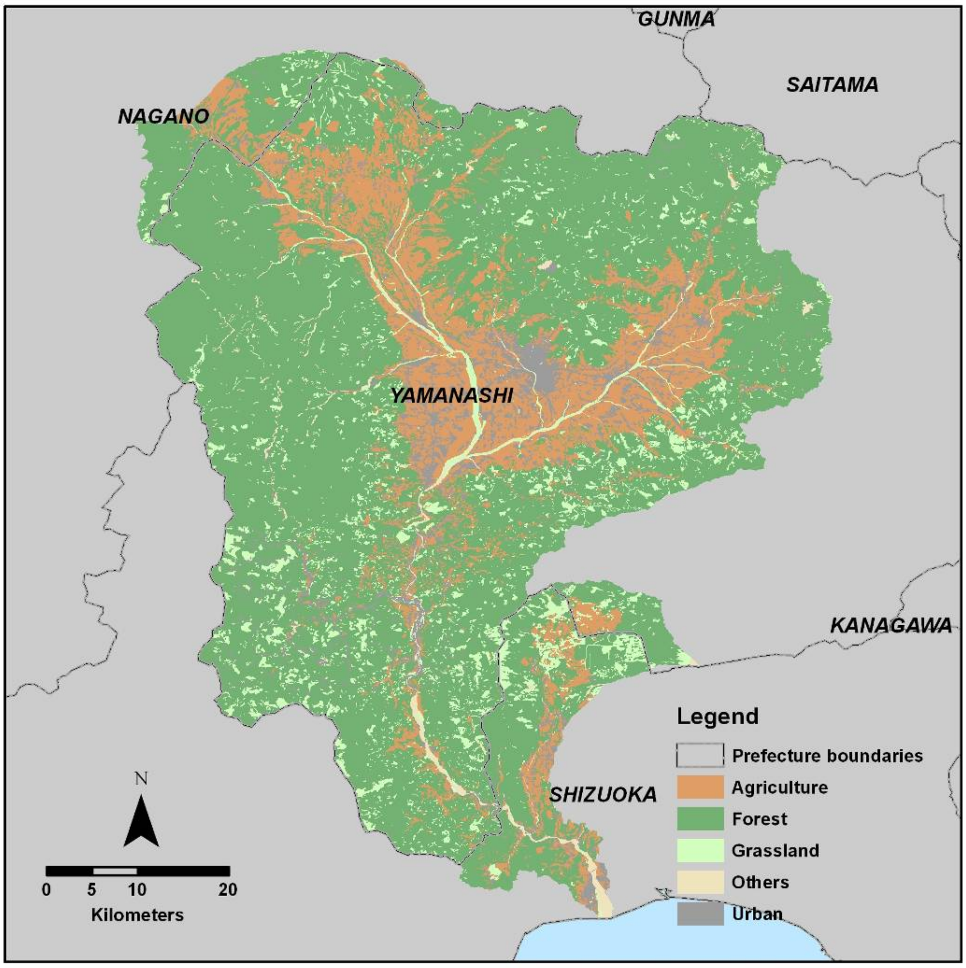


Figure 5. Distribution of general land use/covers in the Fuji River basin in 1995–1999

2.3. Kuji River

The Kuji River or Kujigawa is 124 km in length and flows within Fukushima and Ibaraki prefectures through the Daigo Basin. It originates at the steep and forested area of the Yamizo Mountains on the border of Fukushisma and Ibaraki prefectures, and flows to the Pacific Ocean (Nagano et al., 2003; Nagao et al., 2003). The 1,484-km^2 drainage basin of the Kuji River includes 69.17% of forested areas that occur widely except for the lowermost basin. Agricultural areas account for 22.67% of the total area, and they are located along the major streams and the lowermost basin (Figure 6). Grassland that accounts for 3.35% of the total area can be found mostly in the upper basin. Urban areas that account for only 4.01% of the total area are mainly located in the lower basin.

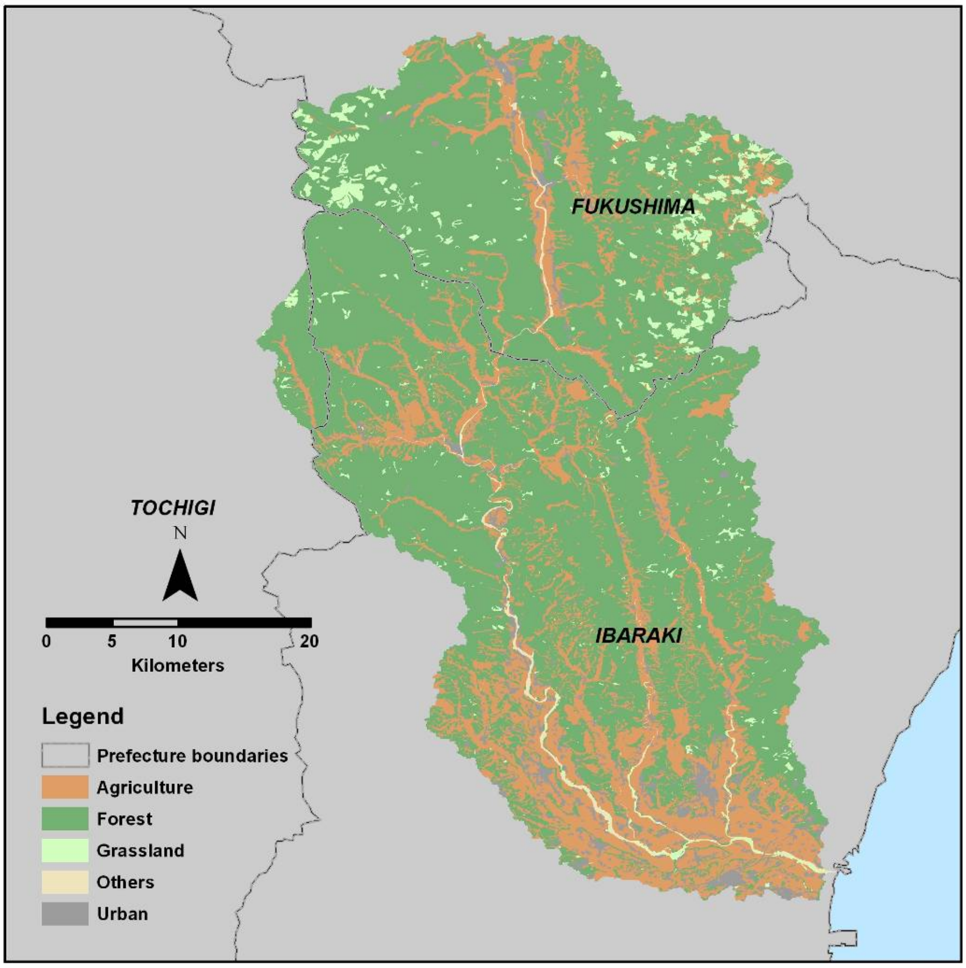


Figure 6. Distribution of general land use/covers in the Kuji River basin in 1995–1999

2.4. Naka River

The Naka River or Nakagawa is located in the northern outskirt of the Kanto region. It has a 150 km mainstream that stretches from Tochigi Prefecture to Ibaraki Prefecture. The origin of this river is Nasu Mountain, and it empties out to the Pacific Ocean. The drainage basin of the Naka River is 3,283 km^2, and it is dominated by forested areas in the upper to middle reaches (54.03% of the total area). In between these forests, agricultural areas occur mainly along major streams, and they account for 34.18% of the total area. Agricultural areas more widely occur in the lower basin.

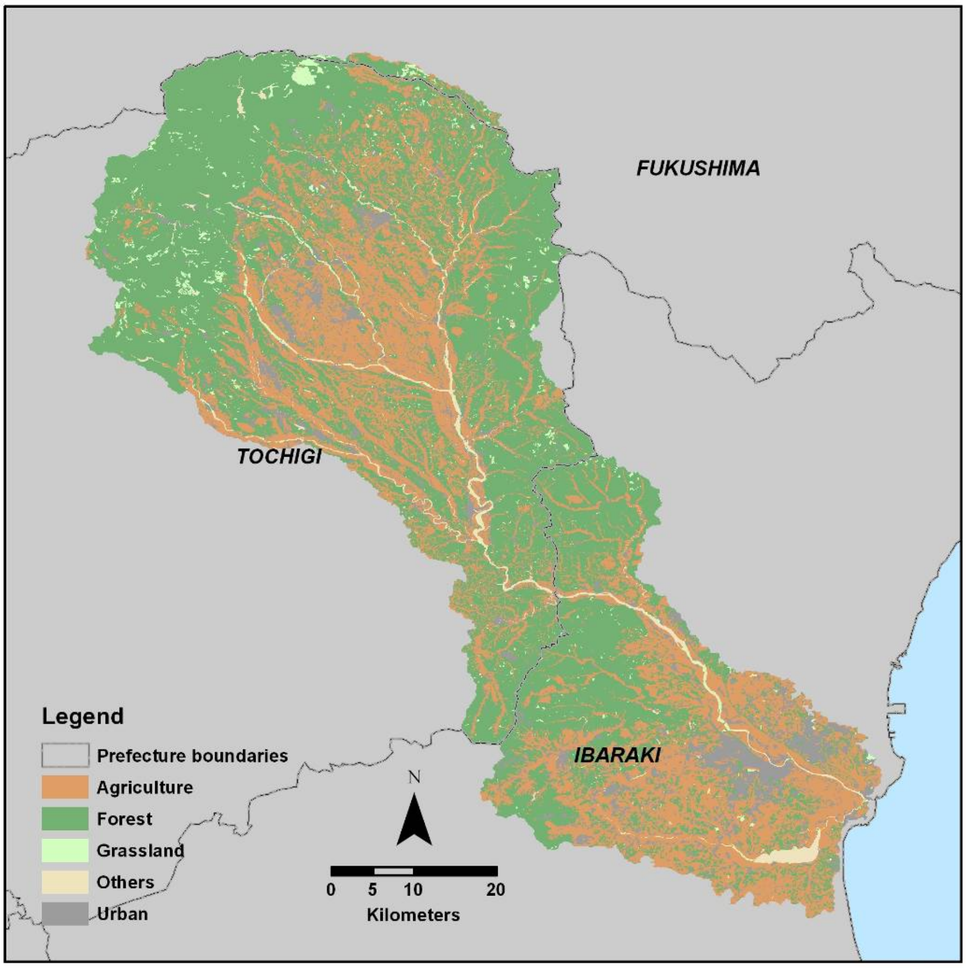


Figure 7. Distribution of general land use/covers in the Naka River basin in 1995–1999

2.5. Sagami River

The Sagami River or Sagamigawa is 109 km in length, located to the southwest of Tokyo, and originates from Lake Yamanaka and empties into the Pacific Ocean at Sagami Bay between the cities of Hiratsuka and Chigasaki. The basin of this river is 1,781 km^2 in area and dominated by forest (64.15%) in its upper and middle reaches. However, the forested areas are fragmented by grassland that occupies 8.20% of the total area (Iwashita & Shimamura, 2003). Agricultural and urban areas that occupy 13.75% and 11.33%, respectively, are mostly found along the upper and middle reaches of the Sagami River. The lower reach of the basin is characterized by the mixture of urban and agricultural areas (Figure 8).

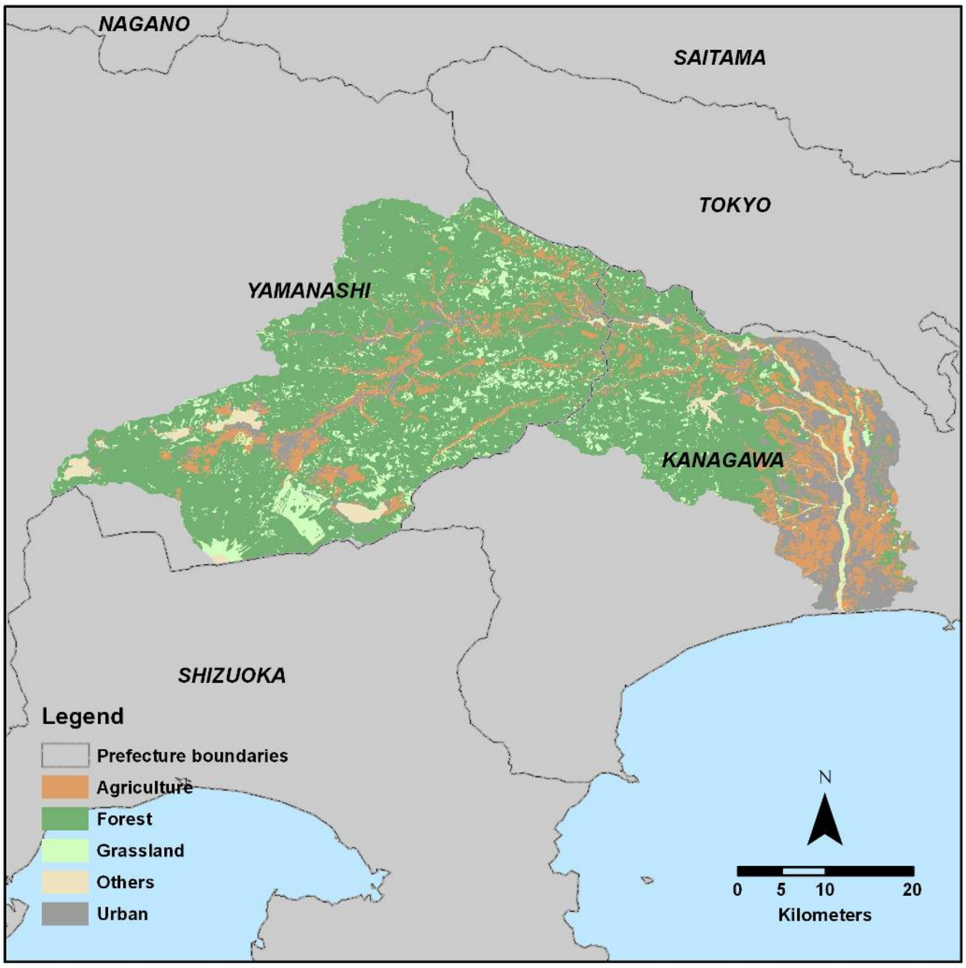


Figure 8. Distribution of general land use/covers in the Sagami River basin in 1995–1999

2.6. Tama River

The Tama River or Tamagawa is located in the western part of Tokyo. It originates at Mt. Kasatori and has a 138 km mainstream that flows through suburban Tokyo into Tokyo Bay. In the lower reach, the stream also acts as a natural division between Tokyo Metropolis and Kanaganawa Prefecture. The area of the Tama River basin is 1,263 km^2 with 56.08% forest, 31.40% urban, 6.98% agriculture, 3.90% grassland, and 1.65% others. The upper reach in the Kanto Mountains is dominated by forested areas and receives limited human impact, while the middle and lower parts are dominated by both urban and agriculture areas (Masunaga et al., 2000).

Figure 9. Distribution of general land use/covers in the Tama River basin in 1995–1999

2.7. Tone River

The Tone River or Tonegawa is 322 km in length, originates in the mountainous region of Gunma Prefecture and flows through Tochigi, Saitama, Ibaraki, and Chiba prefectures before it emptied out into the Pacific Ocean in Choshi. This river is known as the second longest river in

Japan while its basin area is the largest in Japan. The basin consists of 47.70% of forest that mainly found in the upper reach (Figure 10). Agricultural and urban areas that occupy 34.26% and 11.64% are mostly found in the middle and lower reaches. Patches of grassland are mostly located in upper and lower reaches, occupying 3.00%. Other land use/covers that occupy 3.40% of the total basin are distributed along the main stream. The large Kasumigaura Lake occurs in the lower part of the basin.

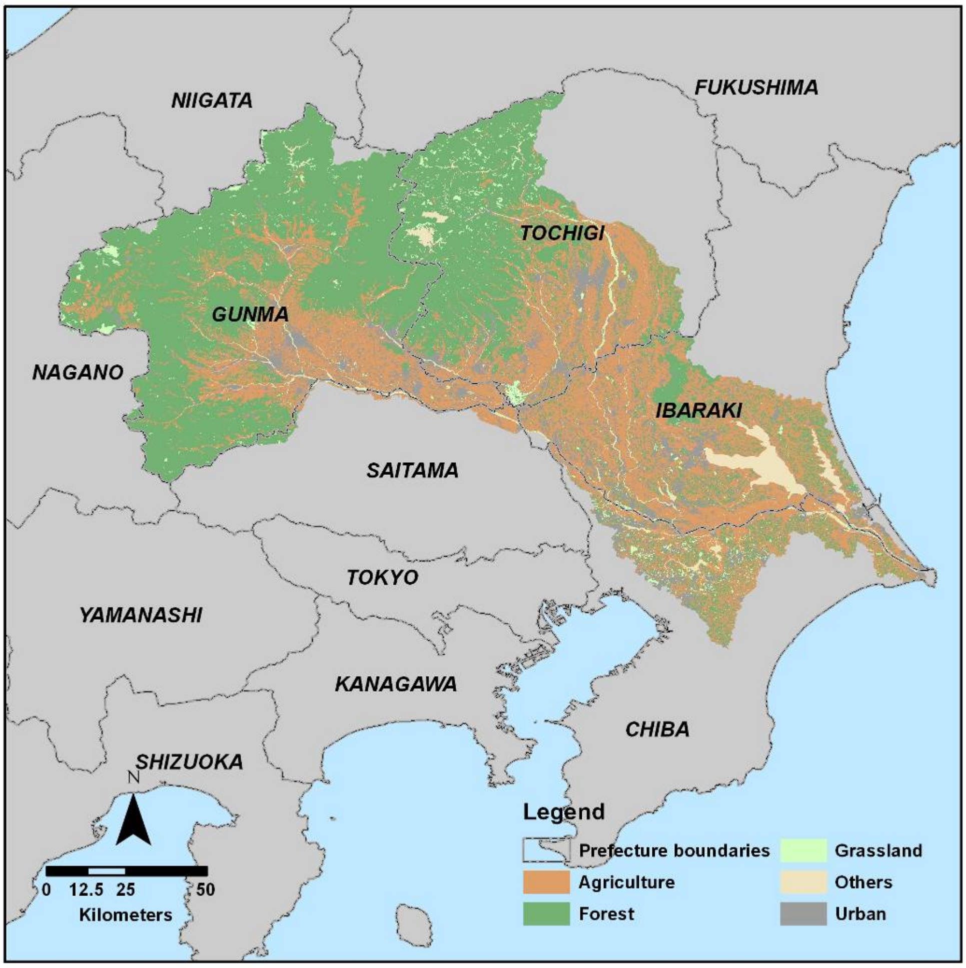


Figure 10. Distribution of general land use/covers in the Tone River basin in 1995–1999

Chapter 3 Data and Methods

3.1. Data

3.1.1. Hydrological data

Hydrological data analyzed in this research were taken from the water quality surveys of public water areas for years 1981 to 2005. The Ministry of Environment (MOE) of the Japanese government, in partnership with local governments, carried out the surveys, to monitor water quality of many sites about once per month, and during a monitoring day, four samples were taken every six hours. The data consist of:

1. Parameters related to the governmental environmental quality standards for protecting human health, with 28 parameters for toxic substances;
2. Parameters related to the environmental quality standards for protecting the living environment with seven parameters; and
3. Parameters on total nitrogen and total phosphorus.

According to the rule of the Japanese government, the parameters related to human health should be monitored at least once per month. However, the sampling frequency of the parameters related to the living environment may be reduced depending on the situation. For example, in the upstream areas or offshore where water quality fluctuations are minor, the monitoring frequency might be reduced. The data have been used by the governmental agencies to ensure compliance to the Water Pollution Control Law and to respond appropriately to emerging public water quality issues. The data are freely downloadable from the website of the National Institute for Environmental Studies (http://www.nies.go.jp/igreen/index.html).

3.1.2. Land use/cover

Land cover data used were prepared from the vegetation naturalness surveys/vegetation surveys as part of the national surveys of the natural environment by the Ministry of the Environment. The surveys have been undertaken approximately every five years since 1973 to document the status and change of the natural environment of Japan. Digital files of these data are available for download from the Japan Integrated Biodiversity Information System (JIBIS - http://www.biodic.go.jp/J-IBIS.html). Note that among data for the six survey periods, only data those for the third (1983–1986), fourth (1989–1992), and fifth (1995–1999) periods are available to the public.

3.1.3. City planning data

City planning data were obtained from the National and Regional Planning Bureau, Ministry of Land, Infrastructure, Transport, and Tourism (MLITT). The data contains the zonation of two types of urban areas in the Kanto region: Urban Promotion Areas (UPA) and Urbanization Control Areas (UCA), based on the City Planning Law enacted in 1968. The data used for this research are as of the 2006 fiscal year. XML files of the data were downloaded from the MLITT website (http://nlftp.mlit.go.jp/ksj/jpgis/datalist/KsjTmplt-A09.html).

3.1.4. Digital elevation model

A digital elevation model (DEM) for the study area was obtained from the Geographical Survey Institute of Japan (GSI). The resolution of the grid DEM is 50 m and it has one-meter elevation increment. The datum used for the projection of the DEM is the GSI Tokyo datum, and the elevation is recorded as altitude above the mean sea level of Tokyo Bay.

3.2. Methodology

This research used spatial and statistical analyses to fulfill the objectives and answer the research questions mentioned in Section 1.3. The following flowchart was used as a guideline during the research.

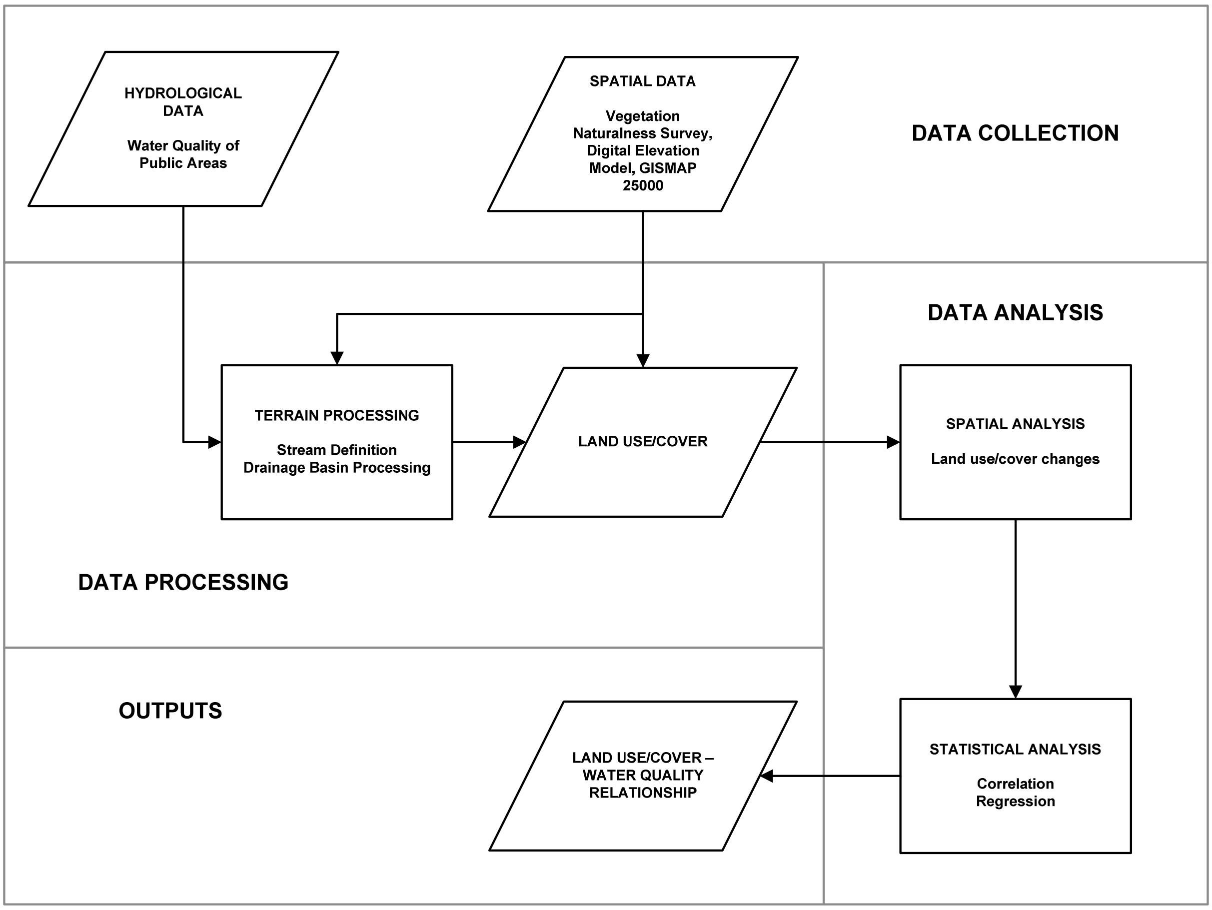


Figure 11. Research flowchart

3.2.1. Data collection and arrangement

The data for the Kanto region available from the governmental agencies were collected. Then the suitability of the data for this research was explored. At the same time, some of the data were arranged and converted for further processing and analyses.

The hydrological data originally provided as comma-separated value (CSV) text files were converted into tables in Microsoft Access Database. By doing so, links between tables were established and queries can be easily used for various purposes. Particularly the selection of sites and parameters considered for this research benefited from this, as a large number of monitoring sites do not have continuous information on water quality. In the end, 472 monitoring sites were considered suitable for data analyses (Figure 12).

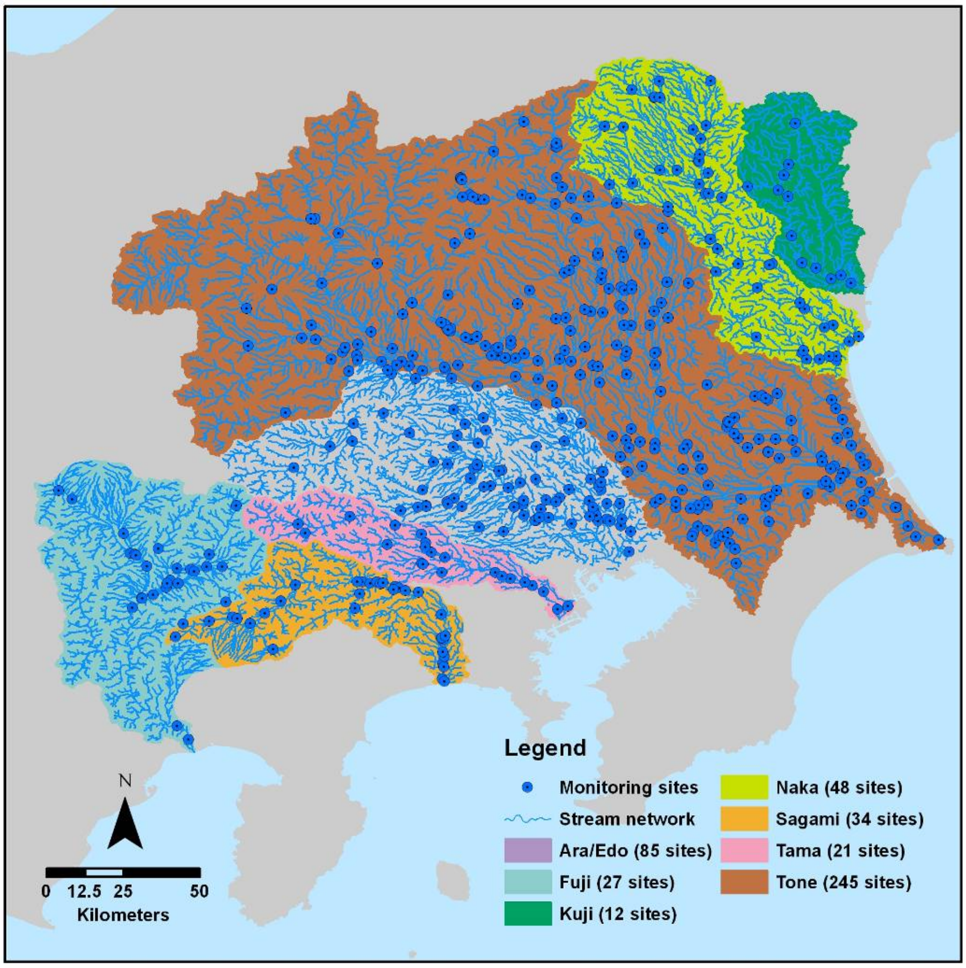


Figure 12. Location of the selected water quality monitoring sites

As for the water quality parameters, queries on the data revealed that only eight parameters were suitable for further analysis (Table 2); the other parameters in the database do not include sufficient records. Among the eight parameters, six (pH, DO, BOD, COD, SSC, and Coliform) are related to the environmental quality standard for protecting the living environment, and two are TN and TP**.** Annual mean values of the selected water quality parameters were then calculated. For statistical analysis, the water quality data were categorized into three periods (1983–1986, 1989–1992, and 1995–1999), which correspond to the periods of the land use/cover data.

Table 2. Water quality parameters, abbreviations, and units

Water quality parameter	Abbreviation	Unit	Period
pH	pH	pH unit	1981–2005
Dissolved oxygen	DO	mg l^{-1}	1981–2005
Biochemical oxygen demand	BOD	mg l^{-1}	1981–2005
Chemical oxygen demand (Mn)	COD	mg l^{-1}	1981–2005
Suspended solids	SSC	mg l^{-1}	1981–2005
Total coliform	Coliform	MPN/100 ml	1981–2005
Total nitrogen	TN	mg l^{-1}	1984–2005
Total phosphorus	TP	mg l^{-1}	1984–2005

The land use/cover data for each prefecture downloaded from the JIBIS were merged to cover the whole of the Kanto region, using the common merge command in ArcGIS. Additionally, since the original data consist of 905 classes and 10 groups of naturalness (excluding open water and unknown data), the classes were regrouped into five general land use/cover types as portrayed in the following figures.

For detailed land use/cover analyses, however, the original land use/cover types for the urban and agricultural areas were used. They consist of five classes of urban land use/cover (concrete pavement site, factory/industrial areas, land constructed for residence/factories, urban/residential districts with many trees, and urban district with a few trees) and 13 classes of agricultural land use/cover (cultivated meadow, deciduous orchard, evergreen orchard, exotic broad-leaved plantation, exotic tree plantation, field weeds communities, mulberry garden, nursery garden, paddy-field weed communities, *Thea sinensis* garden, weed communities in uncultivated field, weed communities in uncultivated paddy field, and weed communities of the roadside). Thus, the total land use/cover types used for the detailed analyses include 21 classes.

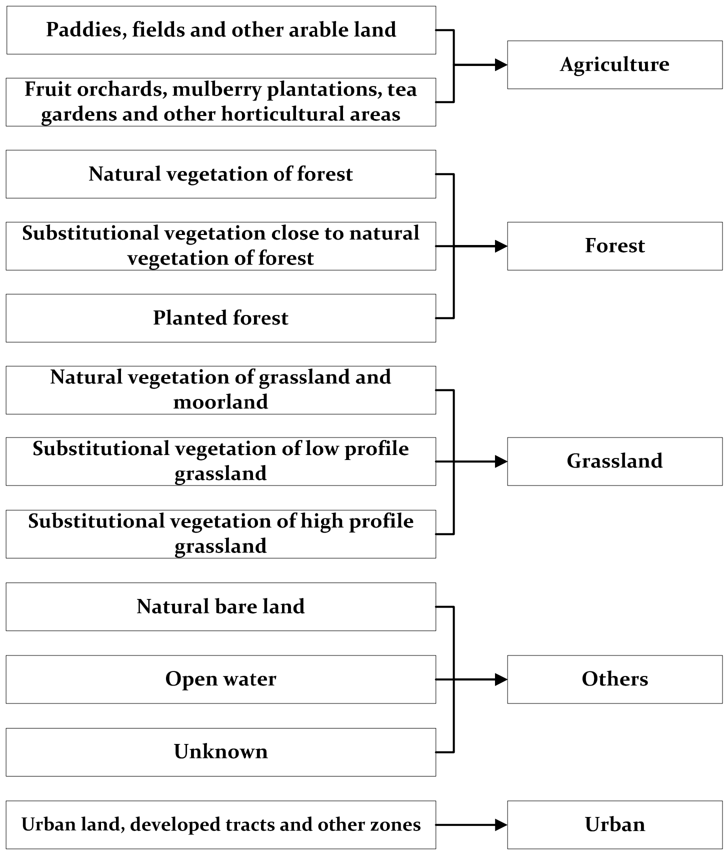


Figure 13. General land use/cover reclassification

3.2.2. Terrain data processing

Terrain data processing was conducted to identify and delineate surface drainage patterns such as river basins and stream networks. The procedure using the ArcHydro module of ArcGIS (ESRI, 2007) employs a series of analysis as shown in the flowchart below (Figure 14). Vector data of hydrological networks from the GISMAP 25,000 data supplied from the Hokkaido Chizu Co. were used for better basin/stream-net delineation in the lowland. The coordinates of major river mouths and monitoring sites were used for the delineation of upstream areas. This process generated three levels of basin boundaries that covers the whole Kanto region, each of the major river basins, and each monitoring site.

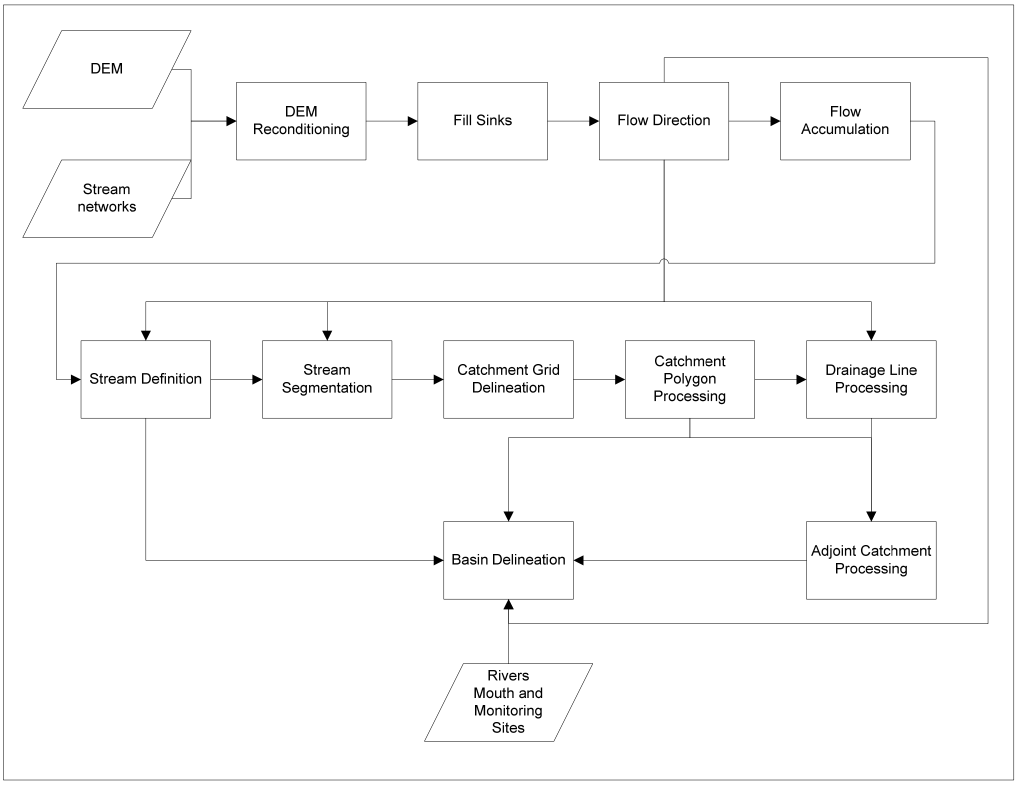


Figure 14. Flowchart of terrain data processing

3.2.3. Data analyses

The data were analyzed using spatial and statistical analysis techniques. First, the spatial data were overlaid in GIS to obtain basic information such as the percentages of land use/cover types for each period and each drainage basin, the percentages of land use/cover changes between two periods, and the spatial distribution of changes. Then the information obtained from the land use/cover data was combined with the water quality data for statistical analyses. In order to describe fundamental characteristics of the data, descriptive statistical parameters were computed using SPSS. Based on this result, the method for correlation analyses was determined. Finally, multiple regression analyses were conducted in order to obtain information on the land use/cover(s) that affect water quality

Chapter 4 Results

4.1. Land use/cover changes

Land use/cover change analysis was the first stage in data analysis to explore the relationship between land use/cover and water quality. This part is mainly related with the extent and trend of land use/cover changes in the Kanto region and those in each river basin. Land use/cover data from different periods were overlaid to observe the spatial distribution of the changes, their amounts, and their average sizes for comparison. As shown in Table 3, the studied river basins experienced reduction in the number of land use/cover changes. The result shows 29,185 land use/cover changes between the third and fourth periods, with an average size of 0.0149 km^2 and a total area of 433.57 km^2. Between the fourth and fifth periods, 25,547 land use/cover changes occurred with an average size of 0.0164 km^2 and a total area of 420 km^2.

Table 3. Number and average size of land use/cover changes in the studied river basins

River basin	Third-fourth periods			Fourth-fifth periods		
	Number of changes	Average size (km^2)	Total area (km^2)	Number of changes	Average size (km^2)	Total area (km^2)
Ara/Edo	2,084	0.0151	31.38	2,949	0.0191	56.20
Fuji	623	0.0057	3.53	2,599	0.0154	40.12
Kuji	762	0.0372	28.37	982	0.0177	17.33
Naka	6,046	0.0158	95.77	3,553	0.0136	48.37
Sagami	625	0.0081	5.09	1,512	0.0189	28.64
Tama	2,650	0.0082	21.85	1,083	0.0113	12.24
Tone	16,395	0.0151	247.57	12,869	0.0169	217.09
Kanto region	29,185	0.0149	433.57	25,547	0.0164	420.00

Significant differences between the two sets of periods in the Fuji River basin, where the number of the changes increased from 623 to 2,599, and the average size of the changes increased from 0.0057 to 0.0154 km^2. On the other hand, the Naka River basin experienced significant reduction in the number of changes by nearly halves.

Figures 15 and 16 present the spatial distribution of locations where land use/cover changed between the third and fourth periods, and between the fourth and fifth periods, respectively. The figures show that the number of changes decreased over time, and the more dispersed distribution of land use/cover changes in the latter duration (between fourth and fifth). In the former duration (between third and fourth), most changes were distributed in the middle and lower reaches of the river basins. The changes were dominated by conversion of agricultural fields and grassland into urban areas. Exceptions are the Naka and Tone River basins where land use/cover changes took place in their upper reaches. In these reaches, forest was converted into agricultural fields, grassland, and urban areas. In the former duration, changes along transportation networks occurred in the upper and lower reaches of the Tone River basin. In the latter duration, land use/cover changes were more dispersed in all reaches. Forest conversion into agricultural fields, grassland, and urban areas were shifted further to the upper reaches.

Table 4 presents the matrix of general land use/cover changes between the earlier two periods, and Figure 17 shows the pattern of the major changes. Among the five general land use/covers, forest is the only land use/cover whose total area changed relatively markedly, from 52.01% to 51.22%. Expansion of the urban and agricultural areas is the main factor of this forest conversion. Conversion into grassland (0.15%) was another result of forest conversion. While 0.37% of forest was converted into the agricultural area, 0.27% of the existing agricultural area was converted into the urban area. Thus, only a slight increase of the agricultural area was observed.

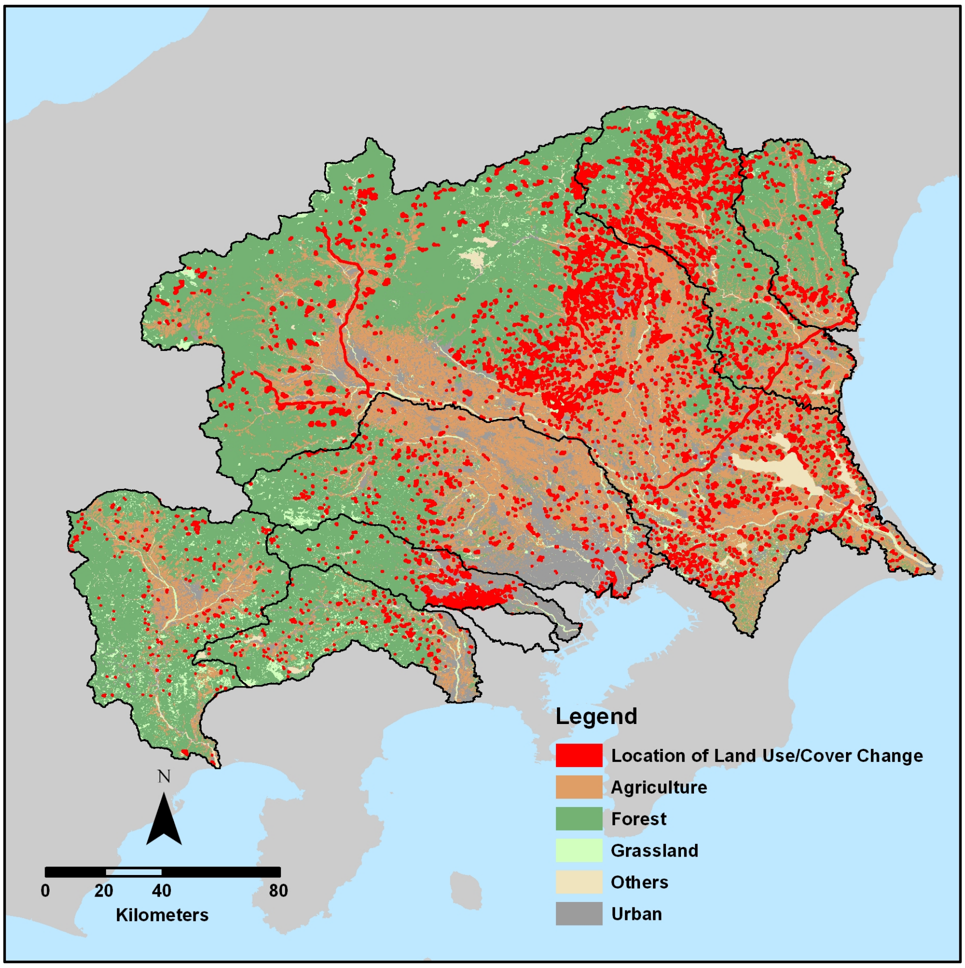


Figure 15. Location of land use/cover changes in the studied river basins (1983–1986 to 1989–1992)

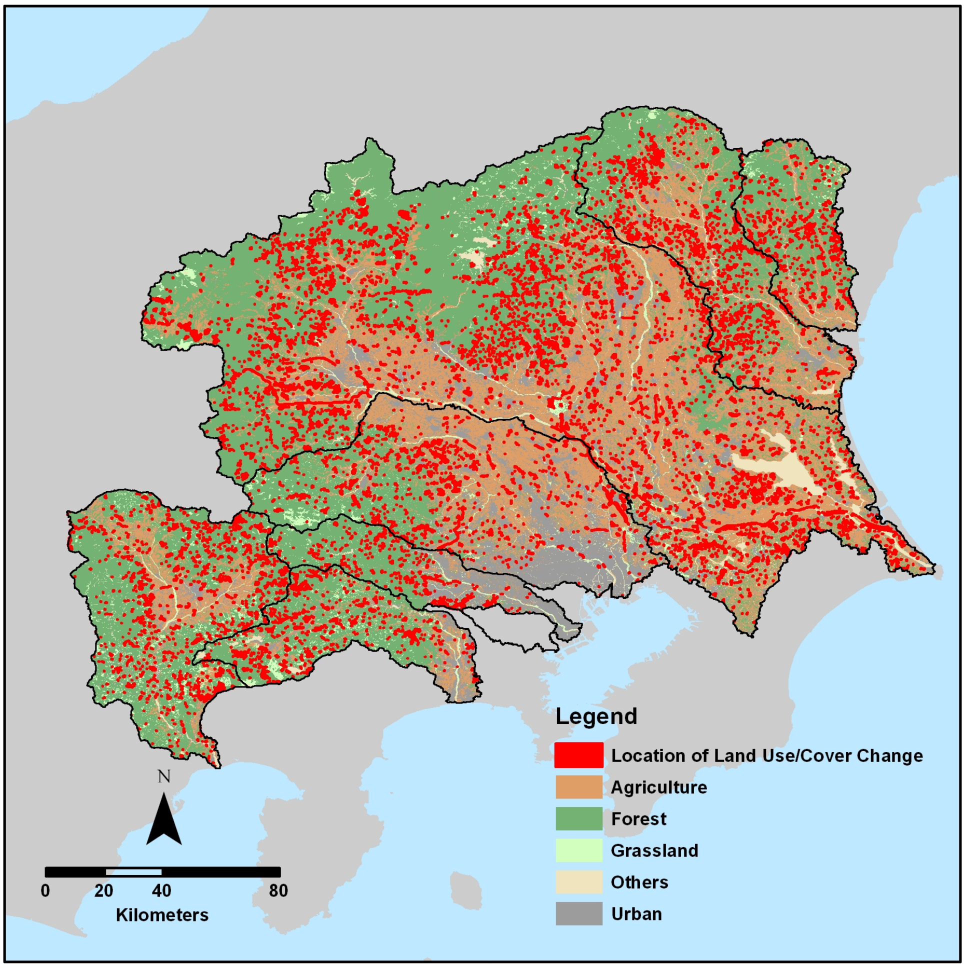


Figure 16. Location of land use/cover changes in the studied river basins (1989–1992 to 1995–1999)

Table 4. General land use/cover changes in the studied river basins (1983–1986 to 1989–1992)

Land use/cover		**1989–1992**					
		Agriculture	Forest	Grassland	Others	Urban	Total
1983–1986	Agriculture	**29.12**	0.03	0.03	0.01	0.27	29.46
	Forest	0.37	**51.15**	0.15	0.02	0.32	52.01
	Grassland	0.02	0.03	**3.48**	0.01	0.06	3.60
	Others			0.01	**2.43**	0.01	2.46
	Urban	0.02	0.01	0.01		**12.43**	12.48
	Total	29.53	51.22	3.68	2.46	13.10	**100.00**
Figure in percentage from total area of 31,162 km^2							

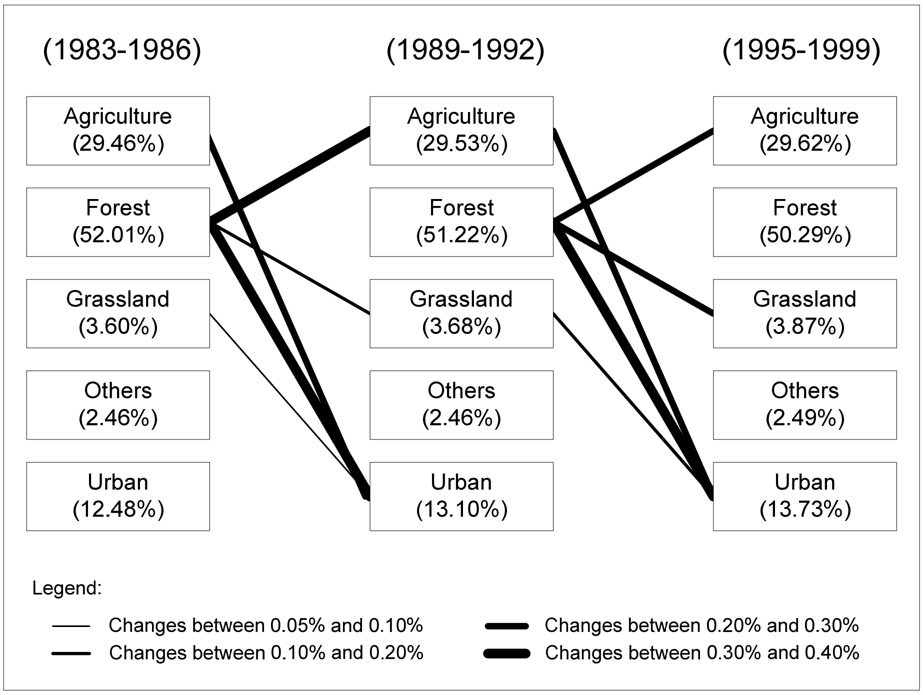


Figure 17. Pattern of major land use/cover changes in the studied river basins

Table 5 presents the matrix of general land use/cover changes between the latter periods. Similar to the earlier periods, land use/cover changes in these periods are characterized by a relatively large conversion of forest and the agricultural area. In these periods, 0.94% of forest was converted into various land use/covers, mainly into urban and agricultural areas, while 0.25% of the agricultural area was converted into the urban area. In these periods, forest conversion into grassland was increased up to 0.27%.

Table 5. General land use/cover changes in the studied river basins (1989–1992 to 1995–1999)

Land use/cover		1995 – 1999					
		Agriculture	Forest	Grassland	Others	Urban	Total
1989–1992	Agriculture	**29.27**		0.01		0.25	29.53
	Forest	0.30	**50.28**	0.27	0.02	0.35	51.22
	Grassland	0.02		**3.59**		0.07	3.68
	Others				**2.46**	0.01	2.46
	Urban	0.03				**13.06**	13.10
	Total	29.62	50.29	3.87	2.49	13.73	**100.00**
Figure in percentage from total area of 31,162 km^2							

Tables 4 and 5 show that grassland and others gradually increased. They were also converted into other land use/covers, despite their slight increments, meaning that they were the most dynamic land use/covers. Figure 17 also indicates agriculture and grassland are potential land use/covers for future urbanization.

Tables 6 and 7 present general land use/cover changes in the studied river basins in relation with the City Planning Law. Out of 0.66% of urbanization in the earlier periods, 0.19% took place in UPA where development was promoted and fewer development restrictions were applied; 0.22% took place in UCA where development was constrained; 0.18% in the areas not classified into UPA/UCA; and 0.06% in the areas not covered by the City Planning Law.

As expected, little conversion into the agricultural area (0.01%) was found in UPA, while conversion into grassland showed a higher value (0.03%). In contrast, conversions into grassland and the agricultural area were prominent in UCA and the areas not covered by the City Planning Law. In total, 0.05% and 0.11% of the total area were converted into grassland in UCA and the areas not covered by the City Planning Law, respectively. As for conversion into the agricultural area, the figures are 0.13% in the areas not classified into UPA/UCA and 0.16% in the areas not covered by the City Planning Law.

In Figure 16, dispersed distribution of land use/cover changes is observed. The land use/cover change matrix in Table 7 for the latter periods explains evenly distributed changes. The only change in UPA was the conversion of 0.16% of the total area into the urban area, slightly less than in the earlier periods. However, in UCA and the areas not covered by the City Planning Law, the level of urbanization was slightly higher in comparison to the previous periods, with 0.22% and 0.14% of the area being converted, respectively. While conversion into the agricultural area in UCA and the areas not covered by the City Planning Law was slightly less in the latter periods (0.08% and 0.15% respectively), conversion into grassland in the areas not covered by the City Planning Law doubled (0.22%) from the earlier periods.

Table 6. General land use/cover changes in the studied river basins based on the City Planning Law (1983–1986 to 1989–1992)

	1989–1992						
1983–1986	**Urbanization Promotion Area (UPA)**						
	Land use/cover	Agriculture	Forest	Grassland	Others	Urban	Total
	Agriculture	**2.21**		0.01		0.10	2.33
	Forest		**0.59**	0.01		0.07	0.67
	Grassland			**0.30**		0.02	0.33
	Others				**0.06**		0.06
	Urban	0.01		0.01		**6.79**	6.81
	Total	2.23	0.59	0.33	0.06	6.98	**10.19**
	Urbanization Control Area (UCA)						
	Agriculture	**14.20**	0.01	0.01		0.10	14.31
	Forest	0.08	**5.44**	0.02		0.09	5.63
	Grassland	0.01		**0.94**		0.03	0.98
	Others			0.01	**0.80**		0.81
	Urban	0.01		0.01		**3.23**	3.25
	Total	14.30	5.45	0.98	0.81	3.45	**24.99**
	Not Classified into UPA/UCA						
	Agriculture	**8.20**	0.01	0.01		0.06	8.29
	Forest	0.13	**8.95**	0.02		0.11	9.22
	Grassland		0.01	**0.48**		0.01	0.51
	Others				**0.56**		0.57
	Urban					**1.77**	1.78
	Total	8.34	8.98	0.52	0.56	1.95	**20.36**
	Not Covered by City Planning Law						
	Agriculture	**4.50**	0.01	0.01		0.01	4.53
	Forest	0.16	**36.17**	0.10	0.01	0.05	36.48
	Grassland		0.02	**1.75**	0.01		1.78
	Others				**1.02**		1.02
	Urban					**0.64**	0.64
	Total	4.67	36.20	1.86	1.03	0.70	**44.46**
Figures in percentage from total area of 31,162 km^2							

Table 7. General land use/cover changes in the studied river basins based on the City Planning Law (1989–1992 to 1995–1999)

	1995–1999						
1989–1992	**Urbanization Promotion Area (UPA)**						
	Land use/cover	Agriculture	Forest	Grassland	Others	Urban	Total
	Agriculture	**2.15**				0.08	2.23
	Forest		**0.53**			0.06	0.59
	Grassland			**0.31**		0.02	0.33
	Others				**0.06**		0.06
	Urban					**6.98**	6.98
	Total	2.15	0.53	0.31	0.06	7.14	**10.19**
	Urbanization Control Area (UCA)						
	Agriculture	**14.20**				0.09	14.30
	Forest	0.06	**5.29**	0.01		0.09	5.45
	Grassland	0.01		**0.93**		0.04	0.98
	Others				**0.80**		0.81
	Urban	0.01				**3.44**	3.45
	Total	14.29	5.29	0.95	0.80	3.66	**24.99**
	Not Classified into UPA/UCA						
	Agriculture	**8.28**				0.06	8.34
	Forest	0.10	**8.75**	0.04		0.08	8.98
	Grassland			**0.50**		0.01	0.52
	Others				**0.56**		0.56
	Urban	0.02				**1.94**	1.95
	Total	8.40	8.75	0.55	0.57	2.09	**20.36**
	Not Covered by City Planning Law						
	Agriculture	**4.65**				0.02	4.67
	Forest	0.13	**35.71**	0.22	0.02	0.12	36.20
	Grassland	0.01		**1.84**			1.86
	Others				**1.03**		1.03
	Urban	0.01				**0.70**	0.70
	Total	4.79	35.71	2.06	1.06	0.84	**44.46**
Figures in percentage from total area of 31,162 km^2							

Tables 8 and 9 present changes in 13 agricultural and five urban land use/covers in the studied river basins, and Figure 18 provide information about the pattern of the major changes. Additionally, Tables 10 to 17 provide information about the changes in relation with the City Planning Law. Table 8 shows that forest conversion contributed to 0.37% increase in the agricultural land use/covers, with 0.32% being converted into the cultivated meadows, 0.04% into the field weed communities, and 0.01% into the paddy-field weed communities. Major conversion of forest into urban land use/covers occurred in the form of the land constructed for residence/factories (0.19%), followed by the urban/residential districts with many trees, the urban district with a few trees, and the factories/industrial areas (0.07%, 0.05%, and 0.02% respectively). The agricultural area was also converted into the urban area, especially the field weed communities (0.12%) and the paddy field weed communities (0.11%). In Table 8, changes among agricultural land use/covers showed the tendency of conversion of the field weed communities and the paddy-field weed communities into the cultivated meadows. Among urban land use/covers, conversion of 0.03% of the urban district with a few trees into the urban district with many trees indicates the reduction of high-density residential area.

In Table 9, forest conversion remained as the focal point. It was converted into the cultivated meadows (0.27%), the land constructed for residence/factories (0.30%), and grassland (0.27%). Another 0.30% of various land use/covers were also converted into the land constructed for residence/factories. Interestingly, 0.03% of the land constructed for residence/factories was converted into the cultivated meadows. Detailed information showed that 0.01% of it was located in UCA (Table 15), 0.01 % in the areas not classified into UPA/UCA (Table 16), and 0.01% in the areas not covered by the City Planning Law (Table 17).

Table 8. Detail land use/cover changes in the studied river basins (1983–1986 to 1989–1992)

LULC		1989–1992																				
		Cul	Dec	Eve	Exb	Ext	Fwc	Mul	Nur	Pwc	The	Wcf	Wcp	Wcr	For	Gra	Oth	Con	Fac	Lan	Urm	Urf
1983–1986	Cul	**0.98**													0.02	0.02				0.01		
	Dec		**0.91**																			
	Eve			**0.02**																		
	Exb																					
	Ext																					
	Fwc	0.03					**9.75**			0.01					0.01				0.01	0.04	0.04	0.03
	Mul							**2.47**														0.01
	Nur								**0.11**													
	Pwc	0.02					0.01			**14.24**						0.01			0.01	0.03	0.03	0.04
	The										**0.08**											
	Wcf											**0.11**										
	Wcp												**0.22**									
	Wcr																					
	For	0.32					0.04			0.01					**50.86**	0.15	0.02		0.02	0.19	0.07	0.05
	Gra	0.01													0.03	**3.47**	0.01		0.01	0.03	0.01	0.01
	Oth															0.01	**2.42**					
	Con																	**0.04**				
	Fac																		**0.75**			
	Lan	0.01														0.01			0.01	**0.70**	0.02	0.02
	Urm																			0.01	**4.02**	0.02
	Urf																		0.02	0.01	0.03	**7.19**

Agricultural land use/cover:

Cul: Cultivated meadow, Dec: Deciduous orchard, Eve: Evergreen orchard, Exb: Exotic broad-leaved plantation, Ext: Exotic tree plantation, Fwc: Field weeds communities, Mul: Mulberry garden, Nur: Nursery garden, Pwc Paddy-field weed communities, The: Thea sinensis garden, Wcf: Weed communities in uncultivated field, Wcp: Weed communities in uncultivated paddy field, Wcr: Weed communities of the roadside

For: Forest, Gra: Grassland, Oth: Others

Urban land use/cover:

Con: Concrete pavement site, Fac: Factory/industrial areas, Lan: Land constructed for residence/factories, Urm: Urban/residential districts with many trees, Urf: Urban district with a few trees

Figure in percentage from total area of 31,162 km^2

Table 9. Detail land use/cover changes in the studied river basins (1989–1992 to 1995–1999)

LULC		1995–1999																				
		Cul	Dec	Eve	Exb	Ext	Fwc	Mul	Nur	Pwc	The	Wcf	Wcp	Wcr	For	Gra	Oth	Con	Fac	Lan	Urm	Urf
1989–1992	Cul	**1.36**					0.01													0.01		0.01
	Dec		**0.91**																	0.01		
	Eve			**0.02**																		
	Exb																					
	Ext																					
	Fwc	0.02					**9.72**													0.06		
	Mul	0.01					0.02	**2.44**												0.01		
	Nur								**0.11**													
	Pwc	0.02								**14.22**									0.01	0.10		0.01
	The										**0.08**											
	Wcf											**0.11**										
	Wcp												**0.21**							0.01		
	Wcr																					
	For	0.27					0.03								**50.28**	0.27	0.02		0.01	0.30	0.03	0.01
	Gra	0.02														**3.59**				0.07		
	Oth																**2.46**			0.01		
	Con																	**0.05**				
	Fac																		**0.82**			
	Lan	0.03																		**0.93**	0.01	
	Urm																			0.01	**4.21**	
	Urf																			0.01		**7.02**

Agricultural land use/cover:

(Cul) Cultivated meadow, Dec: Deciduous orchard, Eve: Evergreen orchard, Exb: Exotic broad-leaved plantation, Ext: Exotic tree plantation, Fwc: Field weeds communities, Mul: Mulberry garden, Nur: Nursery garden, Pwc Paddy-field weed communities, The: Thea sinensis garden, Wcf: Weed communities in uncultivated field, Wcp: Weed communities in uncultivated paddy field, Wcr: Weed communities of the roadside

For: Forest, Gra: Grassland, Oth: Others

Urban land use/cover:

Con: Concrete pavement site, Fac: Factory/industrial areas, Lan: Land constructed for residence/factories, Urm: Urban/residential districts with many trees, Urf: Urban district with a few trees

Figure in percentage from total area of 31,162 km^2

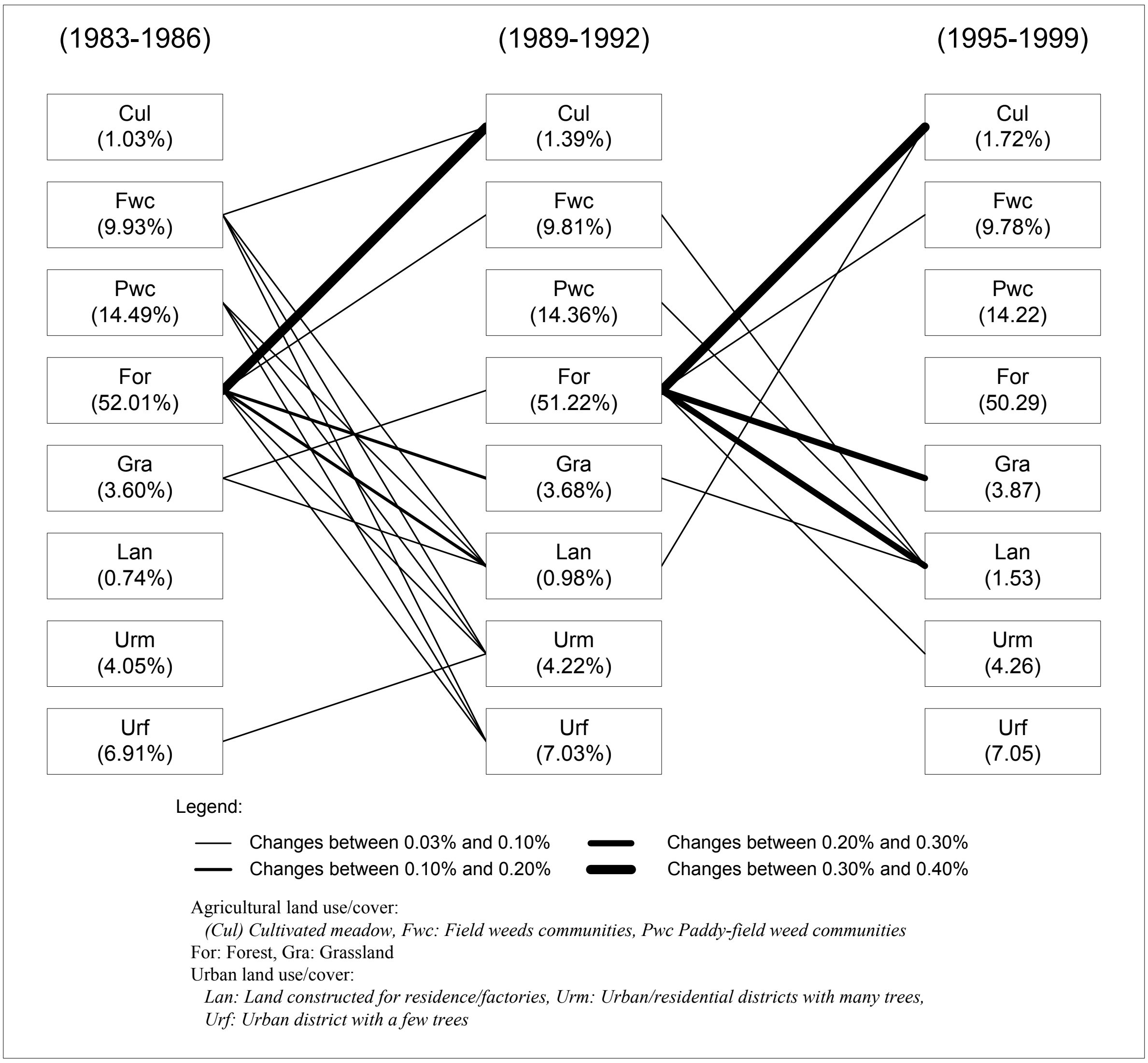


Figure 18. Pattern of major changes in detailed land use/covers in the studied river basins

Figure 18 shows that the patterns of land use/cover changes in the studied river were slightly different between the former and latter durations. In the former duration, conversions of the field weed communities, the paddy field weed communities, and forest into the urban/residential districts with many trees and the urban district with a few trees were considerable. However, these conversions were minor in the latter periods. Major forest conversions into the cultivated meadow, grassland, and the land constructed for residence/factories were tended to increase in the latter period. Whereas, forest conversion into the field weed communities also slightly increased (Table 9).

Further details on land use/cover changes in each studied river basin are shown in Tables 18 to 31. In general, each river basin showed land use/cover change patterns similar to those for the total basins noted above. In most river basins, a larger percentage of forest was converted into the urban area, mainly into the land constructed for residence/factories, and into the urban district with a few trees. In the Naka, Tama, and Tone river basins, a large percentage of forest was also converted into the urban/residential districts with many trees. Conversion into the urban area from the agricultural area generally took place in the field weed communities and the paddy field weed communities. Similar to the forest conversion, these agricultural areas were generally converted into the land constructed for residence/factories. Apart from conversions into the urban area, forest was also converted into the agricultural area in most river basins, specifically into the cultivated meadows. Conversion from forest into grassland was also observed, especially in the Ara/Edo River basin.

Table 10. Detail land use/cover changes in urbanization promotion area in the studied river basins (1983–1986 to 1989–1992)

LULC		**1989–1992**																				
		Urbanization Promotion Area (UPA)																				
		Cul	Dec	Eve	Exb	Ext	Fwc	Mul	Nur	Pwc	The	Wcf	Wcp	Wcr	For	Gra	Oth	Con	Fac	Lan	Urm	Urf
1983–1986	Cul	**0.07**																				
	Dec		**0.08**																			
	Eve																					
	Exb																					
	Ext																					
	Fwc						**0.99**													0.01	0.02	0.01
	Mul							**0.15**														
	Nur								**0.06**													
	Pwc									**0.74**										0.01	0.01	0.02
	The										**0.02**											
	Wcf											**0.03**										
	Wcp												**0.07**									
	Wcr																					
	For														**0.59**	0.01			0.01	0.02	0.02	0.02
	Gra															**0.30**				0.01		0.01
	Oth																**0.06**					
	Con																	**0.01**				
	Fac																		**0.57**			
	Lan																		0.01	**0.22**	0.01	0.02
	Urm																				**1.12**	0.01
	Urf																		0.01	0.01	0.01	**4.79**

Agricultural land use/cover:
Cul: Cultivated meadow, Dec: Deciduous orchard, Eve: Evergreen orchard, Exb: Exotic broad-leaved plantation, Ext: Exotic tree plantation, Fwc: Field weeds communities, Mul: Mulberry garden, Nur: Nursery garden, Pwc Paddy-field weed communities, The: Thea sinensis garden, Wcf: Weed communities in uncultivated field, Wcp: Weed communities in uncultivated paddy field, Wcr: Weed communities of the roadside
For: Forest, Gra: Grassland, Oth: Others
Urban land use/cover:
Con: Concrete pavement site, Fac: Factory/industrial areas, Lan: Land constructed for residence/factories, Urm: Urban/residential districts with many trees, Urf: Urban district with a few trees
Figure in percentage from total area of 31,162 km^2

Table 11. Detail land use/cover changes in urbanization control area in the studied river basins (1983–1986 to 1989–1992)

LULC		1989–1992																				
		Urbanization Control Area																				
		Cul	Dec	Eve	Exb	Ext	Fwc	Mul	Nur	Pwc	The	Wcf	Wcp	Wcr	For	Gra	Oth	Con	Fac	Lan	Urm	Urf
1983–1986	Cul	**0.43**																				
	Dec		**0.24**																			
	Eve																					
	Exb																					
	Ext																					
	Fwc	0.01					**4.24**													0.02	0.01	0.01
	Mul							**0.83**														
	Nur								**0.04**													
	Pwc	0.01								**8.17**										0.01	0.01	0.02
	The										**0.05**											
	Wcf											**0.03**										
	Wcp												**0.14**									
	Wcr																					
	For	0.07					0.01								**5.44**	0.02			0.01	0.06	0.01	0.02
	Gra	0.01														**0.94**				0.02		
	Oth															0.01	**0.80**					
	Con																	**0.02**				
	Fac																		**0.13**			
	Lan																			**0.21**		
	Urm																				**1.88**	
	Urf																				0.01	**0.97**

Agricultural land use/cover:

Cul: Cultivated meadow, Dec: Deciduous orchard, Eve: Evergreen orchard, Exb: Exotic broad-leaved plantation, Ext: Exotic tree plantation, Fwc: Field weeds communities, Mul: Mulberry garden, Nur: Nursery garden, Pwc Paddy-field weed communities, The: Thea sinensis garden, Wcf: Weed communities in uncultivated field, Wcp: Weed communities in uncultivated paddy field, Wcr: Weed communities of the roadside

For: Forest, Gra: Grassland, Oth: Others

Urban land use/cover:

Con: Concrete pavement site, Fac: Factory/industrial areas, Lan: Land constructed for residence/factories, Urm: Urban/residential districts with many trees, Urf: Urban district with a few trees

Figure in percentage from total area of 31,162 km^2

Table 12. Detail land use/cover changes in area not classified into UPA/UCA in the studied river basins (1983–1986 to 1989–1992)

LULC		**1989–1992**																				
		Not Classified into UPA/UCA																				
		Cul	Dec	Eve	Exb	Ext	Fwc	Mul	Nur	Pwc	The	Wcf	Wcp	Wcr	For	Gra	Oth	Con	Fac	Lan	Urm	Urf
1983–1986	Cul	**0.23**													0.01							
	Dec		**0.51**																			
	Eve			**0.01**																		
	Exb																					
	Ext																					
	Fwc	0.02					**2.47**													0.01	0.01	0.01
	Mul							**0.98**														
	Nur								**0.01**													
	Pwc	0.01								**3.94**										0.01	0.01	0.01
	The																					
	Wcf											**0.01**										
	Wcp												**0.01**									
	Wcr																					
	For	0.10					0.02			0.01					**8.95**	0.02				0.06	0.03	0.01
	Gra														0.01	**0.48**						
	Oth																**0.56**					
	Con																					
	Fac																		**0.04**			
	Lan																			**0.10**		
	Urm																				**0.77**	
	Urf																					**0.83**

Agricultural land use/cover:

Cul: Cultivated meadow, Dec: Deciduous orchard, Eve: Evergreen orchard, Exb: Exotic broad-leaved plantation, Ext: Exotic tree plantation, Fwc: Field weeds communities, Mul: Mulberry garden, Nur: Nursery garden, Pwc Paddy-field weed communities, The: Thea sinensis garden, Wcf: Weed communities in uncultivated field, Wcp: Weed communities in uncultivated paddy field, Wcr: Weed communities of the roadside

For: Forest, Gra: Grassland, Oth: Others

Urban land use/cover:

Con: Concrete pavement site, Fac: Factory/industrial areas, Lan: Land constructed for residence/factories, Urm: Urban/residential districts with many trees, Urf: Urban district with a few trees

Figure in percentage from total area of 31,162 km^2

Table 13. Detail land use/cover changes in area not covered by the City Planning Law in the studied river basins (1983–1986 to 1989–1992)

LULC		1989–1992																				
		Not Covered by City Planning Law																				
		Cul	Dec	Eve	Exb	Ext	Fwc	Mul	Nur	Pwc	The	Wcf	Wcp	Wcr	For	Gra	Oth	Con	Fac	Lan	Urm	Urf
1983–1986	Cul	**0.26**													0.01							
	Dec		**0.09**																			
	Eve			**0.01**																		
	Exb																					
	Ext																					
	Fwc	0.01					**2.04**															
	Mul							**0.54**														
	Nur																					
	Pwc	0.01								**1.48**												
	The										**0.02**											
	Wcf											**0.04**										
	Wcp																					
	Wcr																					
	For	0.15					0.01								**36.17**	0.10	0.01			0.04		0.01
	Gra														0.02	**1.75**	0.01					
	Oth																**1.02**					
	Con																					
	Fac																		**0.01**			
	Lan																			**0.13**		
	Urm																				**0.24**	
	Urf																					**0.25**

Agricultural land use/cover:

Cul: Cultivated meadow, Dec: Deciduous orchard, Eve: Evergreen orchard, Exb: Exotic broad-leaved plantation, Ext: Exotic tree plantation, Fwc: Field weeds communities, Mul: Mulberry garden, Nur: Nursery garden, Pwc Paddy-field weed communities, The: Thea sinensis garden, Wcf: Weed communities in uncultivated field, Wcp: Weed communities in uncultivated paddy field, Wcr: Weed communities of the roadside

For: Forest, Gra: Grassland, Oth: Others

Urban land use/cover:

Con: Concrete pavement site, Fac: Factory/industrial areas, Lan: Land constructed for residence/factories, Urm: Urban/residential districts with many trees, Urf: Urban district with a few trees

Figure in percentage from total area of 31,162 km^2

Table 14. Detail land use/cover changes in urbanization promotion area in the studied river basins (1989–1992 to 1995–1999)

LULC		1995–1999																				
		Urbanization Promotion Area																				
		Cul	Dec	Eve	Exb	Ext	Fwc	Mul	Nur	Pwc	The	Wcf	Wcp	Wcr	For	Gra	Oth	Con	Fac	Lan	Urm	Urf
1989–1992	Cul	**0.07**																		0.01		
	Dec		**0.07**																			
	Eve																					
	Exb																					
	Ext																					
	Fwc						**0.98**													0.02		
	Mul							**0.15**														
	Nur								**0.06**													
	Pwc									**0.70**									0.01	0.03		
	The										**0.02**											
	Wcf											**0.03**										
	Wcp												**0.07**							0.01		
	Wcr																					
	For														**0.53**					0.06		
	Gra															**0.31**				0.02		
	Oth																**0.06**					
	Con																	**0.02**				
	Fac																		**0.61**			
	Lan																			**0.27**		
	Urm																				**1.20**	
	Urf																					**4.87**

Agricultural land use/cover:

Cul: Cultivated meadow, Dec: Deciduous orchard, Eve: Evergreen orchard, Exb: Exotic broad-leaved plantation, Ext: Exotic tree plantation, Fwc: Field weeds communities, Mul: Mulberry garden, Nur: Nursery garden, Pwc Paddy-field weed communities, The: Thea sinensis garden, Wcf: Weed communities in uncultivated field, Wcp: Weed communities in uncultivated paddy field, Wcr: Weed communities of the roadside

For: Forest, Gra: Grassland, Oth: Others

Urban land use/cover:

Con: Concrete pavement site, Fac: Factory/industrial areas, Lan: Land constructed for residence/factories, Urm: Urban/residential districts with many trees, Urf: Urban district with a few trees

Figure in percentage from total area of 31,162 km^2

Table 15. Detail land use/cover changes in urbanization control area in the studied river basins (1989–1992 to 1995–1999)

LULC		1995–1999																				
		Urbanization Control Area																				
		Cul	Dec	Eve	Exb	Ext	Fwc	Mul	Nur	Pwc	The	Wcf	Wcp	Wcr	For	Gra	Oth	Con	Fac	Lan	Urm	Urf
1989–1992	Cul	**0.51**																				
	Dec		**0.24**																			
	Eve																					
	Exb																					
	Ext																					
	Fwc						**4.23**													0.02		
	Mul							**0.82**														
	Nur								**0.04**													
	Pwc	0.01								**8.12**										0.03		
	The										**0.05**											
	Wcf											**0.03**										
	Wcp												**0.13**									
	Wcr																					
	For	0.06													**5.29**	0.01				0.08		
	Gra	0.01														**0.93**				0.03		
	Oth																**0.80**					
	Con																	**0.02**				
	Fac																		**0.15**			
	Lan	0.01																		**0.31**		
	Urm																				**1.93**	
	Urf																					**1.02**

Agricultural land use/cover:

Cul: Cultivated meadow, Dec: Deciduous orchard, Eve: Evergreen orchard, Exb: Exotic broad-leaved plantation, Ext: Exotic tree plantation, Fwc: Field weeds communities, Mul: Mulberry garden, Nur: Nursery garden, Pwc Paddy-field weed communities, The: Thea sinensis garden, Wcf: Weed communities in uncultivated field, Wcp: Weed communities in uncultivated paddy field, Wcr: Weed communities of the roadside

For: Forest, Gra: Grassland, Oth: Others

Urban land use/cover:

Con: Concrete pavement site, Fac: Factory/industrial areas, Lan: Land constructed for residence/factories, Urm: Urban/residential districts with many trees, Urf: Urban district with a few trees

Figure in percentage from total area of 31,162 km^2

Table 16. Detail land use/cover changes in area not classified into UPA/UCA in the studied river basins (1989–1992 to 1995–1999)

LULC		**1995–1999**																				
		Not Classified into UPA/UCA																				
		Cul	Dec	Eve	Exb	Ext	Fwc	Mul	Nur	Pwc	The	Wcf	Wcp	Wcr	For	Gra	Oth	Con	Fac	Lan	Urm	Urf
1989–1992	Cul	**0.35**																				
	Dec		**0.50**																			
	Eve			**0.01**																		
	Exb																					
	Ext																					
	Fwc						**2.48**													0.02		
	Mul						0.02	**0.95**														
	Nur								**0.01**													
	Pwc									**3.93**										0.02		
	The																					
	Wcf											**0.01**										
	Wcp												**0.01**									
	Wcr																					
	For	0.09					0.01								**8.75**	0.04				0.07	0.01	
	Gra															**0.50**				0.01		
	Oth																**0.56**					
	Con																					
	Fac																		**0.06**			
	Lan	0.01																		**0.17**	0.01	
	Urm																				**0.83**	
	Urf																					**0.86**

Agricultural land use/cover:

Cul: Cultivated meadow, Dec: Deciduous orchard, Eve: Evergreen orchard, Exb: Exotic broad-leaved plantation, Ext: Exotic tree plantation, Fwc: Field weeds communities, Mul: Mulberry garden, Nur: Nursery garden, Pwc Paddy-field weed communities, The: Thea sinensis garden, Wcf: Weed communities in uncultivated field, Wcp: Weed communities in uncultivated paddy field, Wcr: Weed communities of the roadside

For: Forest, Gra: Grassland, Oth: Others

Urban land use/cover:

Con: Concrete pavement site, Fac: Factory/industrial areas, Lan: Land constructed for residence/factories, Urm: Urban/residential districts with many trees, Urf: Urban district with a few trees

Figure in percentage from total area of 31,162 km^2

Table 17. Detail land use/cover changes in area not covered by the City Planning Law in the studied river basins (1989–1992 to 1995–1999)

LULC		1995–1999																				
		Not Covered by City Planning Law																				
		Cul	Dec	Eve	Exb	Ext	Fwc	Mul	Nur	Pwc	The	Wcf	Wcp	Wcr	For	Gra	Oth	Con	Fac	Lan	Urm	Urf
1989–1992	Cul	**0.43**																				0.01
	Dec		**0.09**																			
	Eve			**0.01**																		
	Exb																					
	Ext																					
	Fwc	0.01					**2.04**															
	Mul							**0.53**														
	Nur																					
	Pwc									**1.47**										0.01		
	The										**0.02**											
	Wcf											**0.04**										
	Wcp																					
	Wcr																					
	For	0.12					0.01								**35.71**	0.22	0.02			0.09	0.02	
	Gra	0.01														**1.84**						
	Oth																**1.03**					
	Con																					
	Fac																		**0.01**			
	Lan	0.01																		**0.18**		
	Urm																				**0.25**	
	Urf																					**0.26**

Agricultural land use/cover:

Cul: Cultivated meadow, Dec: Deciduous orchard, Eve: Evergreen orchard, Exb: Exotic broad-leaved plantation, Ext: Exotic tree plantation, Fwc: Field weeds communities, Mul: Mulberry garden, Nur: Nursery garden, Pwc Paddy-field weed communities, The: Thea sinensis garden, Wcf: Weed communities in uncultivated field, Wcp: Weed communities in uncultivated paddy field, Wcr: Weed communities of the roadside

For: Forest, Gra: Grassland, Oth: Others

Urban land use/cover:

Con: Concrete pavement site, Fac: Factory/industrial areas, Lan: Land constructed for residence/factories, Urm: Urban/residential districts with many trees, Urf: Urban district with a few trees

Figure in percentage from total area of 31,162 km^2

Table 18. Detail land use/cover changes in the Ara/Edo River basin (1983–1986 to 1989–1992)

LULC		1989–1992																				
		Cul	Dec	Eve	Exb	Ext	Fwc	Mul	Nur	Pwc	The	Wcf	Wcp	Wcr	For	Gra	Oth	Con	Fac	Lan	Urm	Urf
1983–1986	Cul	**1.19**																		0.01		
	Dec		**0.63**																			
	Eve																					
	Exb																					
	Ext																					
	Fwc						**8.71**															0.01
	Mul	0.01						**4.85**													0.01	
	Nur								**0.50**													0.01
	Pwc						0.01			**17.40**									0.01	0.02	0.01	0.05
	The										**0.45**											
	Wcf											**0.36**										
	Wcp												**0.97**			0.01				0.01		0.02
	Wcr																					
	For	0.11					0.01								**29.31**	0.07			0.01	0.06	0.03	0.06
	Gra	0.01														**3.58**			0.01	0.02	0.01	0.03
	Oth	0.01															**1.50**					
	Con																	**0.16**				
	Fac																		**1.88**		0.01	
	Lan	0.01														0.01		0.01	0.01	**0.59**	0.01	0.04
	Urm																				**6.18**	0.02
	Urf	0.01																0.01	0.04	0.02	0.01	**20.84**

Agricultural land use/cover:

Cul: Cultivated meadow, Dec: Deciduous orchard, Eve: Evergreen orchard, Exb: Exotic broad-leaved plantation, Ext: Exotic tree plantation, Fwc: Field weeds communities, Mul: Mulberry garden, Nur: Nursery garden, Pwc Paddy-field weed communities, The: Thea sinensis garden, Wcf: Weed communities in uncultivated field, Wcp: Weed communities in uncultivated paddy field, Wcr: Weed communities of the roadside

For: Forest, Gra: Grassland, Oth: Others

Urban land use/cover:

Con: Concrete pavement site, Fac: Factory/industrial areas, Lan: Land constructed for residence/factories, Urm: Urban/residential districts with many trees, Urf: Urban district with a few trees

Figure in percentage from total area of 4,440 km^2

Table 19. Detail land use/cover changes in the Ara/Edo River basin (1989–1992 to 1995–1999)

LULC		1995–1999																				
		Cul	Dec	Eve	Exb	Ext	Fwc	Mul	Nur	Pwc	The	Wcf	Wcp	Wcr	For	Gra	Oth	Con	Fac	Lan	Urm	Urf
1989–1992	Cul	**1.34**														0.01						
	Dec		**0.63**																			
	Eve																					
	Exb																					
	Ext																					
	Fwc	0.01					**8.67**			0.01						0.01				0.02		0.01
	Mul	0.01						**4.79**		0.01					0.01					0.01		0.01
	Nur								**0.49**													
	Pwc	0.02	0.01							**17.14**			0.01		0.01	0.01			0.05	0.12	0.01	0.03
	The										**0.44**											0.01
	Wcf											**0.35**										
	Wcp	0.01											**0.92**						0.01	0.04		
	Wcr																					
	For	0.40					0.01								**28.57**	0.08	0.01		0.02	0.18	0.01	0.03
	Gra	0.03														**3.58**				0.06		0.01
	Oth																**1.49**			0.01		
	Con																	**0.18**				
	Fac																		**1.97**			
	Lan	0.01																		**0.72**		
	Urm																				**6.27**	
	Urf																			0.01		**21.07**

Agricultural land use/cover:

Cul: Cultivated meadow, Dec: Deciduous orchard, Eve: Evergreen orchard, Exb: Exotic broad-leaved plantation, Ext: Exotic tree plantation, Fwc: Field weeds communities, Mul: Mulberry garden, Nur: Nursery garden, Pwc Paddy-field weed communities, The: Thea sinensis garden, Wcf: Weed communities in uncultivated field, Wcp: Weed communities in uncultivated paddy field, Wcr: Weed communities of the roadside

For: Forest, Gra: Grassland, Oth: Others

Urban land use/cover:

Con: Concrete pavement site, Fac: Factory/industrial areas, Lan: Land constructed for residence/factories, Urm: Urban/residential districts with many trees, Urf: Urban district with a few trees

Figure in percentage from total area of 4,440 km^2

Table 20. Detail land use/cover changes in the Fuji River basin (1983–1986 to 1989–1992)

LULC		**1989–1992**																				
		Cul	Dec	Eve	Exb	Ext	Fwc	Mul	Nur	Pwc	The	Wcf	Wcp	Wcr	For	Gra	Oth	Con	Fac	Lan	Urm	Urf
1983–1986	Cul	**0.71**																				
	Dec		**4.36**																			
	Eve			**0.16**																		
	Exb				**0.01**																	
	Ext																					
	Fwc						**2.89**															
	Mul							**3.57**														
	Nur																					
	Pwc									**4.85**												
	The										**0.15**											
	Wcf											**0.41**										
	Wcp												**0.01**									
	Wcr																					
	For	0.03													**69.09**	0.04				0.01		
	Gra														0.01	**7.31**						
	Oth																**1.24**					
	Con																					
	Fac																		**0.07**			
	Lan																			**0.93**		
	Urm																				**0.31**	
	Urf																					**3.82**

Agricultural land use/cover:

Cul: Cultivated meadow, Dec: Deciduous orchard, Eve: Evergreen orchard, Exb: Exotic broad-leaved plantation, Ext: Exotic tree plantation, Fwc: Field weeds communities, Mul: Mulberry garden, Nur: Nursery garden, Pwc Paddy-field weed communities, The: Thea sinensis garden, Wcf: Weed communities in uncultivated field, Wcp: Weed communities in uncultivated paddy field, Wcr: Weed communities of the roadside

For: Forest, Gra: Grassland, Oth: Others

Urban land use/cover:

Con: Concrete pavement site, Fac: Factory/industrial areas, Lan: Land constructed for residence/factories, Urm: Urban/residential districts with many trees, Urf: Urban district with a few trees

Figure in percentage from total area of 3,564 km^2

Table 21. Detail land use/cover changes in the Fuji River basin (1989–1992 to 1995–1999)

LULC		1995–1999																				
		Cul	Dec	Eve	Exb	Ext	Fwc	Mul	Nur	Pwc	The	Wcf	Wcp	Wcr	For	Gra	Oth	Con	Fac	Lan	Urm	Urf
1989–1992	Cul	**0.74**																				
	Dec	0.01	**4.31**													0.01				0.04		
	Eve			**0.16**																		
	Exb				**0.01**																	
	Ext																					
	Fwc	0.04					**2.84**													0.01		
	Mul	0.01						**3.53**								0.01				0.02		
	Nur																					
	Pwc	0.01								**4.79**										0.05		
	The										**0.15**											
	Wcf											**0.41**										
	Wcp												**0.01**									
	Wcr																					
	For	0.20					0.02								**68.20**	0.44	0.05			0.20		
	Gra	0.02													0.01	**7.29**	0.01			0.02		
	Oth																**1.25**					
	Con																					
	Fac																		**0.07**			
	Lan																			**0.93**		
	Urm																				**0.31**	
	Urf																					**3.83**

Agricultural land use/cover:

Cul: Cultivated meadow, Dec: Deciduous orchard, Eve: Evergreen orchard, Exb: Exotic broad-leaved plantation, Ext: Exotic tree plantation, Fwc: Field weeds communities, Mul: Mulberry garden, Nur: Nursery garden, Pwc Paddy-field weed communities, The: Thea sinensis garden, Wcf: Weed communities in uncultivated field, Wcp: Weed communities in uncultivated paddy field, Wcr: Weed communities of the roadside

For: Forest, Gra: Grassland, Oth: Others

Urban land use/cover:

Con: Concrete pavement site, Fac: Factory/industrial areas, Lan: Land constructed for residence/factories, Urm: Urban/residential districts with many trees, Urf: Urban district with a few trees

Figure in percentage from total area of 3,564 km^2

Table 22. Detail land use/cover changes in the Kuji River basin (1983–1986 to 1989–1992)

LULC		1989–1992																				
		Cul	Dec	Eve	Exb	Ext	Fwc	Mul	Nur	Pwc	The	Wcf	Wcp	Wcr	For	Gra	Oth	Con	Fac	Lan	Urm	Urf
1983–1986	Cul	**0.67**																				
	Dec	0.04	**0.06**																			
	Eve																					
	Exb																					
	Ext																					
	Fwc	0.02					**9.49**													0.06		0.01
	Mul							**0.17**														
	Nur																					
	Pwc	0.08								**10.93**										0.05	0.01	
	The																					
	Wcf																					
	Wcp												**0.06**									
	Wcr																					
	For	0.90					0.04								**70.30**	0.55			0.01	0.17	0.03	0.02
	Gra															**2.08**	0.01					
	Oth																**0.80**					
	Con																					
	Fac																		**0.01**			
	Lan																			**0.20**		0.01
	Urm																			0.01	**1.51**	
	Urf																					**1.66**

Agricultural land use/cover:
Cul: Cultivated meadow, Dec: Deciduous orchard, Eve: Evergreen orchard, Exb: Exotic broad-leaved plantation, Ext: Exotic tree plantation, Fwc: Field weeds communities, Mul: Mulberry garden, Nur: Nursery garden, Pwc Paddy-field weed communities, The: Thea sinensis garden, Wcf: Weed communities in uncultivated field, Wcp: Weed communities in uncultivated paddy field, Wcr: Weed communities of the roadside
For: Forest, Gra: Grassland, Oth: Others
Urban land use/cover:
Con: Concrete pavement site, Fac: Factory/industrial areas, Lan: Land constructed for residence/factories, Urm: Urban/residential districts with many trees, Urf: Urban district with a few trees
Figure in percentage from total area of 1,484 km^2

Table 23. Detail land use/cover changes in the Kuji River basin (1989–1992 to 1995–1999)

LULC		**1995–1999**																				
		Cul	Dec	Eve	Exb	Ext	Fwc	Mul	Nur	Pwc	The	Wcf	Wcp	Wcr	For	Gra	Oth	Con	Fac	Lan	Urm	Urf
1989–1992	Cul	**1.71**																				
	Dec		**0.06**																			
	Eve																					
	Exb																					
	Ext																					
	Fwc						**9.53**									0.01				0.01		
	Mul							**0.17**														
	Nur																					
	Pwc	0.02								**10.90**										0.01		
	The																					
	Wcf																					
	Wcp												**0.05**									
	Wcr																					
	For	0.19					0.03								**69.17**	0.70			0.03	0.18		
	Gra															**2.63**						
	Oth																**0.81**					
	Con																					
	Fac																		**0.02**			
	Lan																			**0.50**		
	Urm																				1.**56**	
	Urf																					**1.69**

Agricultural land use/cover:

Cul: Cultivated meadow, Dec: Deciduous orchard, Eve: Evergreen orchard, Exb: Exotic broad-leaved plantation, Ext: Exotic tree plantation, Fwc: Field weeds communities, Mul: Mulberry garden, Nur: Nursery garden, Pwc Paddy-field weed communities, The: Thea sinensis garden, Wcf: Weed communities in uncultivated field, Wcp: Weed communities in uncultivated paddy field, Wcr: Weed communities of the roadside

For: Forest, Gra: Grassland, Oth: Others

Urban land use/cover:

Con: Concrete pavement site, Fac: Factory/industrial areas, Lan: Land constructed for residence/factories, Urm: Urban/residential districts with many trees, Urf: Urban district with a few trees

Figure in percentage from total area of 1,484 km^2

Table 24. Detail land use/cover changes in the Naka River basin (1983–1986 to 1989–1992)

LULC		1989–1992																				
		Cul	Dec	Eve	Exb	Ext	Fwc	Mul	Nur	Pwc	The	Wcf	Wcp	Wcr	For	Gra	Oth	Con	Fac	Lan	Urm	Urf
1983–1986	Cul	**1.26**								0.02					0.09	0.06	0.01			0.01	0.01	
	Dec	0.01	**0.37**																	0.01		
	Eve																					
	Exb				**0.01**																	
	Ext																					
	Fwc	0.09	0.01				**11.84**	0.01		0.02					0.02		0.01		0.02	0.06	0.06	0.02
	Mul	0.01						**0.46**														
	Nur																					
	Pwc	0.07					0.01			**18.65**					0.02	0.02	0.01		0.01	0.06	0.06	0.04
	The																					
	Wcf																					
	Wcp												**0.01**									
	Wcr																					
	For	0.78	0.01				0.14	0.01		0.07					**54.85**	0.19	0.06		0.03	0.41	0.23	0.06
	Gra	0.01					0.01								0.14	**1.18**	0.01		0.02	0.01	0.02	
	Oth														0.02	0.01	**1.79**			0.01	0.01	
	Con																					
	Fac																		**0.23**			
	Lan	0.01													0.01					**0.24**	0.01	0.01
	Urm																		0.01		**2.16**	0.03
	Urf																		0.01		0.02	**3.69**

Agricultural land use/cover:

Cul: Cultivated meadow, Dec: Deciduous orchard, Eve: Evergreen orchard, Exb: Exotic broad-leaved plantation, Ext: Exotic tree plantation, Fwc: Field weeds communities, Mul: Mulberry garden, Nur: Nursery garden, Pwc Paddy-field weed communities, The: Thea sinensis garden, Wcf: Weed communities in uncultivated field, Wcp: Weed communities in uncultivated paddy field, Wcr: Weed communities of the roadside

For: Forest, Gra: Grassland, Oth: Others

Urban land use/cover:

Con: Concrete pavement site, Fac: Factory/industrial areas, Lan: Land constructed for residence/factories, Urm: Urban/residential districts with many trees, Urf: Urban district with a few trees

Figure in percentage from total area of 3,283 km^2

Table 25. Detail land use/cover changes in the Naka River basin (1989–1992 to 1995–1999)

LULC		**1995–1999**																				
		Cul	Dec	Eve	Exb	Ext	Fwc	Mul	Nur	Pwc	The	Wcf	Wcp	Wcr	For	Gra	Oth	Con	Fac	Lan	Urm	Urf
1989–1992	Cul	**2.21**																		0.03		
	Dec		**0.38**																			
	Eve																					
	Exb				**0.01**																	
	Ext																					
	Fwc	0.03					**11.84**													0.14		
	Mul							**0.47**														
	Nur																					
	Pwc	0.03								**18.68**										0.08		
	The																					
	Wcf																					
	Wcp												**0.01**									
	Wcr																					
	For	0.41					0.05								**54.03**	0.34	0.01			0.31	0.01	
	Gra	0.01														**1.44**				0.02		
	Oth																**1.87**					
	Con																					
	Fac																		**0.32**			
	Lan	0.03															0.01			**0.74**	0.04	
	Urm																			0.01	**2.56**	
	Urf																					**3.85**

Agricultural land use/cover:

Cul: Cultivated meadow, Dec: Deciduous orchard, Eve: Evergreen orchard, Exb: Exotic broad-leaved plantation, Ext: Exotic tree plantation, Fwc: Field weeds communities, Mul: Mulberry garden, Nur: Nursery garden, Pwc Paddy-field weed communities, The: Thea sinensis garden, Wcf: Weed communities in uncultivated field, Wcp: Weed communities in uncultivated paddy field, Wcr: Weed communities of the roadside

For: Forest, Gra: Grassland, Oth: Others

Urban land use/cover:

Con: Concrete pavement site, Fac: Factory/industrial areas, Lan: Land constructed for residence/factories, Urm: Urban/residential districts with many trees, Urf: Urban district with a few trees

Figure in percentage from total area of 3,283 km^2

Table 26. Detail land use/cover changes in the Sagami River basin (1983–1986 to 1989–1992)

LULC		1989–1992																				
		Cul	Dec	Eve	Exb	Ext	Fwc	Mul	Nur	Pwc	The	Wcf	Wcp	Wcr	For	Gra	Oth	Con	Fac	Lan	Urm	Urf
1983–1986	Cul	**0.62**																				
	Dec		**0.14**																			
	Eve																					
	Exb				**0.01**																	
	Ext																					
	Fwc						**6.03**															0.01
	Mul							**2.03**														
	Nur								**0.02**													
	Pwc									**4.31**												
	The																					
	Wcf											**0.06**										
	Wcp												**0.01**									
	Wcr																					
	For	0.09													**65.58**	0.09				0.03		0.03
	Gra														0.01	**7.77**						0.01
	Oth																**2.31**					
	Con																					
	Fac																		**1.07**			
	Lan																			**0.36**		
	Urm																				**0.95**	
	Urf																			0.02		**8.40**

Agricultural land use/cover:

Cul: Cultivated meadow, Dec: Deciduous orchard, Eve: Evergreen orchard, Exb: Exotic broad-leaved plantation, Ext: Exotic tree plantation, Fwc: Field weeds communities, Mul: Mulberry garden, Nur: Nursery garden, Pwc Paddy-field weed communities, The: Thea sinensis garden, Wcf: Weed communities in uncultivated field, Wcp: Weed communities in uncultivated paddy field, Wcr: Weed communities of the roadside

For: Forest, Gra: Grassland, Oth: Others

Urban land use/cover:

Con: Concrete pavement site, Fac: Factory/industrial areas, Lan: Land constructed for residence/factories, Urm: Urban/residential districts with many trees, Urf: Urban district with a few trees

Figure in percentage from total area of 1,781 km^2

Table 27. Detail land use/cover changes in the Sagami River basin (1989–1992 to 1995–1999)

LULC		1995–1999																				
		Cul	Dec	Eve	Exb	Ext	Fwc	Mul	Nur	Pwc	The	Wcf	Wcp	Wcr	For	Gra	Oth	Con	Fac	Lan	Urm	Urf
1989–1992	Cul	**0.71**																				
	Dec		**0.14**																			
	Eve																					
	Exb				**0.01**																	
	Ext																					
	Fwc	0.01					**5.99**										0.01			0.01		
	Mul	0.01						**2.01**												0.01		
	Nur								**0.03**													
	Pwc	0.01								**4.30**										0.01		
	The																					
	Wcf											**0.06**										
	Wcp												**0.01**									
	Wcr																					
	For	0.40					0.03								**64.15**	0.42	0.21			0.36		0.02
	Gra	0.03														**7.78**	0.01			0.03		0.01
	Oth																**2.31**					
	Con																					
	Fac																		**1.08**			
	Lan																0.01			**0.40**		
	Urm																				**0.95**	
	Urf																0.01					**8.43**

Agricultural land use/cover:

Cul: Cultivated meadow, Dec: Deciduous orchard, Eve: Evergreen orchard, Exb: Exotic broad-leaved plantation, Ext: Exotic tree plantation, Fwc: Field weeds communities, Mul: Mulberry garden, Nur: Nursery garden, Pwc Paddy-field weed communities, The: Thea sinensis garden, Wcf: Weed communities in uncultivated field, Wcp: Weed communities in uncultivated paddy field, Wcr: Weed communities of the roadside

For: Forest, Gra: Grassland, Oth: Others

Urban land use/cover:

Con: Concrete pavement site, Fac: Factory/industrial areas, Lan: Land constructed for residence/factories, Urm: Urban/residential districts with many trees, Urf: Urban district with a few trees

Figure in percentage from total area of 1,781 km^2

Table 28. Detail land use/cover changes in the Tama River basin (1983–1986 to 1989–1992)

LULC		1989–1992																				
		Cul	Dec	Eve	Exb	Ext	Fwc	Mul	Nur	Pwc	The	Wcf	Wcp	Wcr	For	Gra	Oth	Con	Fac	Lan	Urm	Urf
1983–1986	Cul	**1.48**													0.02	0.07		0.02		0.06	0.03	0.03
	Dec		**0.42**																			
	Eve																					
	Exb																					
	Ext																					
	Fwc						**3.57**								0.01	0.01				0.03	0.01	0.01
	Mul							**0.05**														
	Nur								**0.40**													
	Pwc						0.01			**0.77**										0.03		0.01
	The										**0.05**											
	Wcf											**0.01**										
	Wcp												**0.03**							0.02		
	Wcr																					
	For	0.05													**56.64**	0.10	0.01	0.01	0.01	0.39	0.04	0.05
	Gra	0.02													0.04	**3.47**				0.10	0.01	0.03
	Oth																**1.62**					
	Con	0.01																**0.41**	0.01			
	Fac																		**1.37**	0.01		
	Lan	0.06													0.03	0.11	0.01	0.03	0.01	**0.96**	0.09	0.18
	Urm	0.03							0.02						0.03	0.04		0.01	0.01	0.05	**5.88**	0.04
	Urf	0.02					0.01								0.02	0.03		0.02	0.14	0.03	0.13	**20.37**

Agricultural land use/cover:

Cul: Cultivated meadow, Dec: Deciduous orchard, Eve: Evergreen orchard, Exb: Exotic broad-leaved plantation, Ext: Exotic tree plantation, Fwc: Field weeds communities, Mul: Mulberry garden, Nur: Nursery garden, Pwc Paddy-field weed communities, The: Thea sinensis garden, Wcf: Weed communities in uncultivated field, Wcp: Weed communities in uncultivated paddy field, Wcr: Weed communities of the roadside

For: Forest, Gra: Grassland, Oth: Others

Urban land use/cover:

Con: Concrete pavement site, Fac: Factory/industrial areas, Lan: Land constructed for residence/factories, Urm: Urban/residential districts with many trees, Urf: Urban district with a few trees

Figure in percentage from total area of 1,263 km^2

Table 29. Detail land use/cover changes in the Tama River basin (1989–1992 to 1995–1999)

LULC		1995–1999																				
		Cul	Dec	Eve	Exb	Ext	Fwc	Mul	Nur	Pwc	The	Wcf	Wcp	Wcr	For	Gra	Oth	Con	Fac	Lan	Urm	Urf
1989–1992	Cul	**1.66**																		0.01		
	Dec		**0.42**																	0.01		
	Eve																					
	Exb																					
	Ext																					
	Fwc						**3.57**													0.03		
	Mul							**0.05**														
	Nur								**0.43**													
	Pwc									**0.75**										0.02		
	The										**0.05**											
	Wcf											**0.01**										
	Wcp												**0.03**									
	Wcr																					
	For	0.01													**56.08**	0.22				0.47	0.01	
	Gra															**3.67**			0.01	0.15		
	Oth																**1.64**					
	Con																	**0.51**				
	Fac																		**1.56**			
	Lan																			**1.64**	0.04	
	Urm																			0.01	**6.19**	
	Urf																			0.01		**20.72**

Agricultural land use/cover:

Cul: Cultivated meadow, Dec: Deciduous orchard, Eve: Evergreen orchard, Exb: Exotic broad-leaved plantation, Ext: Exotic tree plantation, Fwc: Field weeds communities, Mul: Mulberry garden, Nur: Nursery garden, Pwc Paddy-field weed communities, The: Thea sinensis garden, Wcf: Weed communities in uncultivated field, Wcp: Weed communities in uncultivated paddy field, Wcr: Weed communities of the roadside

For: Forest, Gra: Grassland, Oth: Others

Urban land use/cover:

Con: Concrete pavement site, Fac: Factory/industrial areas, Lan: Land constructed for residence/factories, Urm: Urban/residential districts with many trees, Urf: Urban district with a few trees

Figure in percentage from total area of 1,263 km^2

Table 30. Detail land use/cover changes in the Tone River basin (1983–1986 to 1989–1992)

LULC		1989–1992																				
		Cul	Dec	Eve	Exb	Ext	Fwc	Mul	Nur	Pwc	The	Wcf	Wcp	Wcr	For	Gra	Oth	Con	Fac	Lan	Urm	Urf
1983–1986	Cul	**0.95**													0.01	0.01				0.01		
	Dec		**0.53**																			
	Eve			**0.01**																		
	Exb																					
	Ext																					
	Fwc	0.04					**12.17**	0.01		0.01					0.01	0.01			0.02	0.05	0.06	0.05
	Mul						0.01	**2.46**														0.01
	Nur								**0.04**													
	Pwc	0.03					0.01			**17.32**						0.01			0.01	0.04	0.05	0.05
	The																					
	Wcf											**0.02**										
	Wcp												**0.15**			0.01						0.01
	Wcr													**0.01**								
	For	0.34					0.04								**48.52**	0.16	0.02		0.03	0.21	0.07	0.06
	Gra	0.02													0.03	**2.69**	0.02		0.01	0.04	0.01	0.01
	Oth														0.01	0.02	**3.35**			0.01		
	Con																					
	Fac																		**0.67**			
	Lan	0.01																	0.01	**0.77**	0.02	0.02
	Urm																				**5.10**	0.02
	Urf																		0.01		0.03	**3.37**

Agricultural land use/cover:

Cul: Cultivated meadow, Dec: Deciduous orchard, Eve: Evergreen orchard, Exb: Exotic broad-leaved plantation, Ext: Exotic tree plantation, Fwc: Field weeds communities, Mul: Mulberry garden, Nur: Nursery garden, Pwc Paddy-field weed communities, The: Thea sinensis garden, Wcf: Weed communities in uncultivated field, Wcp: Weed communities in uncultivated paddy field, Wcr: Weed communities of the roadside

For: Forest, Gra: Grassland, Oth: Others

Urban land use/cover:

Con: Concrete pavement site, Fac: Factory/industrial areas, Lan: Land constructed for residence/factories, Urm: Urban/residential districts with many trees, Urf: Urban district with a few trees

Figure in percentage from total area of 15,343 km^2

Table 31. Detail land use/cover changes in the Tone River basin (1989–1992 to 1995–1999)

LULC		1995–1999																				
		Cul	Dec	Eve	Exb	Ext	Fwc	Mul	Nur	Pwc	The	Wcf	Wcp	Wcr	For	Gra	Oth	Con	Fac	Lan	Urm	Urf
1989–1992	Cul	**1.35**					0.01													0.02		0.01
	Dec		**0.53**																	0.01		
	Eve			**0.01**																		
	Exb																					
	Ext																					
	Fwc	0.01					**12.12**													0.09		
	Mul						0.04	**2.40**												0.01		
	Nur								**0.04**													
	Pwc	0.02								**17.18**										0.13	0.01	
	The																					
	Wcf											**0.02**										
	Wcp												**0.14**							0.01		
	Wcr													**0.01**								
	For	0.23					0.04								**47.69**	0.21	0.01			0.35	0.06	
	Gra	0.02														**2.79**				0.09		
	Oth																**3.39**			0.01		
	Con																					
	Fac																		**0.75**	0.01		
	Lan	0.05																		**1.08**	0.01	
	Urm																			0.01	**5.34**	
	Urf																			0.01		**3.60**

Agricultural land use/cover:

Cul: Cultivated meadow, Dec: Deciduous orchard, Eve: Evergreen orchard, Exb: Exotic broad-leaved plantation, Ext: Exotic tree plantation, Fwc: Field weeds communities, Mul: Mulberry garden, Nur: Nursery garden, Pwc Paddy-field weed communities, The: Thea sinensis garden, Wcf: Weed communities in uncultivated field, Wcp: Weed communities in uncultivated paddy field, Wcr: Weed communities of the roadside

For: Forest, Gra: Grassland, Oth: Others

Urban land use/cover:

Con: Concrete pavement site, Fac: Factory/industrial areas, Lan: Land constructed for residence/factories, Urm: Urban/residential districts with many trees, Urf: Urban district with a few trees

Figure in percentage from total area of 15,343 km^2

4.2. Water quality changes

The temporal trend of water quality in each studied river basin was observed by plotting the average annual value of a determinand for all monitoring sites against year (Figure 19). Overall, despite fluctuations, water quality in the studied river basins shows improvement throughout the years. Based on the standard for preservation of the living environment, pH values on these basins remained in the permissible range of 6.0–8.5 (Figure 19a). However, pH values in these river basins showed a slight increment. The smallest increment occurred in the Ara/Edo River basin, from 7.2 in 1982 to 7.5 in 2004. The largest pH increment was observed in the Kuji River basin, from 7.4 in 1981 to 7.9 in 2001, and in the Naka River basin, from 7.3 in 1981 to 7.8 in 2003.

DO increased by approximately 1.0 to 2.0 mg/l in the studied river basins (Figure 19b). Based on DO values and improvement, three distinct groups can be observed. The first group shows higher DO and a stable DO increment of ca. 1.0 mg/l throughout the years. This group consists of the Fuji, Kuji, Naka, and Tone River basins. The second group consists of the Sagami and Tama River basins. The group shows faster DO improvements in comparison to the first group. DO for this group improved approximately from 8.0 to 9.7 mg/l. The last group consists of the Ara/Edo River basin with lower DO values compares to the others.

Figure 19c presents temporal trend in BOD. A sharp reduction in BOD occurred in the Ara/Edo River basin. In the early 1980s, mean BOD in this river basin was 12.7 mg/l, but it decreased to 3.3 mg/l in 2005. A moderate reduction in BOD concentration is found in the Fuji, Sagami, Tama, and Toner River basins. The reduction was 4.0 mg/l BOD in the Tama River basin, 3.0 mg/l in the Fuji and Sagami River basins, and 2.0 mg/l in the Tone River basin. BOD in the Naka and Kuji River basins was more stable. Fluctuations of BOD in these river basins were generally less than 1.0 mg/l.

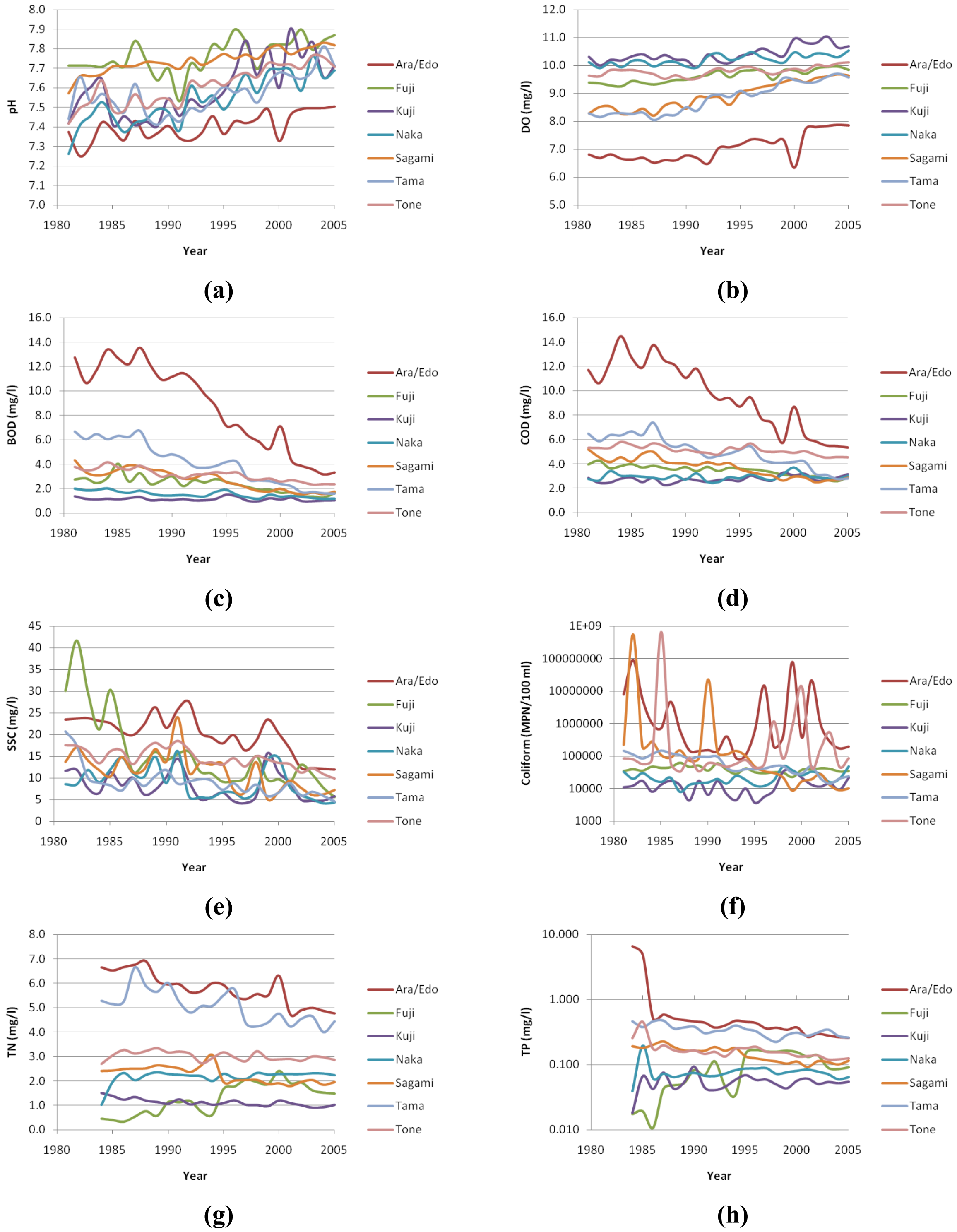


Figure 19. Water quality trends in the studied river basins
(a) pH, (b) DO, (c) BOD, (d) COD, (e) SSC, (f) Coliform, (g) TN, (h) TP

BOD (Figure 19c) and COD (Figure 19d) show similar fluctuation trends in each river basin. Like BOD, the Ara/Edo River basin experienced a sharp reduction in COD; moderate COD reduction occurred in the Fuji, Sagami, Tama, and Tone River basins; the Naka and Kuji River basins had more stable values of COD.

With regard to SSC in the studied river basins, a significant reduction took place in the Fuji River basin (Figure 19e), from 42 mg/l in 1982 to 6 mg/l in 2005. A gradual reduction in SSC occurred in the Ara/Edo River basin, from 20–25 mg/l in the early 1980s to 12 mg/l in the early 2000s. In the Tama River basin, a major reduction in SSC was observed in the early 1980s but it remained stable after that at approximately 10 mg/l. Fluctuations of SSC in the Fuji and Naka River basins exhibited similar patterns. Despite the annual fluctuations of SSC, a stable concentration around 5mg/l was observed in 1992–1998 and 2002–2005.

Concerning the concentration of coliform in the studied river basins (Figure 19f), high fluctuations occurred in the Ara/Edo and Tone River basins throughout the years. In the Sagami River basin, high fluctuations were observed prior to the 1990s. After that, the concentration tended to be stable at approximately 10,000 MPN/100 ml. Low fluctuations were observed in the Fuji, Kuji, and Naka River basins. However, in the Fuji and Kuji River basins, the concentration tended to increase from approximately 10,000 MPN/100 ml in between the early 1980s and the mid 1990s to approximately 50,000 MPN/100 ml at the end of the 1990s.

Figure 19g presents the temporal trend of TN in the studied river basins. TN decreased in five river basins. Reductions in the Ara/Edo and Tama River basins (about 2.0 mg/l) were prominent in comparison to the other river basins. These two river basins had higher TN values. A modest reduction in TN occurred in the Kuji, Sagami, and Tone River basins despite annual fluctuations. In the Fuji River basin, TN tended to increase. A slight TN increase occurred in the Naka River basin.

Similar to TN, TP in the studied river basins considerably decreased with time (Figure 19h). The Ara/Edo River basin experienced a significant reduction in TP from approximately 6.6 mg/l in the early 1980s to 0.3 mg/l in the mid 2000s. A moderate reduction was also observed in the

Naka, Sagami, Tama, and Tone River basins. On the other hand, TP in the Fuji and Kuji River basins tended to increase. Similar to TN, increase in TP in the Fuji River basin from 0.018 mg/l in 1984 to 0.092 mg/l in 2005 can be depicted more easily than the increase in the Kuji River basin.

4.3. Spatial distribution of water quality

To obtain information on the spatial distribution of water quality in the studied river basins, the average value of water quality for each of the three periods (third period = 1983–1986, fourth period = 1989–1992, and fifth period = 1995–1999) at each monitoring site was overlaid on the land use/cover map for the corresponding period. To assist visual interpretation, graduate symbols and Jenks' natural break were used to represent the average water quality (Figures 20 to 27).

The spatial distribution of pH in the studied river basins is presented in Figure 20. In general, pH values in most monitoring sites are within the permissible range of 6.0–8.5. pH values of 7.0–7.5 are concentrated in the lower and middle reaches. These sites located in the urban and agricultural area. pH values of 7.5–8.5 are mostly concentrated in urban and forested areas in the lower and upper reaches. Only several monitoring sites have pH outside the permissible range, such as those in the lower reaches of the Naka and Tone River basins as well as in the upper reaches of the Ara/Edo River basin. Many sites show increase in pH with time, especially in the lower and middle reaches.

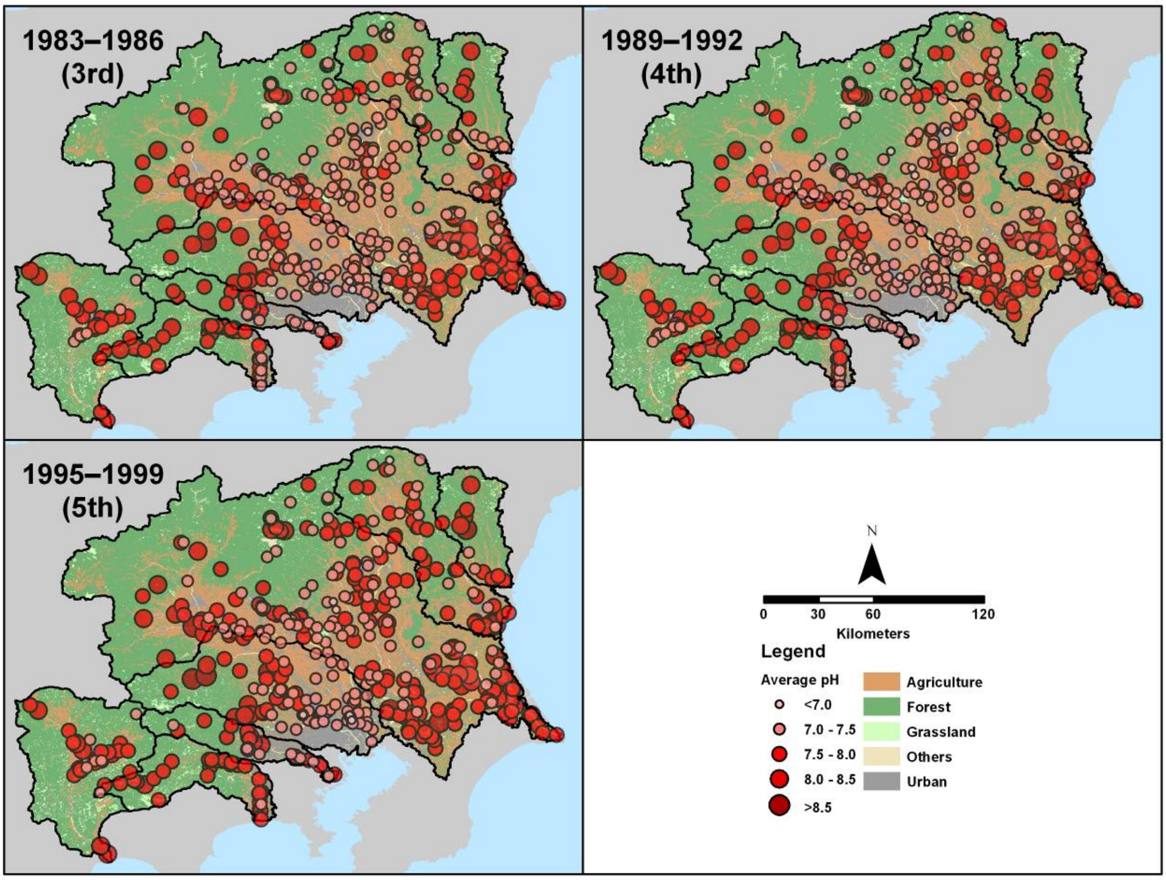


Figure 20. Spatial distribution of pH in the studied river basins

Figure 21 presents the spatial distribution of DO in the studied river basins. In general, higher DO values (>10.0 mg/l) are found in the middle and upper reaches where land use/cover is dominated by agriculture and forest. Higher DO values are also found in the lower reaches of the Kuji, Naka, and Tone River basins. In contrast, lower DO values (<7.5 mg/l) are observed in the lower reaches, especially in the Ara/Edo, Sagami, and Tama River basins, where land use/cover is dominated by urban. In general, increase in DO is observed in the lower reaches of the Ara/Edo and Tone River basins.

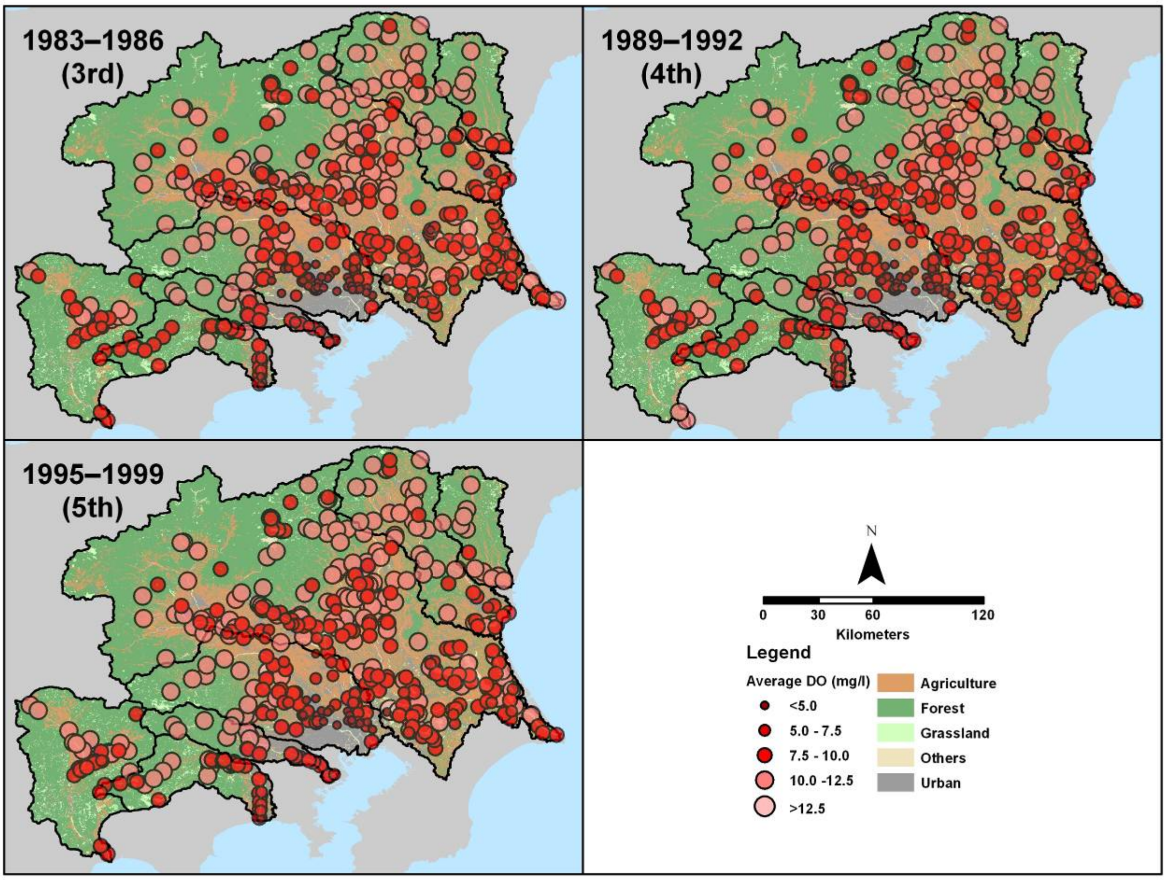


Figure 21. Spatial distribution of DO in the studied river basins

The spatial distribution of BOD in the studied river basins is presented in Figure 22. Monitoring sites with lower BOD (<5.0 mg/l) occur across the studied river basins, especially in the upper reaches where land use/cover is dominated by forest. Higher BOD values (>10 mg/l) are found in the lower reaches of the Ara/Edo, Sagami, Tama, and Tone River basins, where their land use/cover is dominated by urban. Higher BOD values are observed in the middle reaches of the Fuji and Tone River basins, where land use/cover is a mixture of urban and agriculture. BOD tended to decrease with time in most monitoring sites, especially in the lower reaches of the Ara/Edo River basin.

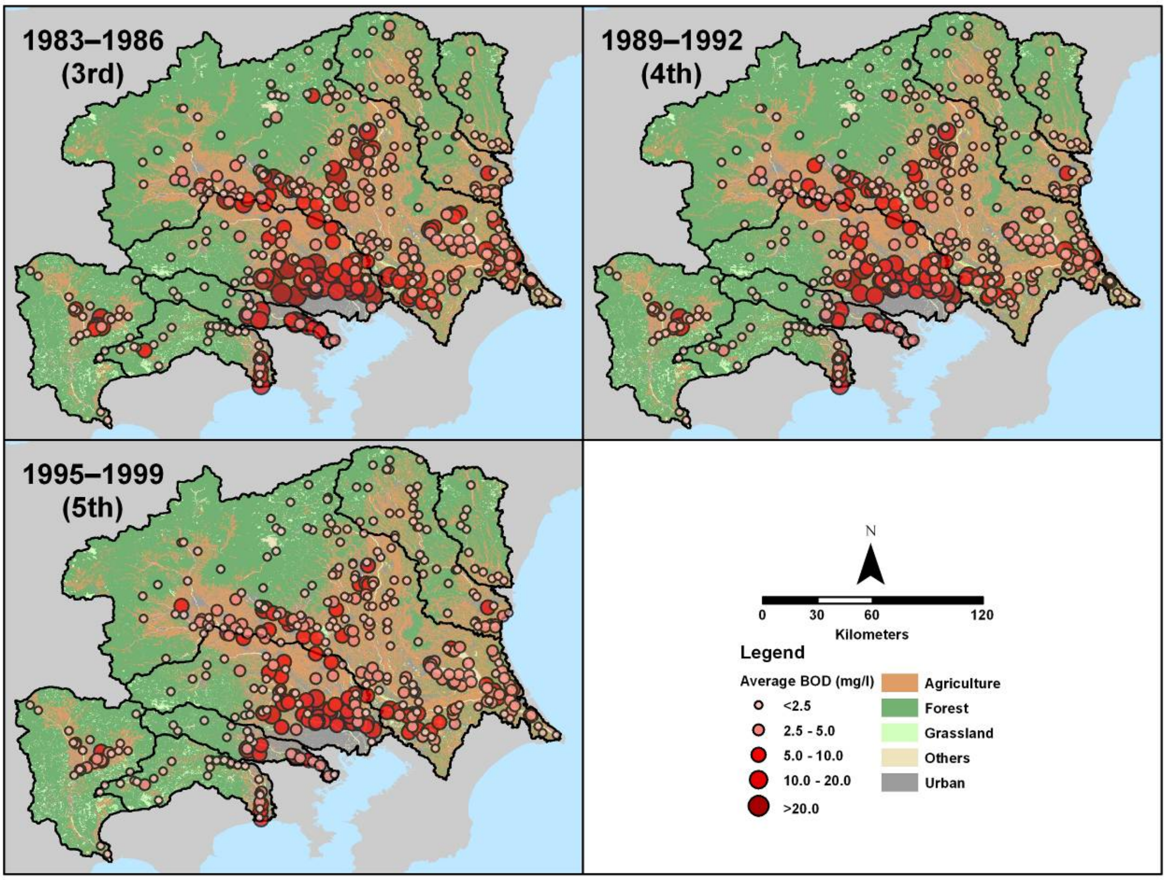


Figure 22. Spatial distribution of BOD in the studied river basins

In Figure 23, monitoring sites with lower COD (<5.0 mg/l) widely occur across the studied river basins, especially in the upper reaches where land use/cover is dominated by forest. Higher COD values (>10 mg/l) are also found in the lower reaches of the Ara/Edo, Naka, Sagami, Tama, and Tone River basins, where their land use/cover is dominated by urban. Similar higher COD values observed in the middle reaches of the Fuji and Tone River basins, where land use/cover is a mixture of urban and agriculture. Reduction of COD across the periods is also observed, especially in the Ara/Edo River basin.

The similarity between BOD and COD trends (Figure 19c, d) is also found in their spatial distributions as shown in Figures 22 and 23. Monitoring sites with high BOD tended to have high COD, and the same for their low values. However, the reductions of COD across the periods were not as apparent as the BOD reductions. In the fifth period, COD in monitoring sites in the middle and lower reaches of the Ara/Edo and Tone River basins remained high.

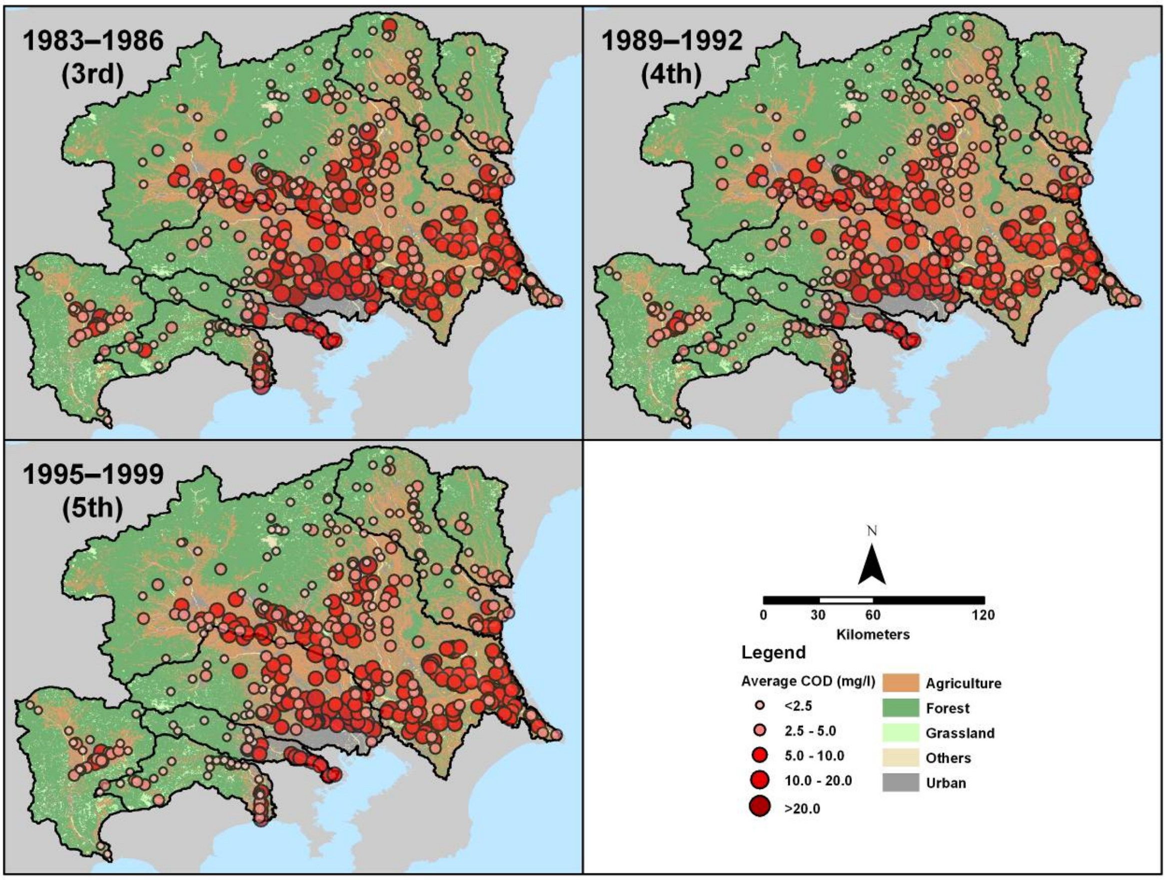


Figure 23. Spatial distribution of COD in the studied river basins

Figure 24 presents the distribution of SSC in the monitoring sites in the studied river basins. The figure shows lower SSC (<10 mg/l) in forested areas in the upper reaches. Higher SSC values (15-20 mg/l) are distributed in agricultural areas in the middle and lower reaches. Highest SSC values (>40 mg/l) are observed in urban areas in the lower reaches of the Ara/Edo and Tone River basins, as well as in the middle reaches of the Fuji River basin that also correspond to urban areas. Reduction in SSC with time is observed in the middle and lower reaches, but SSC in the lower reaches remains higher compares to the other reaches.

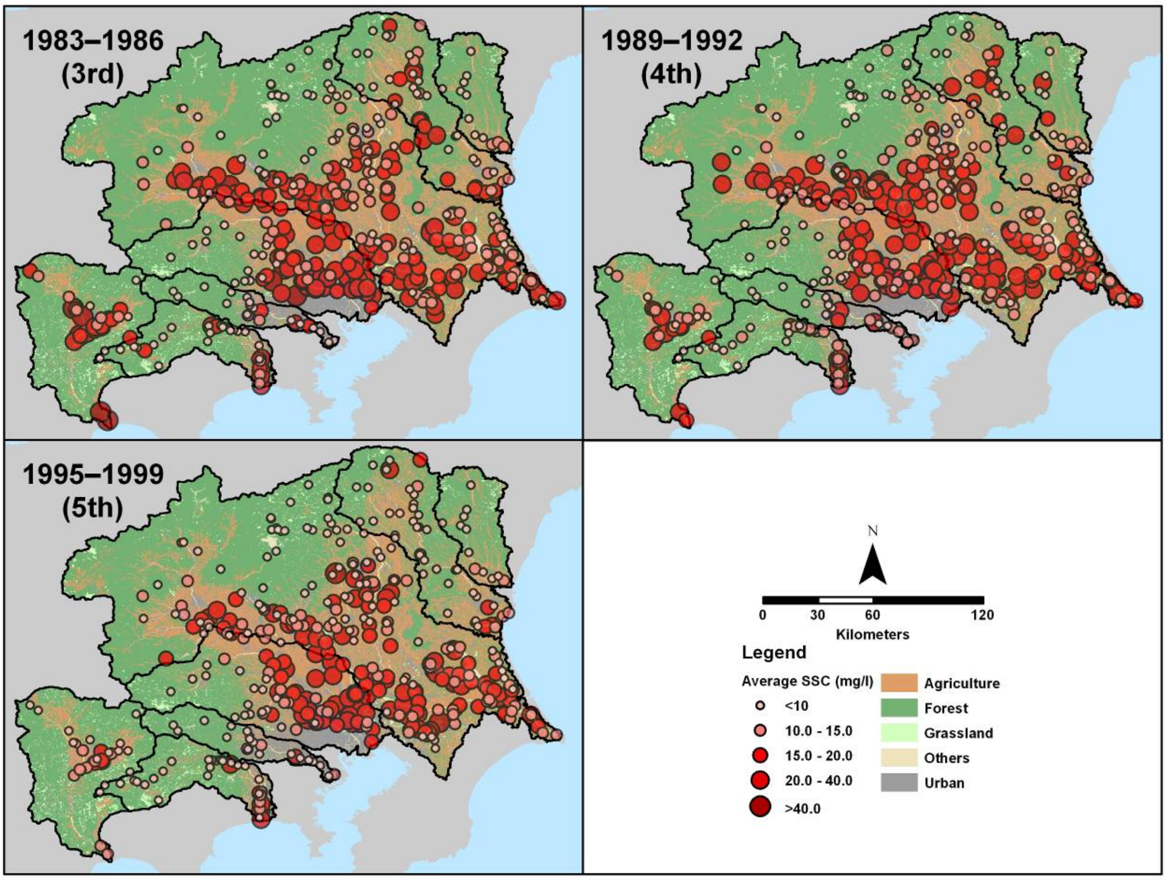


Figure 24. Spatial distribution of SSC in the studied river basins

Figure 25 presents the spatial distribution of coliform concentration in the studied river basins. It shows higher coliform concentrations (>150,000 MPN/100 ml) in the lower and middle reaches. On the other hand, lower coliform concentrations (<25,000 MPN/100 ml) are also found in the middle and lower reaches. In the upper reaches, coliform concentrations are generally lower (<5,000 MPN/100 ml) compare to the other reaches. Reduction in coliform concentration with time took place in the upper reaches; however, this reduction is more obscured in the other reaches.

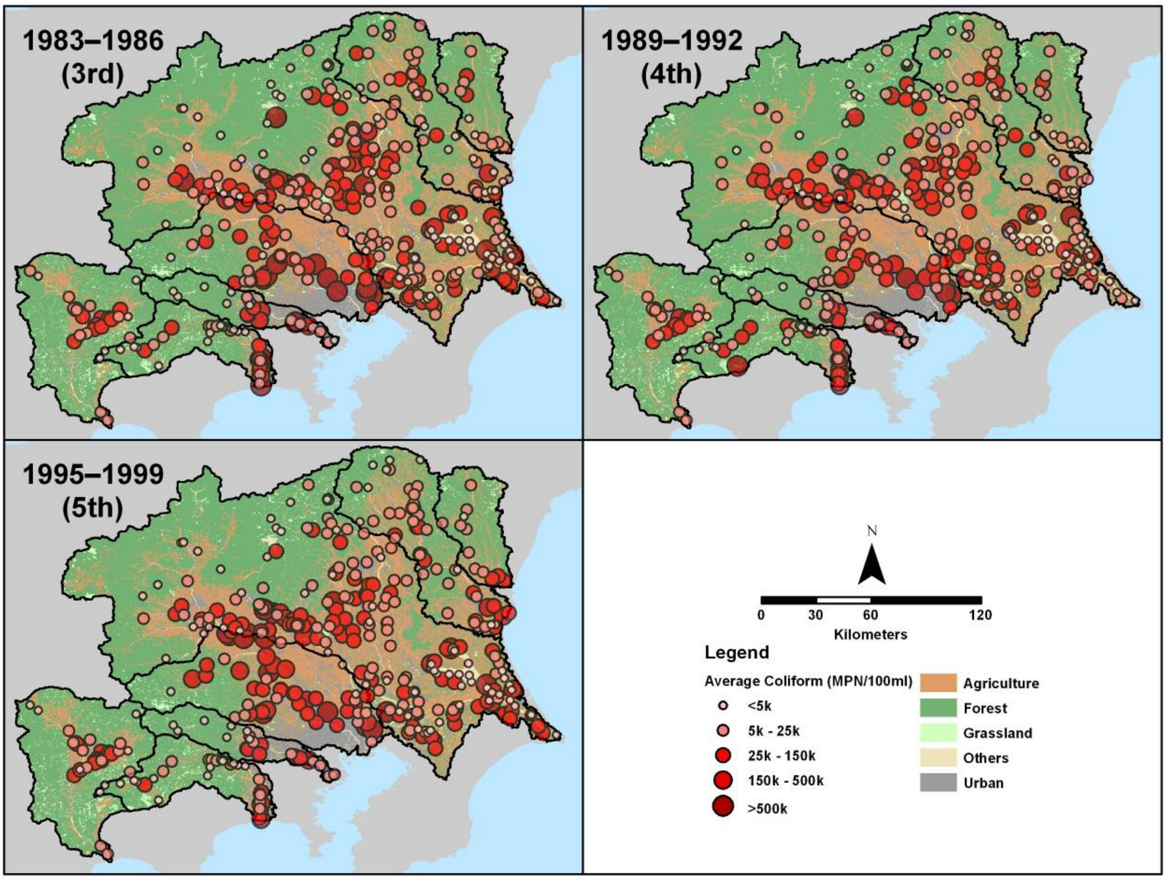


Figure 25. Spatial distribution of coliform concentration in the studied river basins

Figure 26 presents the spatial distribution of TN in the studied river basins. Higher TN values (>7.5 mg/l) are observed in urban areas in the lower reaches of the Ara/Edo, Naka, Sagami, Tama, and Tone River basins, as well as in the middle reaches of the Ara/Edo, Tama, and Tone River basins corresponding to urban and agricultural areas. Lower TN values (<2.0 mg/l) are observed in the upper reaches of all basins, as well as in the lower reaches of the Fuji, Kuji, Naka, and Tone River basins. Reduction of TN with time is observed in the upper and middle reaches except those in the Fuji River basins where TN tended to increase.

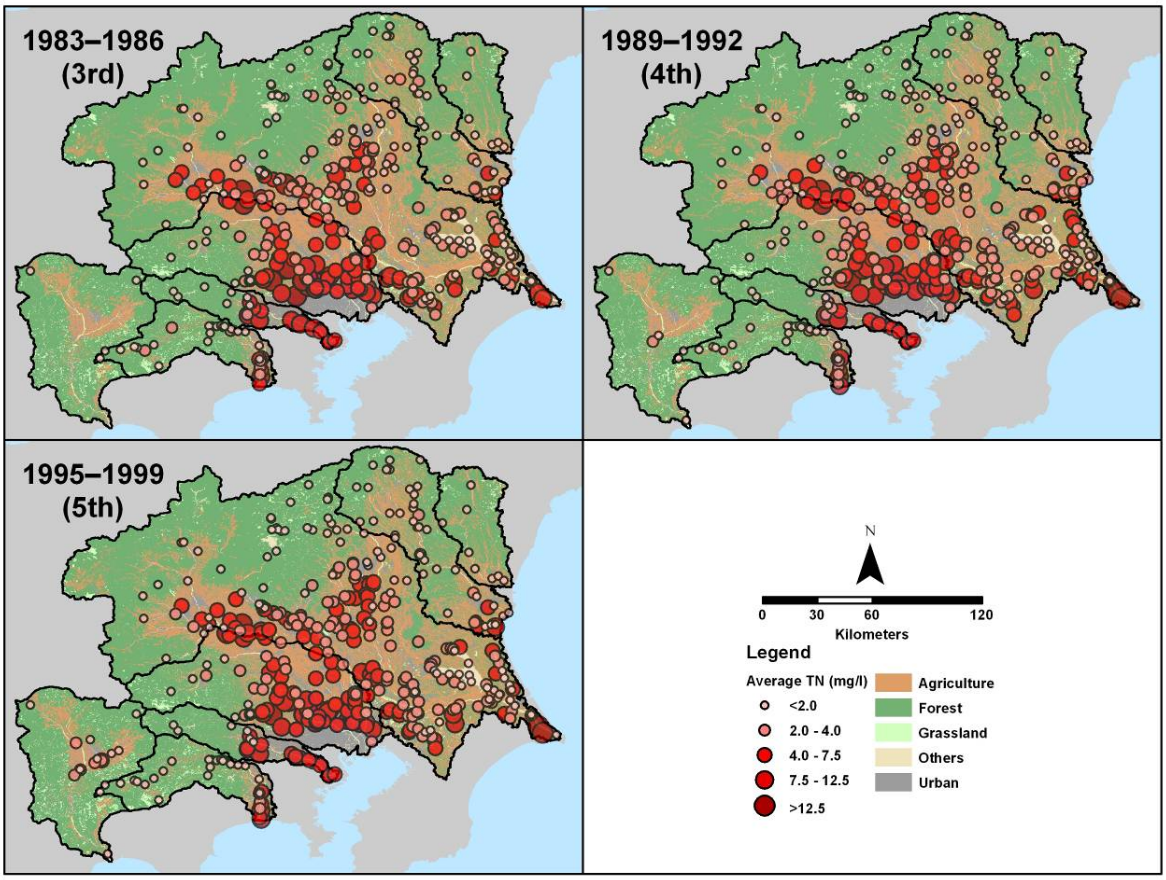


Figure 26. Spatial distribution of TN in the studied river basins

Figure 27 presents the spatial distribution of TP in the studied river basins. Similar to TN, higher TP values are found in the lower reaches of the Ara/Edo, Sagami, Tama, and Tone River basins, as well as in the middle reaches of the Ara/Edo, Tama, and Tone River basins. These reaches are dominated by urban and agricultural areas. Lower TP values are found in the upper reaches, as well as in the lower reaches of the Kuji, Naka, Sagami, and Tone River basins. Major reduction in TP with time can be observed from the figure, especially in the upper reaches of the Naka River basin, and the middle reaches of the Ara/Edo and Tone River basins. Reduction is also evident in the lower reaches of the Ara/Edo River basin.

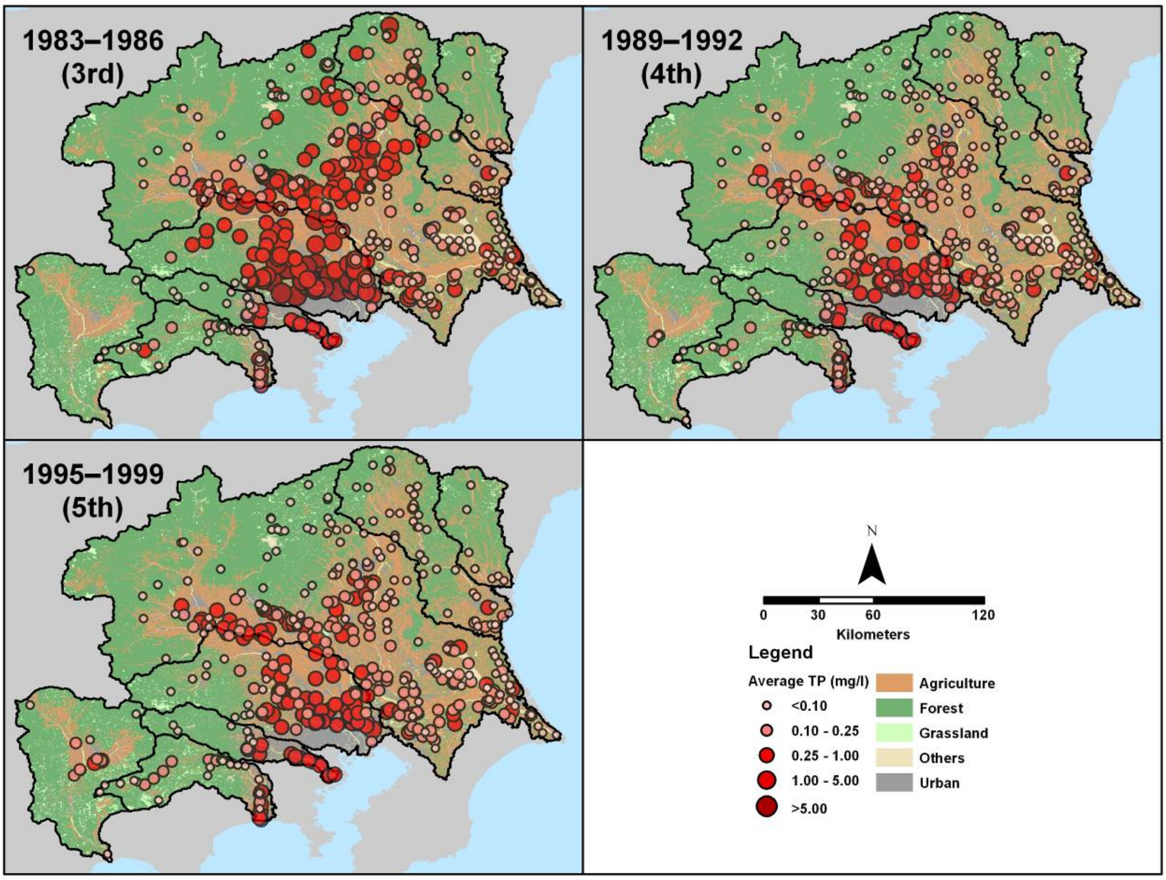


Figure 27. Spatial distribution of TP in the studied river basins

4.4. Relation between land use/cover and water quality

To understand the relationship between land use/cover and water quality in the studied river basins, percentages of land use/cover for the upstream area of each monitoring site were plotted against its average water quality value. Subsequently, the correlation analysis using Kendall's tau was carried out to measure the strength of the correlation between a land use/cover and water quality. The Kendall's tau method was used because of the non-normal frequency distribution of the land use/cover and water quality data. Additionally, previous research indicates the possibility of non-linear relationships between land use/cover and water quality (Nikolaidis et al., 1998; Wang, 1997). In these situations, Kendall's tau method is considered more robust compared to other correlation methods (Belle & Hughes, 1984; Schaeffer & Levitt, 1956). Cohen's scale was modified and used to interpret the correlation strength between land use/cover and water quality (Cohen, 1988; Hopkins, 2002). The scale divides the correlation coefficient into following six categories: very weak (0 to <0.1), weak (0.1 to <0.3), moderate (0.3 to <0.5), strong (0.5 to <0.7), very strong (0.7 to <0.9), and perfect (0.9 to 1).

Figure 28 and Table 32 present the relationship between the percentage of general land use/cover and water quality showing significant correlations, except for some relationships of grassland and others with COD and SSC. The percentage of the agricultural area is positively correlated with COD and SSC. The percentage of the urban area has a positive correlation with BOD, COD, SSC, TN, and TP. In contrast, the percentage of forest is negatively correlated with the water quality parameters. The urban area shows the strongest correlation with all water quality parameters, except for SSC where forest shows a stronger correlation.

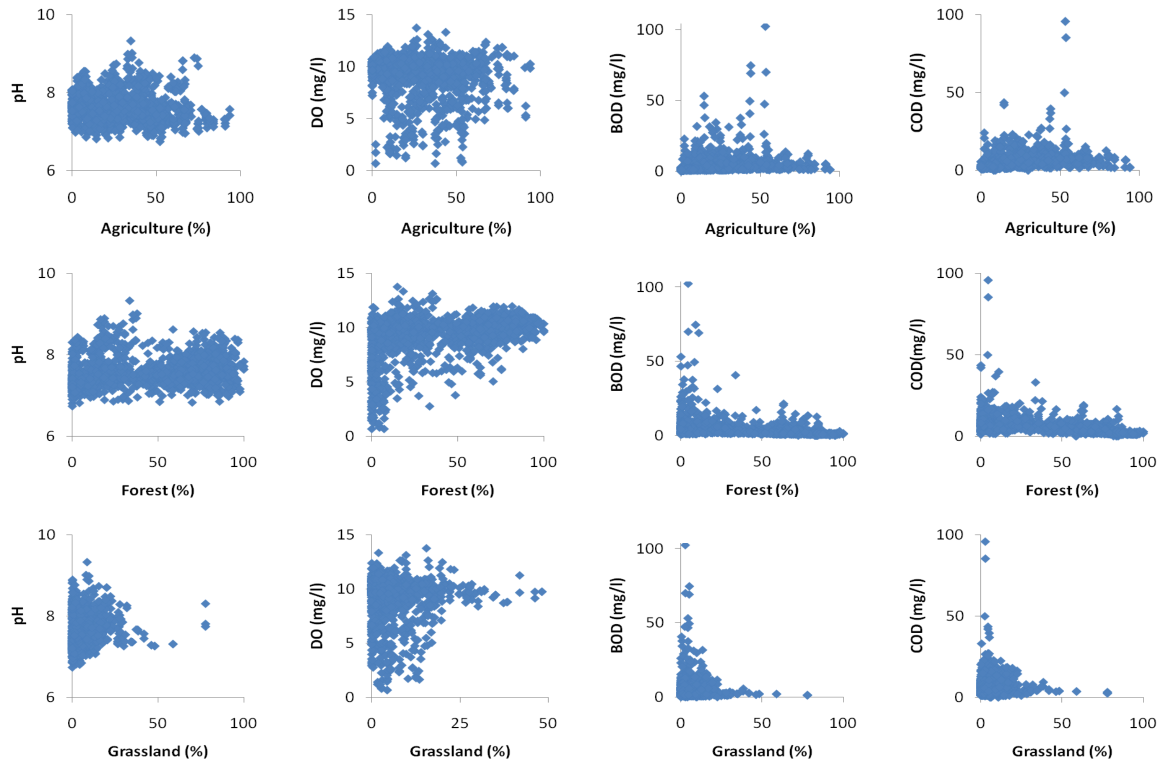


Figure 28. Relations between water quality and the percentages of general land use/covers in the studied river basins

Figure 28 (Continued)

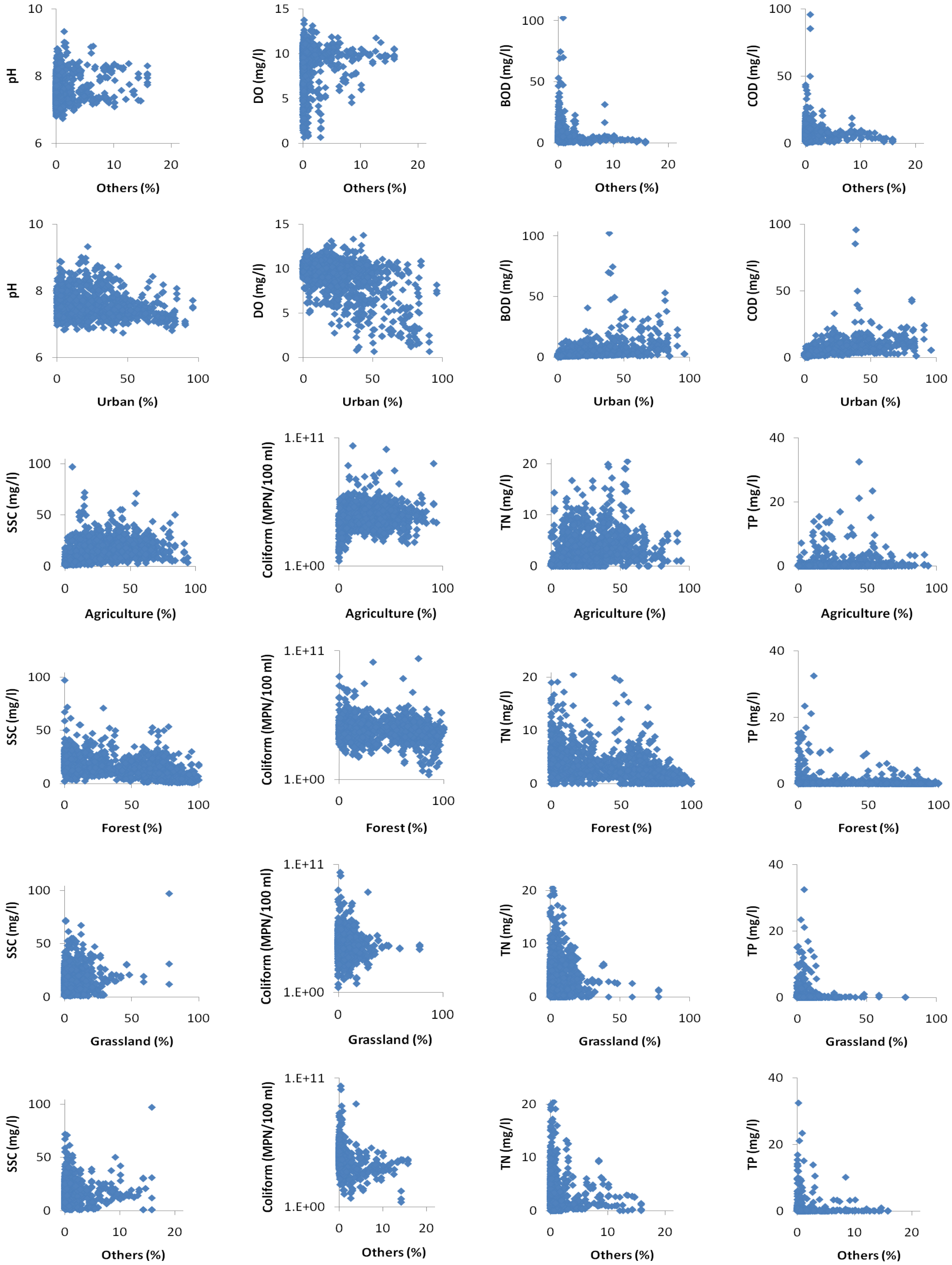


Figure 28 (Continued)

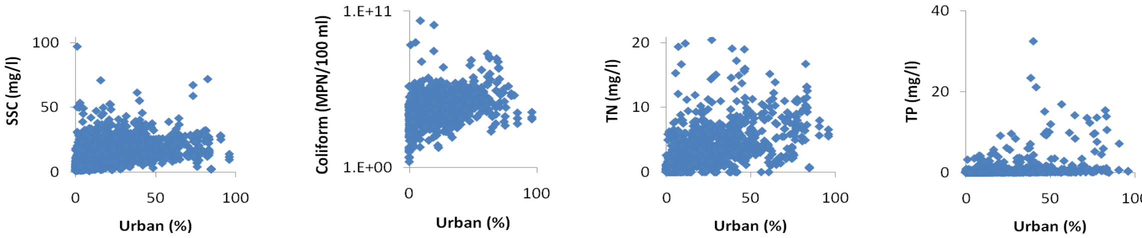


Table 32. Correlation between water quality and the percentages of general land use/cover in the studied river basins

LULC	pH	DO	BOD	COD	SSC	Coliform	TN	TP
Agriculture	-0.098 (-- VW)	-0.121 (-- W)	0.293 (++ W)	0.357 (++ M)	0.326 (++ M)	0.148 (++ W)	0.291 (++ W)	0.206 (++ W)
Forest	0.162 (++ W)	0.298 (++ W)	-0.433 (-- M)	-0.483 (-- M)	-0.401 (-- M)	-0.173 (-- W)	-0.410 (-- M)	-0.333 (-- M)
Grassland	0.148 (++ W)	-0.043 (- VW)	-0.035 (- VW)			-0.073 (-- VW)	-0.051 (-- VW)	-0.039 (- VW)
Others	0.090 (++ VW)	0.064 (++ VW)	-0.068 (-- VW)	-0.076 (-- VW)		-0.250 (-- W)	-0.177 (-- W)	-0.122 (-- W)
Urban	-0.168 (-- W)	-0.313 (-- M)	0.495 (++ M)	0.525 (++ S)	0.380 (++ M)	0.236 (++ W)	0.492 (++ M)	0.392 (++ M)

(++) Positive correlation with more than 99% significance, (+) Positive correlation with more than 95% significance, (--) Negative correlation with more than 99% significance, (-) Negative correlation with more than 95% significance
(VW) Very weak correlation, (W) Weak correlation, (M) Moderate correlation, (S) Strong correlation

In relation to water quality, detailed land use/cover types regarding agricultural and urban areas were investigated and the results are presented in Figure 29 and Table 33. In general, both the figure and the table show that the agricultural land use/covers contribute to the degradation of water quality. Similarly, urban land use/covers contribute to the degradation. Interesting findings are observed for the agricultural land use/covers. Among thirteen types of agricultural land use/covers, several could contribute to improving water quality:

1) Cultivated meadow and mulberry garden for DO improvement,
2) Exotic broad-leaved plantation and mulberry garden for BOD reduction,
3) Exotic broad-leaved plantation for COD reduction,
4) Evergreen orchard and exotic tree plantation for coliform reduction, and
5) Exotic tree plantation for TN and TP reductions.

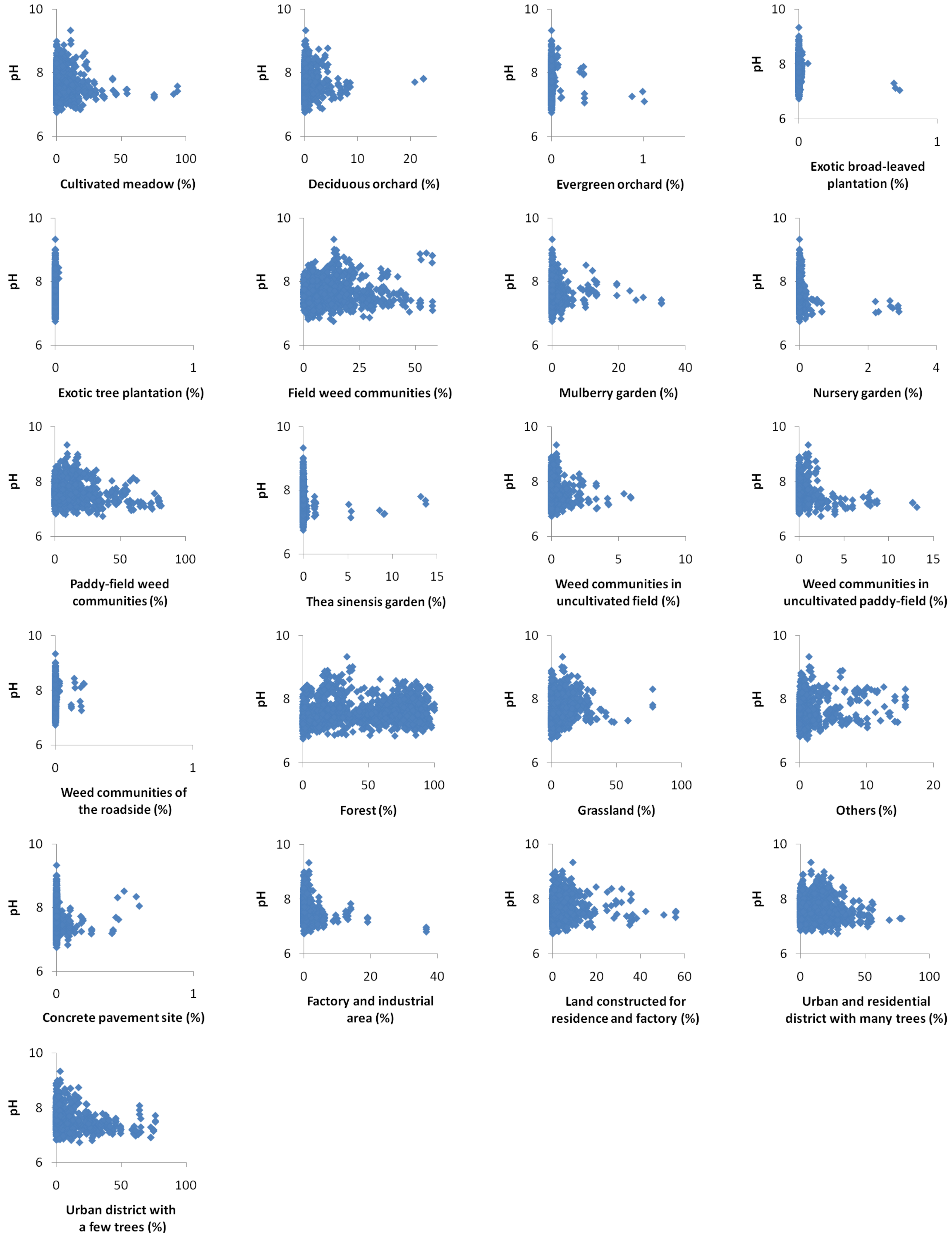


Figure 29. Relations between water quality and the percentages of detailed land use/covers in the studied river basins

Figure 29. (Continued)

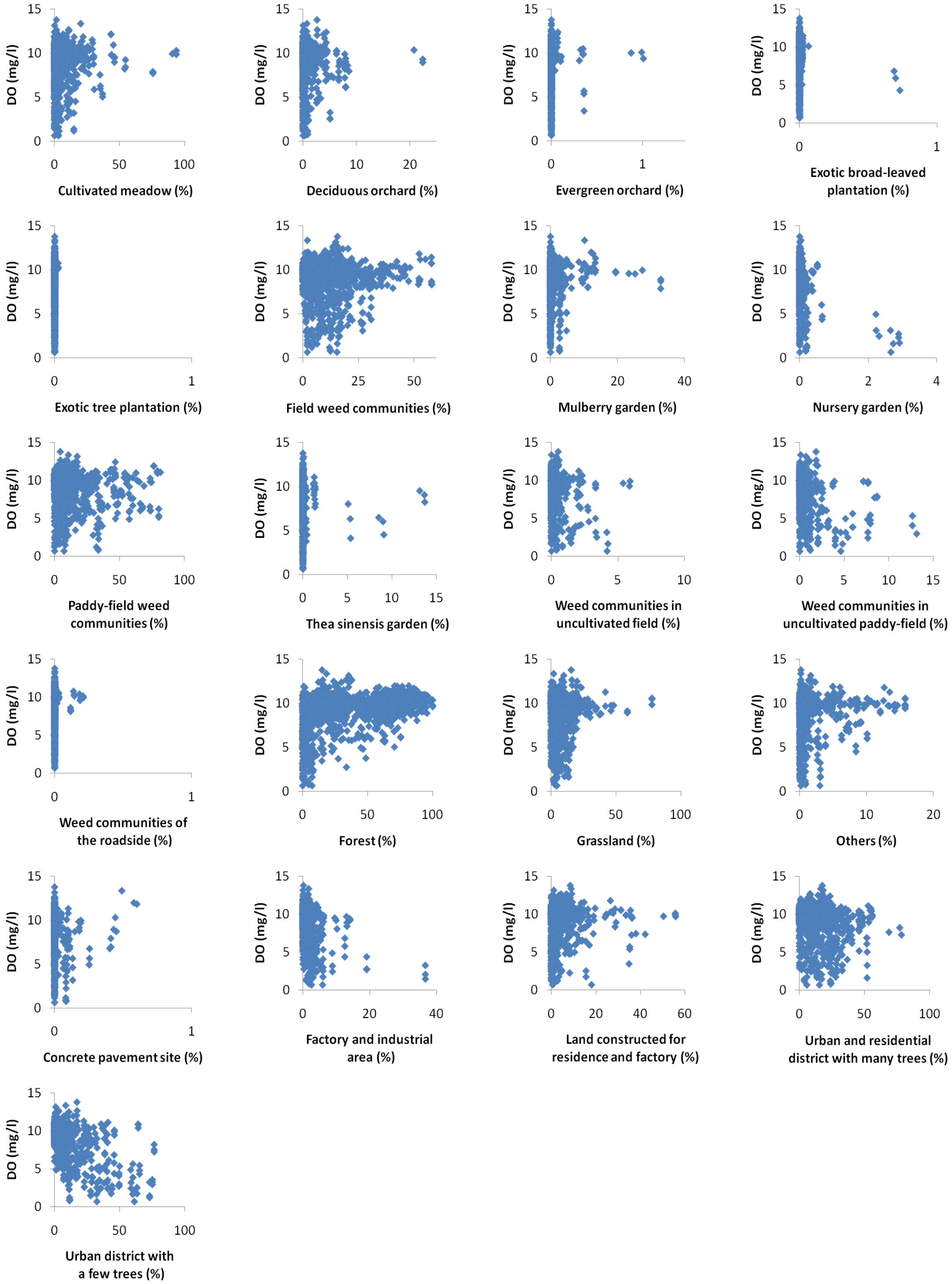


Figure 29. (Continued)

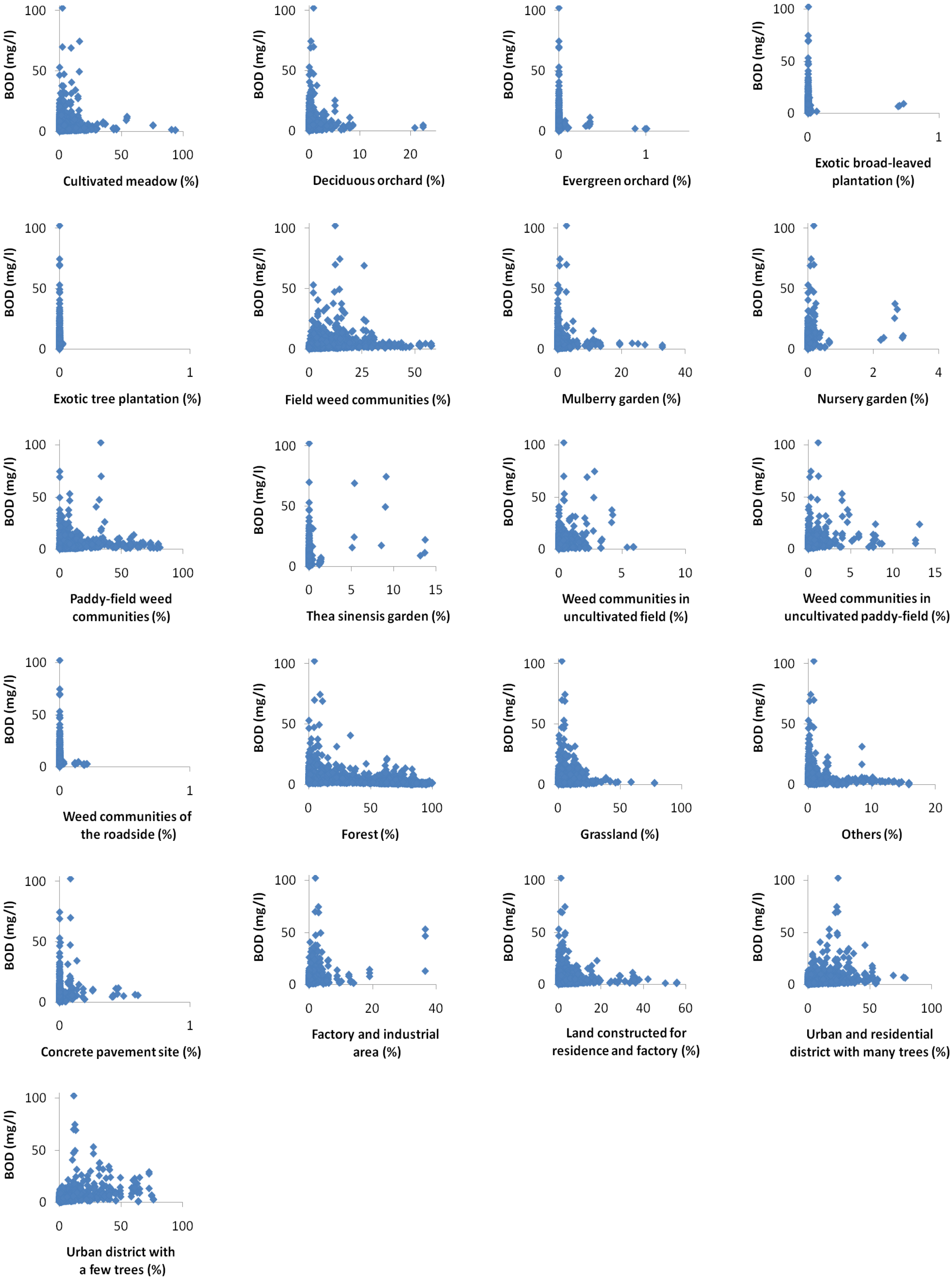


Figure 29. (Continued)

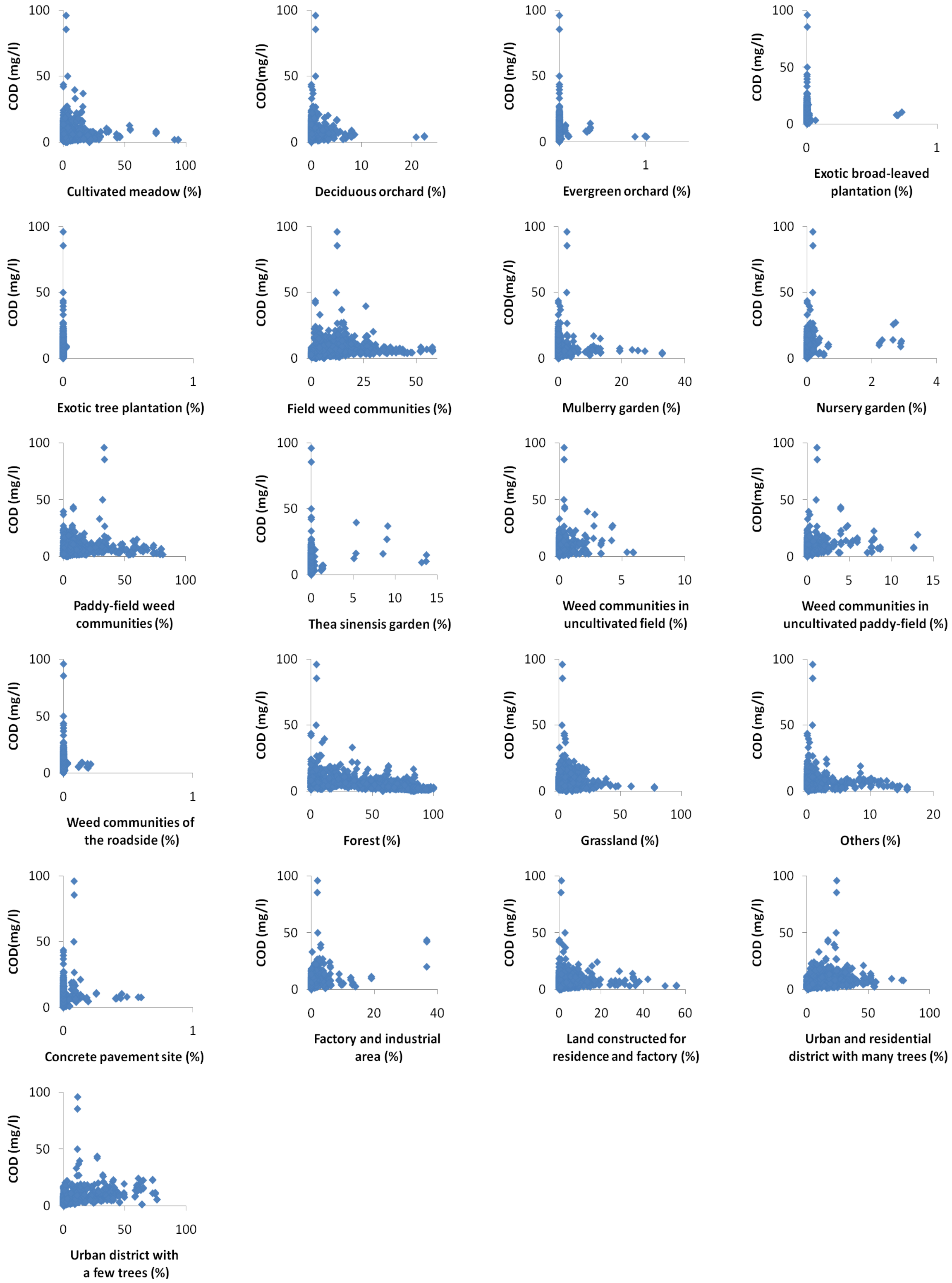


Figure 29. (Continued)

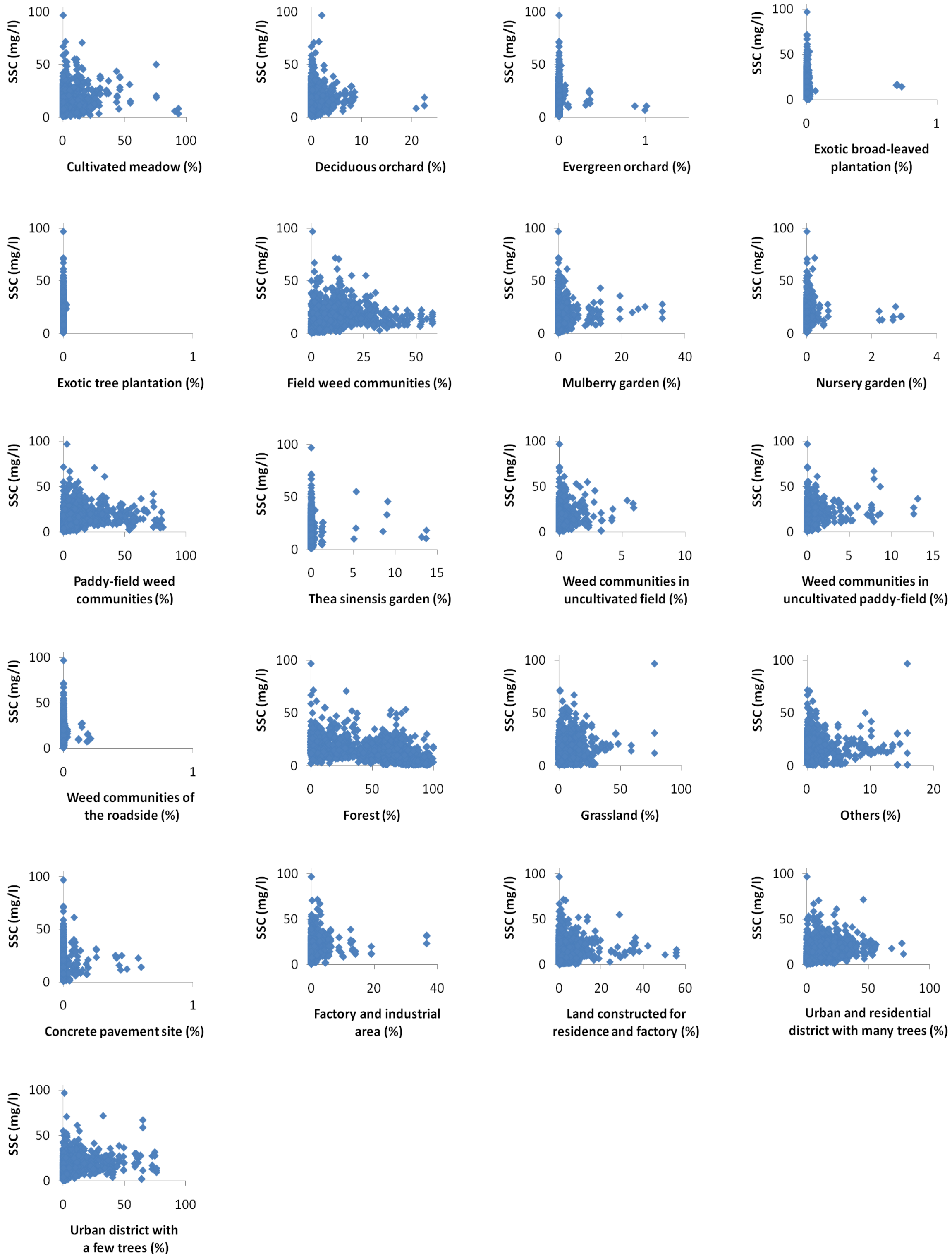


Figure 29. (Continued)

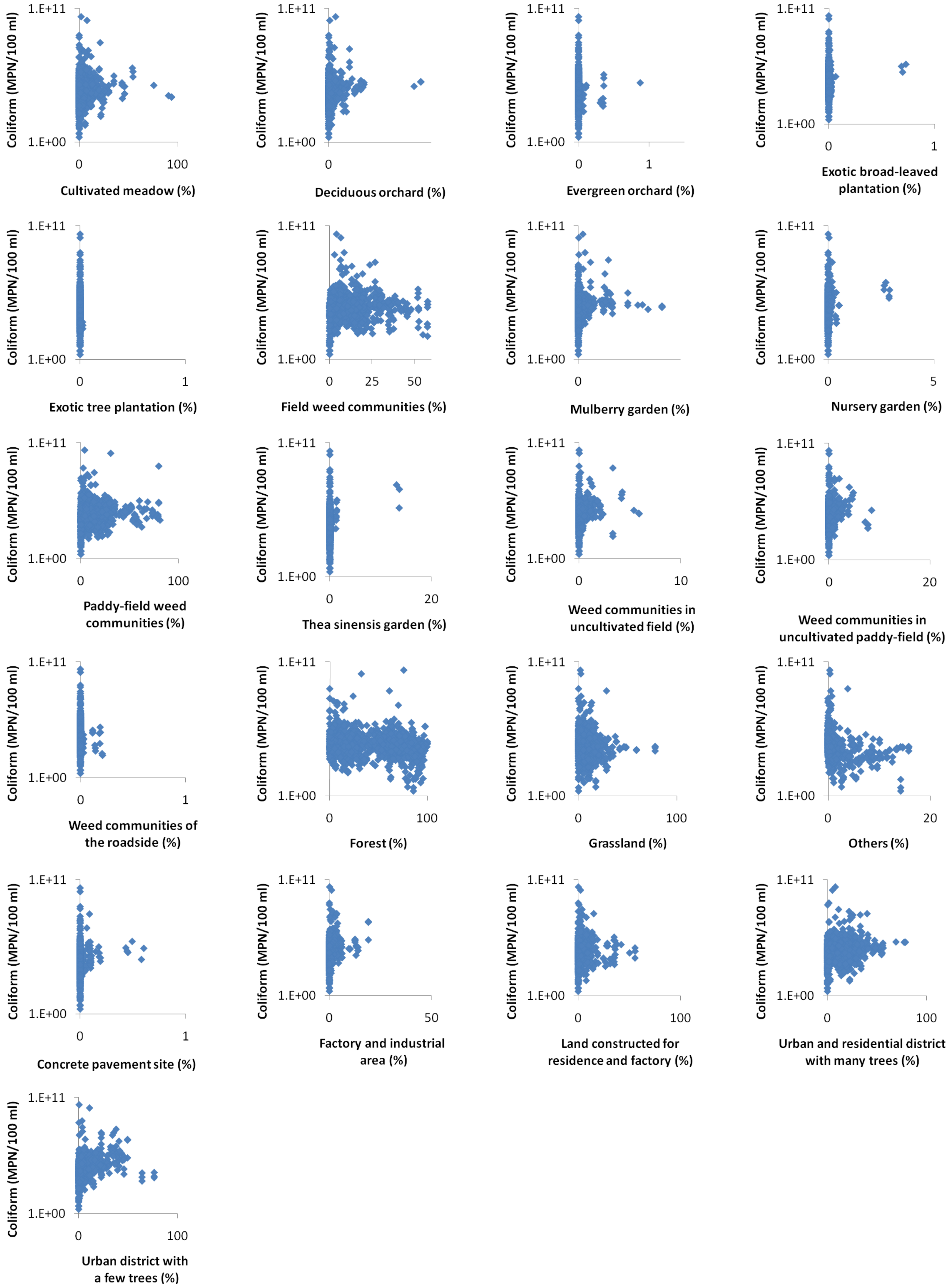


Figure 29. (Continued)

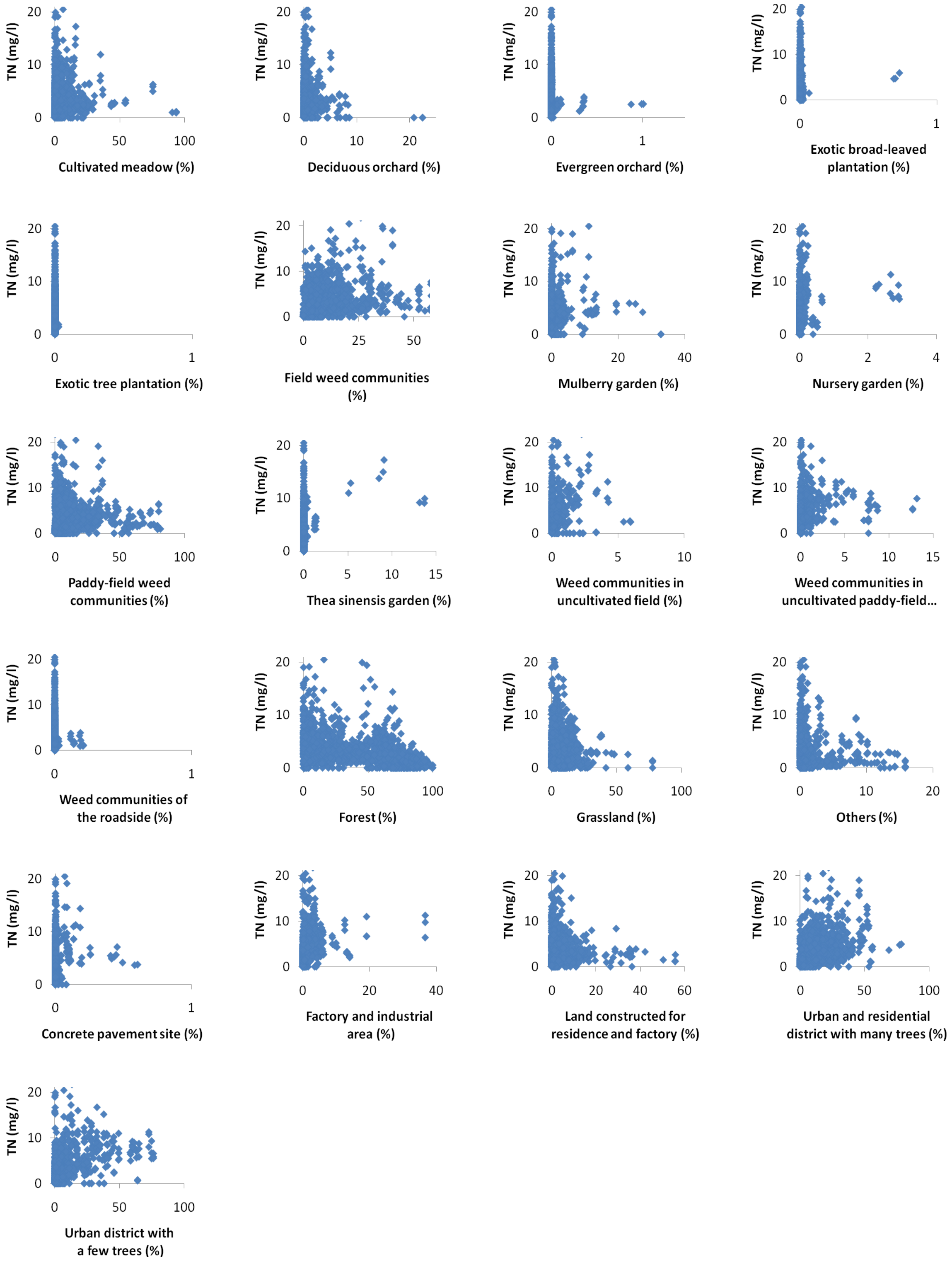
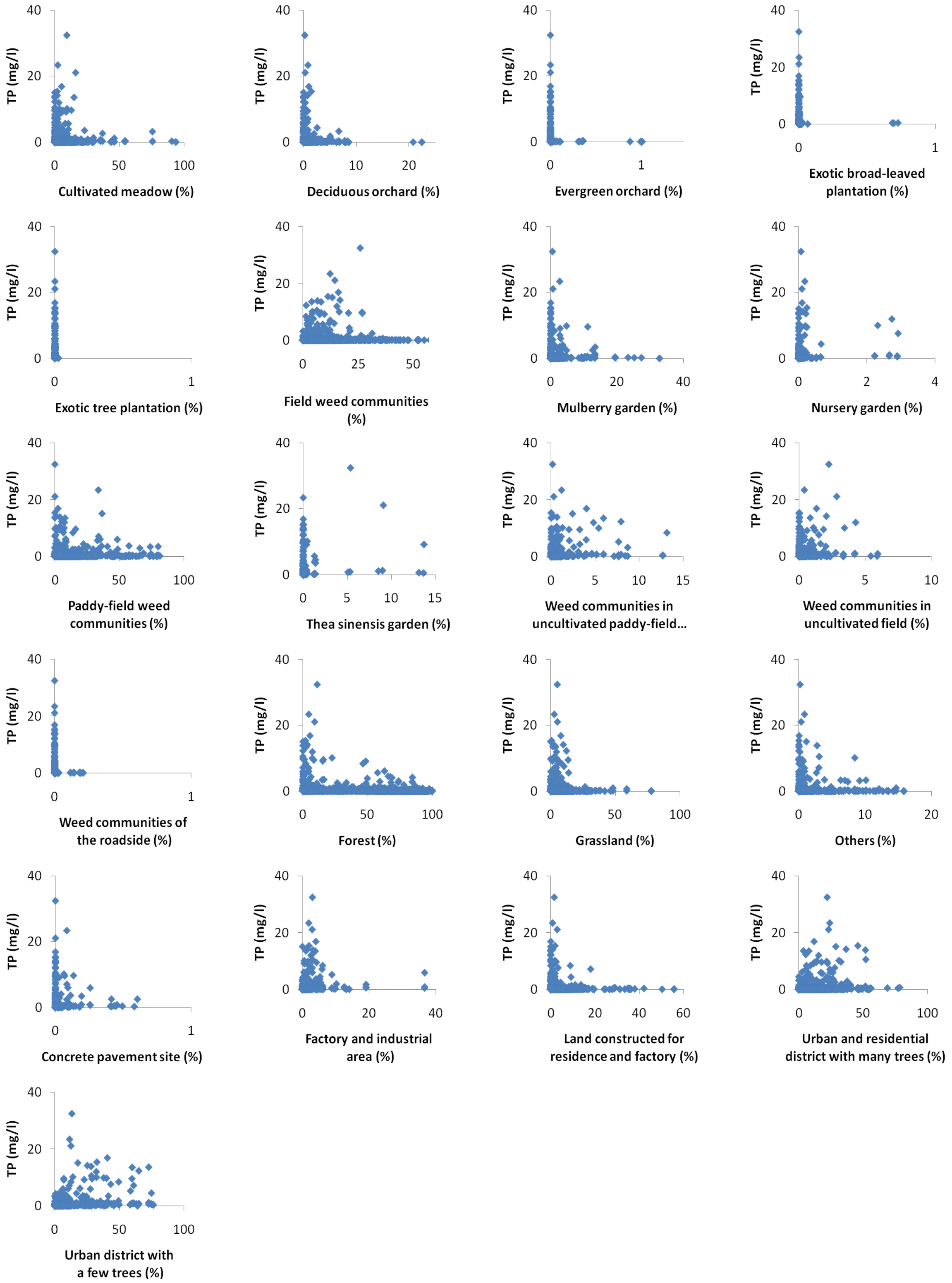


Figure 29. (Continued)



Among the agricultural land use/covers, the weed communities of the roadside show the highest correlation with pH; the weed communities in uncultivated paddy-field with DO, BOD, TN, and TP; field weed communities with COD; the paddy field weed communities with SSC; and the deciduous orchard with coliform. Among the urban land use/covers, the factory/industrial areas show the highest correlation with pH and TN; the urban district with a few trees with DO, coliform, and TP; and the urban/residential districts with many trees with BOD, COD, and SSC. Further assessment on the relations between detailed agricultural and urban land use/covers and water quality was made for the individual river basin. The results are presented in Tables 34 to 40. In general, correlation patterns similar to Table 33 are found in each river basin. Both the percentages of agricultural land use/covers and that of urban land use/covers contributed to the degradation of water quality.

Contrasting correlation patterns from several agricultural land use/covers are found for different basins. The cultivated meadow has a potential to improve DO in the Ara/Edo and Kuji River basins. In the Tone River basin, the exotic broad-leaved plantation have a potential to improve DO as well as to reduce BOD and coliform concentration. Additionally, in the Tone River basin, the exotic tree plantation has a potential to reduce coliform, TN, and TP. In the Ara/ Edo River basin, the mulberry gardens have a potential to improve DO, as well as to reduce BOD, COD, SSC, TN, and TP. The *Thea sinensis* gardens in the Ara/Edo River basin also have a potential to improve DO and to reduce both COD and SSC.

Contrasting correlation patterns are also observed between urban land use/covers and water quality. In general, urban land use/covers contribute to deteriorating water quality. In the Ara/Edo River basin, the land constructed for residence/factories has a potential to improve DO, and to reduce BOD, COD, SSC, TN, and TP. Similarly, in the Fuji River basin, the land constructed for residence/factories has a potential to reduce coliform concentration, whereas in the Kuji River basin it has a potential to improve DO.

The following agricultural land use/covers show high correlations with water quality:

1) Field weed communities in the Ara/Edo, Kuji, Naka, and Tone River basins,
2) Mulberry garden in the Ara/Edo and Tone River basins,
3) Deciduous orchard in the Fuji River basin,
4) Nursery garden in the Sagami River basin, and
5) Paddy field weed communities in the Tama River basin.

Among the urban land use/covers, the residential area, either the urban/residential districts with many trees or the urban district with a few trees, have a potential to degrade water quality in the Ara/Edo, Fuji, Kuji, and Tone River basins. In the Naka River basin, both the factory/industrial areas and the urban/residential districts with many trees show the highest correlations with water quality parameters. In the Sagami River basin, a combination of the factory/industrial areas and the urban district with a few trees holds the highest correlation with water quality parameters. In the Tama River basin, the concrete pavement sites as well as the urban district with a few trees have higher correlations compared to the other urban land use/covers.

Table 33. Correlation between water quality and percentages of detailed land use/covers in the studied river basins

LULC	pH	DO	BOD	COD	SSC	Coliform	TN	TP
Cul		0.055 (++ VW)		0.062 (++ VW)	0.084 (++ VW)	0.081 (++ VW)	0.098 (++ VW)	0.078 (++ VW)
Dec		-0.051 (-- VW)	0.162 (++ W)	0.181 (++ W)	0.172 (++ W)	0.184 (++ W)	0.233 (++ W)	0.165 (++ W)
Eve	0.105 (++ W)	-0.076 (-- VW)	0.048 (+ VW)	0.083 (++ VW)	0.116 (++ W)	-0.079 (-- VW)		
Exb	0.074 (++ VW)		-0.058 (-- VW)	-0.057 (-- VW)				
Ext	0.100 (++ W)		0.056 (++ VW)	0.103 (++ W)	0.091 (++ VW)	-0.108 (-- W)	-0.078 (-- VW)	-0.056 (- VW)
Fwc		-0.124 (-- W)	0.278 (++ W)	0.363 (++ M)	0.270 (++ W)	0.106 (++ W)	0.312 (++ M)	0.170 (++ W)
Mul	0.082 (++ VW)	0.084 (++ VW)	-0.038 (- VW)		0.055 (++ VW)	0.083 (++ VW)	0.061 (++ VW)	0.053 (++ VW)
Nur	-0.054 (-- VW)	-0.145 (-- W)	0.196 (++ W)	0.206 (++ W)	0.136 (++ W)	0.106 (++ W)	0.274 (++ W)	0.177 (++ W)
Pwc	-0.081 (-- VW)	-0.052 (-- VW)	0.232 (++ W)	0.292 (++ W)	0.291 (++ W)	0.095 (++ VW)	0.179 (++ W)	0.157 (++ W)
The		-0.078 (-- VW)	0.112 (++ W)	0.111 (++ W)	0.074 (++ VW)		0.185 (++ W)	0.151 (++ W)
Wcf	0.041 (+ VW)	-0.165 (-- W)	0.164 (++ W)	0.173 (++ W)	0.166 (++ W)	0.120 (++ W)	0.295 (++ W)	0.221 (++ W)
Wcp	-0.075 (-- VW)	-0.263 (-- W)	0.304 (++ M)	0.321 (++ M)	0.260 (++ W)	0.131 (++ W)	0.371 (++ M)	0.286 (++ W)
Wcr	0.129 (++ W)					-0.131 (-- W)	-0.101 (-- W)	-0.111 (-- W)
For	0.162 (++ W)	0.298 (++ W)	-0.433 (-- M)	-0.483 (-- M)	-0.401 (-- M)	-0.173 (-- W)	-0.410 (-- M)	-0.333 (-- M)
Gra	0.148 (++ W)	-0.043 (- VW)	-0.035 (- VW)			-0.073 (-- VW)	-0.051 (-- VW)	-0.039 (- VW)
Oth	0.090 (++ VW)	0.064 (++ VW)	-0.068 (-- VW)	-0.076 (-- VW)		-0.250 (-- W)	-0.177 (-- W)	-0.122 (-- W)
Con	-0.062 (-- VW)	-0.127 (-- W)	0.141 (++ W)	0.109 (++ W)	0.048 (+ VW)	0.050 (+ VW)	0.196 (++ W)	0.174 (++ W)
Fac	-0.199 (-- W)	-0.259 (-- W)	0.370 (++ M)	0.385 (++ M)	0.321 (++ M)	0.231 (++ W)	0.441 (++ M)	0.370 (++ M)
Lan	0.076 (++ VW)	-0.046 (-- VW)	0.145 (++ W)	0.200 (++ W)	0.120 (++ W)	0.095 (++ VW)	0.181 (++ W)	0.076 (++ VW)
Urm	-0.122 (-- W)	-0.204 (-- W)	0.389 (++ M)	0.436 (++ M)	0.332 (++ M)	0.125 (++ W)	0.385 (++ M)	0.283 (++ W)
Urf	-0.168 (-- W)	-0.280 (-- W)	0.383 (++ M)	0.349 (++ M)	0.267 (++ W)	0.288 (++ W)	0.405 (++ M)	0.389 (++ M)

Agricultural land use/cover:

Cul: Cultivated meadow, Dec: Deciduous orchard, Eve: Evergreen orchard, Exb: Exotic broad-leaved plantation, Ext: Exotic tree plantation, Fwc: Field weeds communities, Mul: Mulberry garden, Nur: Nursery garden, Pwc Paddy-field weed communities, The: Thea sinensis garden, Wcf: Weed communities in uncultivated field, Wcp: Weed communities in uncultivated paddy field, Wcr: Weed communities of the roadside

For: Forest, Gra: Grassland, Oth: Others

Urban land use/cover:

Con: Concrete pavement site, Fac: Factory/industrial areas, Lan: Land constructed for residence/factories, Urm: Urban/residential districts with many trees, Urf: Urban district with a few trees

(++) Positive correlation with more than 99% significance, (+) Positive correlation with more than 95% significance, (--) Negative correlation with more than 99% significance, (-) Negative correlation with more than 95% significance

(VW) Very weak correlation, (W) Weak correlation, (M) Moderate correlation, (S) Strong correlation

Table 34. Correlation between water quality and detailed land use/cover in the Ara/Edo River basin

LULC	pH	DO	BOD	COD	SSC	Coliform	TN	TP
Cul	0.173 (++ W)	0.169 (++ W)	-0.089 (- VW)					
Dec						0.201 (++ W)	0.104 (+ W)	
Eve								
Exb	0.145 (++ W)	0.134 (++ W)	-0.101 (- W)	-0.101 (- W)				
Ext								
Fwc	-0.152 (-- W)	-0.238 (-- W)	0.277 (++ W)	0.255 (++ W)	0.110 (++ W)	0.353 (++ M)	0.337 (++ M)	0.232 (++ W)
Mul	0.338 (++ M)	0.309 (++ M)	-0.190 (-- W)	-0.211 (-- W)	-0.204 (-- W)		-0.144 (-- W)	-0.097 (- VW)
Nur	-0.089 (- VW)	-0.175 (-- W)	0.253 (++ W)	0.237 (++ W)		0.287 (++ W)	0.310 (++ M)	0.209 (++ W)
Pwc	-0.239 (-- W)	-0.187 (-- W)	0.145 (++ W)	0.168 (++ W)	0.237 (++ W)	0.157 (++ W)	0.115 (++ W)	0.142 (++ W)
The	0.172 (++ W)	0.170 (++ W)		-0.096 (- VW)	-0.156 (-- W)			
Wcf							0.142 (++ W)	
Wcp	-0.261 (-- W)	-0.293 (-- W)	0.248 (++ W)	0.260 (++ W)	0.175 (++ W)	0.182 (++ W)	0.258 (++ W)	0.182 (++ W)
Wcr								
For	0.475 (++ M)	0.419 (++ M)	-0.319 (-- M)	-0.350 (-- M)	-0.407 (-- M)	-0.162 (-- W)	-0.301 (-- M)	-0.208 (-- W)
Gra			-0.094 (- VW)			-0.163 (-- W)	-0.128 (-- W)	
Oth			-0.103 (- W)	-0.091 (- VW)	0.143 (++ W)	-0.164 (-- W)	-0.087 (- VW)	
Con								
Fac	-0.346 (-- M)	-0.419 (-- M)	0.397 (++ M)	0.418 (++ M)	0.317 (++ M)	0.281 (++ W)	0.352 (++ M)	0.270 (++ W)
Lan	0.253 (++ W)	0.233 (++ W)	-0.172 (-- W)	-0.180 (-- W)	-0.242 (-- W)		-0.132 (-- W)	-0.214 (-- W)
Urm	-0.279 (-- W)	-0.256 (-- W)	0.297 (++ W)	0.292 (++ W)	0.295 (++ W)	0.156 (++ W)	0.331 (++ M)	0.210 (++ W)
Urf	-0.393 (-- M)	-0.512 (-- S)	0.495 (++ M)	0.513 (++ S)	0.295 (++ W)	0.379 (++ M)	0.476 (++ M)	0.336 (++ M)

Agricultural land use/cover:

Cul: Cultivated meadow, Dec: Deciduous orchard, Eve: Evergreen orchard, Exb: Exotic broad-leaved plantation, Ext: Exotic tree plantation, Fwc: Field weeds communities, Mul: Mulberry garden, Nur: Nursery garden, Pwc Paddy-field weed communities, The: Thea sinensis garden, Wcf: Weed communities in uncultivated field, Wcp: Weed communities in uncultivated paddy field, Wcr: Weed communities of the roadside

For: Forest, Gra: Grassland, Oth: Others

Urban land use/cover:

Con: Concrete pavement site, Fac: Factory/industrial areas, Lan: Land constructed for residence/factories, Urm: Urban/residential districts with many trees, Urf: Urban district with a few trees

(++) Positive correlation with more than 99% significance, (+) Positive correlation with more than 95% significance, (--) Negative correlation with more than 99% significance, (-) Negative correlation with more than 95% significance

(VW) Very weak correlation, (W) Weak correlation, (M) Moderate correlation, (S) Strong correlation

Table 35. Correlation between water quality and detailed land use/cover in the Fuji River basin

LULC	pH	DO	BOD	COD	SSC	Coliform	TN	TP
Cul	0.315 (++ M)						0.438 (++ M)	0.373 (+ M)
Dec	-0.225 (-- W)	-0.263 (-- W)	0.449 (++ M)	0.426 (++ M)	0.246 (++ W)	0.444 (++ M)	0.632 (++ S)	0.670 (++ S)
Eve		-0.216 (- W)			0.332 (++ M)			
Exb					0.249 (++ W)		0.335 (+ M)	
Ext								
Fwc	0.209 (++ W)						0.371 (+ M)	0.351 (+ M)
Mul		-0.247 (-- W)	0.297 (++ W)	0.370 (++ M)		0.341 (++ M)	0.420 (++ M)	0.421 (+ M)
Nur								
Pwc			0.246 (++ W)	0.300 (++ M)	0.255 (++ W)	0.244 (++ W)	0.449 (++ M)	0.500 (++ S)
The		-0.172 (- W)			0.221 (+ W)			
Wcf	0.240 (++ W)						0.409 (+ M)	0.368 (+ M)
Wcp	-0.194 (- W)	-0.330 (-- M)	0.175 (+ W)	0.173 (+ W)	0.255 (++ W)		0.351 (+ M)	
Wcr								
For		0.191 (+ W)	-0.358 (-- M)	-0.383 (-- M)	-0.254 (-- W)	-0.335 (-- M)	-0.433 (-- M)	-0.459 (-- M)
Gra								
Oth						-0.196 (- W)	-0.312 (- M)	
Con								
Fac			-0.176 (- W)	-0.179 (- W)	0.256 (++ W)			
Lan						-0.150 (- W)		
Urm	0.232 (++ W)				0.206 (++ W)			
Urf	-0.205 (-- W)	-0.399 (-- M)	0.546 (++ S)	0.559 (++ S)	0.290 (++ W)	0.551 (++ S)	0.598 (++ S)	0.627 (++ S)

Agricultural land use/cover:

Cul: Cultivated meadow, Dec: Deciduous orchard, Eve: Evergreen orchard, Exb: Exotic broad-leaved plantation, Ext: Exotic tree plantation, Fwc: Field weeds communities, Mul: Mulberry garden, Nur: Nursery garden, Pwc Paddy-field weed communities, The: Thea sinensis garden, Wcf: Weed communities in uncultivated field, Wcp: Weed communities in uncultivated paddy field, Wcr: Weed communities of the roadside

For: Forest, Gra: Grassland, Oth: Others

Urban land use/cover:

Con: Concrete pavement site, Fac: Factory/industrial areas, Lan: Land constructed for residence/factories, Urm: Urban/residential districts with many trees, Urf: Urban district with a few trees

(++) Positive correlation with more than 99% significance, (+) Positive correlation with more than 95% significance, (--) Negative correlation with more than 99% significance, (-) Negative correlation with more than 95% significance

(VW) Very weak correlation, (W) Weak correlation, (M) Moderate correlation, (S) Strong correlation

Table 36. Correlation between water quality and detailed land use/cover in the Kuji River basin

LULC	pH	DO	BOD	COD	SSC	Coliform	TN	TP
Cul	0.259 (+ W)	0.259 (+ W)	0.381 (++ M)	0.386 (++ M)				0.327 (+ M)
Dec				0.351 (++ M)				
Eve								
Exb								
Ext								
Fwc	-0.282 (- W)	-0.410 (-- M)					0.320 (+ M)	
Mul								
Nur								
Pwc								
The								
Wcf								
Wcp				0.521 (++ S)	0.326 (+ M)			0.504 (++ S)
Wcr								
For				-0.400 (-- M)				
Gra								
Oth				0.287 (+ W)				
Con								
Fac	0.303 (+ M)	0.277 (+ W)						
Lan								
Urm	-0.286 (- W)	-0.260 (- W)		0.468 (++ M)			0.298 (+ W)	
Urf	-0.244 (- W)	-0.295 (- W)						

Agricultural land use/cover:

Cul: Cultivated meadow, Dec: Deciduous orchard, Eve: Evergreen orchard, Exb: Exotic broad-leaved plantation, Ext: Exotic tree plantation, Fwc: Field weeds communities, Mul: Mulberry garden, Nur: Nursery garden, Pwc Paddy-field weed communities, The: Thea sinensis garden, Wcf: Weed communities in uncultivated field, Wcp: Weed communities in uncultivated paddy field, Wcr: Weed communities of the roadside

For: Forest, Gra: Grassland, Oth: Others

Urban land use/cover:

Con: Concrete pavement site, Fac: Factory/industrial areas, Lan: Land constructed for residence/factories, Urm: Urban/residential districts with many trees, Urf: Urban district with a few trees

(++) Positive correlation with more than 99% significance, (+) Positive correlation with more than 95% significance, (--) Negative correlation with more than 99% significance, (-) Negative correlation with more than 95% significance

(VW) Very weak correlation, (W) Weak correlation, (M) Moderate correlation, (S) Strong correlation

Table 37. Correlation between water quality and detailed land use/cover in the Naka River basin

	pH	DO	BOD	COD	SSC	Coliform	TN	TP
Cul				0.194 (++ W)	0.147 (+ W)	0.122 (+ W)	0.148 (+ W)	
Dec	0.194 (++ W)		0.191 (++ W)	0.339 (++ M)	0.248 (++ W)	0.123 (+ W)	0.296 (++ W)	
Eve	0.172 (++ W)	-0.318 (-- M)					0.158 (+ W)	
Exb		-0.389 (-- M)		0.201 (++ W)	0.156 (+ W)		0.279 (++ W)	
Ext								
Fwc			0.285 (++ W)	0.404 (++ M)	0.245 (++ W)		0.440 (++ M)	
Mul	0.211 (++ W)				0.126 (+ W)			
Nur	0.230 (++ W)		-0.136 (- W)				0.169 (+ W)	
Pwc	0.280 (++ W)		0.179 (++ W)	0.248 (++ W)	0.227 (++ W)		0.278 (++ W)	
The								
Wcf								
Wcp	0.181 (++ W)	-0.217 (-- W)	0.132 (+ W)	0.233 (++ W)	0.196 (++ W)		0.254 (++ W)	
Wcr	0.277 (++ W)	-0.218 (-- W)	-0.211 (-- W)			-0.143 (- W)	0.183 (++ W)	
For	-0.143 (- W)	0.148 (++ W)	-0.295 (-- W)	-0.429 (-- M)	-0.267 (-- W)		-0.470 (-- M)	-0.142 (- W)
Gra			-0.194 (-- W)				-0.124 (- W)	
Oth	0.209 (++ W)						0.125 (+ W)	
Con								
Fac	0.211 (++ W)			0.234 (++ W)	0.232 (++ W)	0.149 (+ W)	0.329 (++ M)	
Lan	0.130 (+ W)			0.173 (++ W)		0.178 (++ W)	0.368 (++ M)	
Urm	0.133 (+ W)	-0.132 (- W)	0.211 (++ W)	0.308 (++ M)	0.178 (++ W)		0.342 (++ M)	0.144 (+ W)
Urf		-0.139 (- W)	0.139 (+ W)	0.244 (++ W)	0.194 (++ W)	0.170 (++ W)	0.281 (++ W)	0.116 (+ W)

Agricultural land use/cover:

Cul: Cultivated meadow, Dec: Deciduous orchard, Eve: Evergreen orchard, Exb: Exotic broad-leaved plantation, Ext: Exotic tree plantation, Fwc: Field weeds communities, Mul: Mulberry garden, Nur: Nursery garden, Pwc Paddy-field weed communities, The: Thea sinensis garden, Wcf: Weed communities in uncultivated field, Wcp: Weed communities in uncultivated paddy field, Wcr: Weed communities of the roadside

For: Forest, Gra: Grassland, Oth: Others

Urban land use/cover:

Con: Concrete pavement site, Fac: Factory/industrial areas, Lan: Land constructed for residence/factories, Urm: Urban/residential districts with many trees, Urf: Urban district with a few trees

(++) Positive correlation with more than 99% significance, (+) Positive correlation with more than 95% significance, (--) Negative correlation with more than 99% significance, (-) Negative correlation with more than 95% significance

(VW) Very weak correlation, (W) Weak correlation, (M) Moderate correlation, (S) Strong correlation

Table 38. Correlation between water quality and detailed land use/cover in the Sagami River basin

	pH	DO	BOD	COD	SSC	Coliform	TN	TP
Cul	-0.280 (-- W)		0.145 (+ W)		0.288 (++ W)	0.235 (++ W)	0.363 (++ M)	0.273 (++ W)
Dec	-0.215 (-- W)	-0.216 (-- W)			0.191 (++ W)	0.199 (++ W)	0.295 (++ W)	0.193 (++ W)
Eve					0.172 (+ W)			
Exb					0.181 (+ W)			
Ext								
Fwc	-0.190 (-- W)	-0.269 (-- W)	0.337 (++ M)	0.294 (++ W)	0.299 (++ W)	0.326 (++ M)	0.327 (++ M)	0.374 (++ M)
Mul	-0.137 (- W)				0.196 (++ W)		0.181 (+ W)	0.179 (+ W)
Nur	-0.385 (-- M)	-0.375 (-- M)	0.319 (++ M)	0.248 (++ W)	0.361 (++ M)	0.396 (++ M)	0.443 (++ M)	0.318 (++ M)
Pwc	-0.259 (-- W)	-0.331 (-- M)	0.305 (++ M)	0.333 (++ M)	0.318 (++ M)	0.390 (++ M)	0.429 (++ M)	0.362 (++ M)
The								
Wcf								
Wcp							0.147 (+ W)	0.160 (+ W)
Wcr								
For	0.258 (++ W)	0.287 (++ W)	-0.248 (-- W)	-0.275 (-- W)	-0.290 (-- W)	-0.352 (-- M)	-0.433 (-- M)	-0.425 (-- M)
Gra		0.193 (++ W)	-0.256 (-- W)	-0.219 (-- W)	-0.219 (-- W)	-0.157 (- W)	-0.195 (-- W)	-0.140 (- W)
Oth			-0.140 (- W)	-0.141 (- W)		-0.204 (-- W)		
Con								
Fac	-0.555 (-- S)	-0.465 (-- M)	0.365 (++ M)	0.334 (++ M)	0.590 (++ S)	0.469 (++ M)	0.619 (++ S)	0.457 (++ M)
Lan								
Urm	-0.271 (-- W)		0.149 (+ W)		0.309 (++ M)	0.321 (++ M)	0.412 (++ M)	0.397 (++ M)
Urf	-0.334 (-- M)	-0.374 (-- M)	0.488 (++ M)	0.392 (++ M)	0.510 (++ S)	0.527 (++ S)	0.590 (++ S)	0.561 (++ S)

Agricultural land use/cover:

Cul: Cultivated meadow, Dec: Deciduous orchard, Eve: Evergreen orchard, Exb: Exotic broad-leaved plantation, Ext: Exotic tree plantation, Fwc: Field weeds communities, Mul: Mulberry garden, Nur: Nursery garden, Pwc Paddy-field weed communities, The: Thea sinensis garden, Wcf: Weed communities in uncultivated field, Wcp: Weed communities in uncultivated paddy field, Wcr: Weed communities of the roadside

For: Forest, Gra: Grassland, Oth: Others

Urban land use/cover:

Con: Concrete pavement site, Fac: Factory/industrial areas, Lan: Land constructed for residence/factories, Urm: Urban/residential districts with many trees, Urf: Urban district with a few trees

(++) Positive correlation with more than 99% significance, (+) Positive correlation with more than 95% significance, (--) Negative correlation with more than 99% significance, (-) Negative correlation with more than 95% significance

(VW) Very weak correlation, (W) Weak correlation, (M) Moderate correlation, (S) Strong correlation

Table 39. Correlation between water quality and detailed land use/cover in the Tama River basin

	pH	DO	BOD	COD	SSC	Coliform	TN	TP
Cul	-0.176 (- W)	-0.327 (-- M)	0.427 (++ M)	0.436 (++ M)	0.377 (++ M)	0.449 (++ M)	0.412 (++ M)	0.428 (++ M)
Dec			0.217 (+ W)			0.283 (++ W)		
Eve								
Exb								
Ext								
Fwc			0.296 (++ W)	0.241 (++ W)	0.210 (+ W)	0.353 (++ M)	0.198 (+ W)	0.221 (+ W)
Mul								
Nur	-0.340 (-- M)	-0.474 (-- M)	0.339 (++ M)	0.408 (++ M)	0.331 (++ M)	0.351 (++ M)	0.407 (++ M)	0.397 (++ M)
Pwc	-0.253 (-- W)	-0.393 (-- M)	0.516 (++ S)	0.546 (++ S)	0.435 (++ M)	0.511 (++ S)	0.425 (++ M)	0.517 (++ S)
The	-0.389 (-- M)	-0.542 (-- S)	0.416 (++ M)	0.450 (++ M)	0.369 (++ M)	0.327 (++ M)	0.387 (++ M)	0.545 (++ S)
Wcf	-0.339 (-- M)	-0.367 (-- M)	0.418 (++ M)	0.406 (++ M)	0.429 (++ M)	0.412 (++ M)	0.246 (+ W)	0.423 (++ M)
Wcp	-0.439 (-- M)	-0.382 (-- M)	0.502 (++ S)	0.449 (++ M)	0.344 (++ M)	0.502 (++ S)	0.469 (++ M)	0.427 (++ M)
Wcr								
For		0.306 (++ M)	-0.253 (-- W)	-0.364 (-- M)	-0.389 (-- M)	-0.208 (- W)	-0.300 (-- M)	-0.271 (-- W)
Gra								
Oth		-0.401 (-- M)		0.228 (++ W)	0.287 (++ W)		0.218 (+ W)	0.209 (+ W)
Con	-0.263 (-- W)	-0.293 (-- W)	0.434 (++ M)	0.407 (++ M)	0.364 (++ M)	0.436 (++ M)	0.414 (++ M)	0.401 (++ M)
Fac		-0.199 (- W)	0.379 (++ M)	0.394 (++ M)	0.340 (++ M)	0.379 (++ M)	0.332 (++ M)	0.355 (++ M)
Lan	-0.254 (-- W)	-0.320 (-- M)	0.360 (++ M)	0.391 (++ M)	0.420 (++ M)	0.402 (++ M)	0.328 (++ M)	0.324 (++ M)
Urm		-0.232 (-- W)	0.389 (++ M)	0.385 (++ M)	0.350 (++ M)	0.341 (++ M)	0.401 (++ M)	0.310 (++ M)
Urf	-0.186 (- W)	-0.431 (-- M)	0.428 (++ M)	0.475 (++ M)	0.467 (++ M)	0.281 (++ W)	0.497 (++ M)	0.348 (++ M)

Agricultural land use/cover:

Cul: Cultivated meadow, Dec: Deciduous orchard, Eve: Evergreen orchard, Exb: Exotic broad-leaved plantation, Ext: Exotic tree plantation, Fwc: Field weeds communities, Mul: Mulberry garden, Nur: Nursery garden, Pwc Paddy-field weed communities, The: Thea sinensis garden, Wcf: Weed communities in uncultivated field, Wcp: Weed communities in uncultivated paddy field, Wcr: Weed communities of the roadside

For: Forest, Gra: Grassland, Oth: Others

Urban land use/cover:

Con: Concrete pavement site, Fac: Factory/industrial areas, Lan: Land constructed for residence/factories, Urm: Urban/residential districts with many trees, Urf: Urban district with a few trees

(++) Positive correlation with more than 99% significance, (+) Positive correlation with more than 95% significance, (--) Negative correlation with more than 99% significance, (-) Negative correlation with more than 95% significance

(VW) Very weak correlation, (W) Weak correlation, (M) Moderate correlation, (S) Strong correlation

Table 40. Correlation between water quality and detailed land use/cover in the Tone River basin

	pH	DO	BOD	COD	SSC	Coliform	TN	TP
Cul					0.108 (++ W)		0.078 (++ VW)	0.079 (++ VW)
Dec			0.189 (++ W)	0.209 (++ W)	0.208 (++ W)	0.153 (++ W)	0.241 (++ W)	0.178 (++ W)
Eve	0.091 (++ VW)	-0.059 (- VW)	0.157 (++ W)	0.211 (++ W)	0.155 (++ W)	-0.120 (-- W)		
Exb		0.103 (++ W)	-0.080 (-- VW)			-0.115 (-- W)		
Ext	0.131 (++ W)		0.075 (+ VW)	0.137 (++ W)	0.120 (++ W)	-0.136 (-- W)	-0.110 (-- W)	-0.076 (- VW)
Fwc	0.117 (++ W)	-0.165 (-- W)	0.289 (++ W)	0.395 (++ M)	0.299 (++ W)	0.069 (++ VW)	0.350 (++ M)	0.146 (++ W)
Mul	-0.061 (- VW)	0.088 (++ VW)			0.144 (++ W)		0.150 (++ W)	0.109 (++ W)
Nur	0.068 (+ VW)			0.104 (++ W)	0.120 (++ W)		0.112 (++ W)	
Pwc		-0.072 (-- VW)	0.245 (++ W)	0.300 (++ M)	0.265 (++ W)	0.075 (++ VW)	0.194 (++ W)	0.183 (++ W)
The				0.082 (++ VW)	0.118 (++ W)	-0.140 (-- W)		
Wcf	0.151 (++ W)		0.106 (++ W)	0.169 (++ W)	0.188 (++ W)		0.274 (++ W)	0.126 (++ W)
Wcp	0.130 (++ W)	-0.120 (-- W)	0.213 (++ W)	0.269 (++ W)	0.245 (++ W)		0.251 (++ W)	0.142 (++ W)
Wcr	0.137 (++ W)		0.075 (+ VW)	0.145 (++ W)	0.109 (++ W)	-0.144 (-- W)	-0.096 (-- VW)	-0.093 (-- VW)
For		0.167 (++ W)	-0.343 (-- M)	-0.396 (-- M)	-0.292 (-- W)	-0.094 (-- VW)	-0.282 (-- W)	-0.206 (-- W)
Gra	0.175 (++ W)					-0.129 (-- W)		-0.049 (- VW)
Oth	0.162 (++ W)	0.201 (++ W)	-0.172 (-- W)	-0.162 (-- W)	-0.110 (-- W)	-0.376 (-- M)	-0.349 (-- M)	-0.243 (-- W)
Con					0.098 (++ VW)	-0.115 (-- W)		
Fac	-0.093 (-- VW)	-0.15 (-- W)	0.257 (++ W)	0.279 (++ W)	0.261 (++ W)	0.166 (++ W)	0.326 (++ M)	0.273 (++ W)
Lan	0.096 (++ VW)	-0.145 (-- W)	0.257 (++ W)	0.334 (++ M)	0.269 (++ W)	0.096 (++ VW)	0.247 (++ W)	0.168 (++ W)
Urm	0.072 (++ VW)	-0.206 (-- W)	0.379 (++ M)	0.451 (++ M)	0.334 (++ M)	0.068 (++ VW)	0.302 (++ M)	0.205 (++ W)
Urf	-0.066 (-- VW)	-0.061 (- VW)	0.224 (++ W)	0.193 (++ W)	0.170 (++ W)	0.183 (++ W)	0.209 (++ W)	0.250 (++ W)

Agricultural land use/cover:

Cul: Cultivated meadow, Dec: Deciduous orchard, Eve: Evergreen orchard, Exb: Exotic broad-leaved plantation, Ext: Exotic tree plantation, Fwc: Field weeds communities, Mul: Mulberry garden, Nur: Nursery garden, Pwc Paddy-field weed communities, The: Thea sinensis garden, Wcf: Weed communities in uncultivated field, Wcp: Weed communities in uncultivated paddy field, Wcr: Weed communities of the roadside

For: Forest, Gra: Grassland, Oth: Others

Urban land use/cover:

Con: Concrete pavement site, Fac: Factory/industrial areas, Lan: Land constructed for residence/factories, Urm: Urban/residential districts with many trees, Urf: Urban district with a few trees

(++) Positive correlation with more than 99% significance, (+) Positive correlation with more than 95% significance, (--) Negative correlation with more than 99% significance, (-) Negative correlation with more than 95% significance

(VW) Very weak correlation, (W) Weak correlation, (M) Moderate correlation, (S) Strong correlation

4.5. Predictors for water quality

To determine the combination of land use/covers for water quality estimation, step-wise multiple regression analyses were carried out. Prior to the analyses, an exploratory regression was carried out for each land use/cover and water quality, and one with the highest r^2 value was used as the first predictor of multiple regression. Then, other land use/covers were added to the regression as long as the addition increases the significance of correlation. The multiple regression was conducted for the general land use/covers and the detailed land use/covers. The results are presented in Tables 41 and 42.

Among the general land use/covers, the percentages of urban areas account most for variations in pH, DO, BOD, COD, TN, and TP. Grassland, forest and others further explain the variations in pH, BOD, COD, and TN. SSC is most strongly related to forest; then grassland.

Table 41. Multiple linear regression between water quality and general land use/covers

Water Quality	1 Predictor	r^2	2 Predictors	r^2	3 Predictors	r^2
pH	Urban	0.041	Urban, Grassland	0.058	Urban, Grassland, Others	0.063
DO	Urban	0.320				
BOD	Urban	0.185	Urban, Others	0.188		
COD	Urban	0.228	Urban, Forest	0.243		
SSC	Forest	0.232	Forest, Grassland	0.238		
Coliform						
TN	Urban	0.285	Urban, Others	0.302	Urban, Others, Forest	0.314
TP	Urban	0.077				

Concerning the multiple regression analysis performed on the detailed land use/covers, six predictors were generated. Overall, the urban district with a few trees is the best predictor for pH, DO, BOD, TN, and TP, while forest is the best for COD and SSC (Table 42). Furthermore, the table shows that the percentages of two categories of urban areas (the urban district with a few trees and the urban/residential districts with many trees) further account for pH, DO, BOD, TN, and TP variations. Another category of urban land use/cover, i.e. the factory/industrial areas further accounted for variations in oxygen-related parameters including DO, BOD, and COD. The agricultural land use/covers account for fewer variations in water quality in comparison to the urban land use/covers. Among the 13 agricultural land use/covers, the *Thea sinensis* garden and the nursery garden account for more water quality variations, which is followed by the weed communities.

Tables 41 and 42 present the predictors of water quality for the whole Kanto region level. However, as shown in Tables 43 to 49, the predictors vary among river basins. For examples, although Table 41 shows that the urban area accounted for larger variations in water quality. On the other hand, Table 43 shows that forest accounts for more water quality variations in the Ara/Edo River basin. Furthermore, Table 48 shows that in the Tama River basin, the *Thea sinensis* garden accounts for more water quality variations.

Table 42. Multiple linear regression between water quality and detailed land use/covers

Water Quality	1 Predictor	r^2	2 Predictors	r^2	3 Predictors	r^2	4 Predictors	r^2	5 Predictors	r^2	6 Predictors	r^2
pH	Urf	0.044	Urf, Gra	0.064	Urf, Gra, Fwc	0.081	Urf, Gra, Fwc, Urm	0.100	Urf, Gra, Fwc, Urm, Ext	0.111	Urf, Gra, Fwc, Urm, Ext, Fac	0.120
DO	Urf	0.354	Urf, Urm	0.390	Urf, Urm, Nur	0.420	Urf, Urm, Nur, Fac	0.442	Urf, Urm, Nur, Fac, Wcp	0.453	Urf, Urm, Nur, Fac, Wcp, Wcf	0.456
BOD	Urf	0.156	Urf, The	0.225	Urf, The, Urm	0.263	Urf, The, Urm, Fac	0.286	Urf, The, Urm, Fac, Wcf	0.303	Urf, The, Urm, Fac, Wcf, Con	0.312
COD	For	0.204	For, Fac	0.241	For, Fac, The	0.260	For, Fac, The, Nur	0.275	For, Fac, The, Nur, Urf	0.284	For, Fac, The, Nur, Urf, Con	0.292
SSC	For	0.232	For, Wcp	0.248	For, Wcp, Gra	0.252	For, Wcp, Gra, Mul	0.257	For, Wcp, Gra, Mul, Wcf	0.259	For, Wcp, Gra, Mul, Wcf, Nur	0.264
Coliform												
TN	Urf	0.199	Urf, Urm	0.318	Urf, Urm, The	0.355	Urf, Urm, The, Fwc	0.379	Urf, Urm, The, Fwc, Con	0.396	Urf, Urm, The, Fwc, Con, Wcf	0.413
TP	Urf	0.096	Urf, The	0.142	Urf, The, Wcf	0.161	Urf, The, Wcf, Urm	0.171	Urf, The, Wcf, Urm, Wcp	0.176	Urf, The, Wcf, Urm, Wcp, Con	0.180

Agricultural land use/cover:

Cul: Cultivated meadow, Dec: Deciduous orchard, Eve: Evergreen orchard, Exb: Exotic broad-leaved plantation, Ext: Exotic tree plantation, Fwc: Field weeds communities, Mul: Mulberry garden, Nur: Nursery garden, Pwc Paddy-field weed communities, The: Thea sinensis garden, Wcf: Weed communities in uncultivated field, Wcp: Weed communities in uncultivated paddy field, Wcr: Weed communities of the roadside

For: Forest, Gra: Grassland, Oth: Others

Urban land use/cover:

Con: Concrete pavement site, Fac: Factory/industrial areas, Lan: Land constructed for residence/factories, Urm: Urban/residential districts with many trees, Urf: Urban district with a few trees

Table 43. Multiple linear regression between water quality and detailed land use/cover in the Ara/Edo River basin

Water Quality	1 Predictor	r^2	2 Predictors	r^2	3 Predictors	r^2	4 Predictors	r^2	5 Predictors	r^2	6 Predictors	r^2
pH	For	0.562	For, Con	0.604	For, Con, Eve	0.627	For, Con, Eve, Exb	0.653	For, Con, Eve, Exb, Pwc	0.660	For, Con, Eve, Exb, Pwc, Oth	0.667
DO	Urf	0.438	Urf, For	0.561	Urf, For, Pwc	0.594	Urf, For, Pwc, Nur	0.631	Urf, For, Pwc, Nur, Mul	0.644	Urf, For, Pwc, Nur, Mul, Eve	0.656
BOD	For	0.109	For, The	0.174	For, The, Oth	0.223	For, The, Oth, Fac	0.242				
COD	For	0.140	For, Fac	0.175	For, Fac, Gra	0.203	For, Fac, Gra, The	0.219				
SSC	For	0.327										
Coliform	Pwc	0.131										
TN	For	0.239	For, Oth	0.333	For, Oth, The	0.399	For, Oth, The, Urm	0.439	For, Oth, The, Urm, Urf	0.468	For, Oth, The, Urm, Urf, Fwc	0.503
TP	Fwc	0.052	Fwc, Urf	0.082	Fwc, Urf, The	0.107	Fwc, Urf, The, Urm	0.124				

Agricultural land use/cover:

Cul: Cultivated meadow, Dec: Deciduous orchard, Eve: Evergreen orchard, Exb: Exotic broad-leaved plantation, Ext: Exotic tree plantation, Fwc: Field weeds communities, Mul: Mulberry garden, Nur: Nursery garden, Pwc Paddy-field weed communities, The: Thea sinensis garden, Wcf: Weed communities in uncultivated field, Wcp: Weed communities in uncultivated paddy field, Wcr: Weed communities of the roadside

For: Forest, Gra: Grassland, Oth: Others

Urban land use/cover:

Con: Concrete pavement site, Fac: Factory/industrial areas, Lan: Land constructed for residence/factories, Urm: Urban/residential districts with many trees, Urf: Urban district with a few trees

Table 44. Multiple linear regression between water quality and detailed land use/cover in the Fuji River basin

Water Quality	1 Predictor	r^2	2 Predictors	r^2	3 Predictors	r^2	4 Predictors	r^2	5 Predictors	r^2	6 Predictors	r^2
pH	Cul	0.188	Cul, Mul	0.277	Cul, Mul, Urm	0.336	Cul, Mul, Urm, Wcp	0.374				
DO	Wcp	0.157	Wcp, Dec	0.218	Wcp, Dec, Mul	0.283	Wcp, Dec, Mul, Pwc	0.320				
BOD	Urf	0.095										
COD	For	0.114	For, Dec	0.162								
SSC	Oth	0.180	Oth, Fac	0.315								
Coliform	Urf	0.211	Urf, Dec	0.287								
TN	Dec	0.538	Dec, Cul	0.687								
TP	Dec	0.643										

Agricultural land use/cover:

Cul: Cultivated meadow, Dec: Deciduous orchard, Eve: Evergreen orchard, Exb: Exotic broad-leaved plantation, Ext: Exotic tree plantation, Fwc: Field weeds communities, Mul: Mulberry garden, Nur: Nursery garden, Pwc Paddy-field weed communities, The: Thea sinensis garden, Wcf: Weed communities in uncultivated field, Wcp: Weed communities in uncultivated paddy field, Wcr: Weed communities of the roadside

For: Forest, Gra: Grassland, Oth: Others

Urban land use/cover:

Con: Concrete pavement site, Fac: Factory/industrial areas, Lan: Land constructed for residence/factories, Urm: Urban/residential districts with many trees, Urf: Urban district with a few trees

Table 45. Multiple linear regression between water quality and detailed land use/cover in the Kuji River basin

Water Quality	1 Predictor	r^2	2 Predictors	r^2	3 Predictors	r^2	4 Predictors	r^2	5 Predictors	r^2	6 Predictors	r^2
pH	Fac	0.225	Fac, Cul	0.336								
DO	Fwc	0.222	Fwc, Dec	0.348								
BOD	Cul	0.217										
COD	Urm	0.387	Urm, Cul	0.641								
SSC	Urf	0.049										
Coliform	Urf	0.001										
TN	Urm	0.177	Urm, Gra	0.431	Urm, Gra, Mul	0.569	Urm, Gra, Mul, Cul	0.710				
TP												

Agricultural land use/cover:

Cul: Cultivated meadow, Dec: Deciduous orchard, Eve: Evergreen orchard, Exb: Exotic broad-leaved plantation, Ext: Exotic tree plantation, Fwc: Field weeds communities, Mul: Mulberry garden, Nur: Nursery garden, Pwc Paddy-field weed communities, The: Thea sinensis garden, Wcf: Weed communities in uncultivated field, Wcp: Weed communities in uncultivated paddy field, Wcr: Weed communities of the roadside

For: Forest, Gra: Grassland, Oth: Others

Urban land use/cover:

Con: Concrete pavement site, Fac: Factory/industrial areas, Lan: Land constructed for residence/factories, Urm: Urban/residential districts with many trees, Urf: Urban district with a few trees

Table 46. Multiple linear regression between water quality and detailed land use/cover in the Naka River basin

Water Quality	1 Predictor	r^2	2 Predictors	r^2	3 Predictors	r^2	4 Predictors	r^2	5 Predictors	r^2	6 Predictors	r^2
pH	Fwc	0.091	Fwc, Pwc	0.155								
DO	Wcp	0.493	Wcp, Eve	0.578	Wcp, Eve, Urm	0.607						
BOD	Wcp	0.540	Wcp, Fwc	0.758	Wcp, Fwc, Oth	0.776						
COD	Fwc	0.478	Fwc, Wcp	0.653	Fwc, Wcp, Dec	0.670	Fwc, Wcp, Dec, Oth	0.691				
SSC	For	0.077										
Coliform	Wcp	0.711	Wcp, Exb	0.726								
TN	Fwc	0.383	Fwc, Exb	0.526	Fwc, Exb, Dec	0.560						
TP	Exb	0.047										

Agricultural land use/cover:
Cul: Cultivated meadow, Dec: Deciduous orchard, Eve: Evergreen orchard, Exb: Exotic broad-leaved plantation, Ext: Exotic tree plantation, Fwc: Field weeds communities, Mul: Mulberry garden, Nur: Nursery garden, Pwc Paddy-field weed communities, The: Thea sinensis garden, Wcf: Weed communities in uncultivated field, Wcp: Weed communities in uncultivated paddy field, Wcr: Weed communities of the roadside
For: Forest, Gra: Grassland, Oth: Others
Urban land use/cover:
Con: Concrete pavement site, Fac: Factory/industrial areas, Lan: Land constructed for residence/factories, Urm: Urban/residential districts with many trees, Urf: Urban district with a few trees

Table 47. Multiple linear regression between water quality and detailed land use/cover in the Sagami River basin

Water Quality	1 Predictor	r^2	2 Predictors	r^2	3 Predictors	r^2	4 Predictors	r^2	5 Predictors	r^2	6 Predictors	r^2
pH	Urf	0.265	Urf, Cul	0.315								
DO	Nur	0.364	Nur, Fwc	0.667								
BOD	Urf	0.618	Urf, Fac	0.733	Urf, Fac, Nur	0.757	Urf, Fac, Nur, Pwc	0.771	Urf, Fac, Nur, Pwc, Oth	0.783		
COD	Urf	0.588	Urf, Fac,	0.674	Urf, Fac, Nur	0.693						
SSC	Urf	0.450	Urf, Cul	0.484								
Coliform	Wcf	0.299										
TN	Fwc	0.632	Fwc, Cul	0.689	Fwc, Cul, Nur	0.706						
TP	Fwc	0.664	Fwc, Nur	0.747								

Agricultural land use/cover:

Cul: Cultivated meadow, Dec: Deciduous orchard, Eve: Evergreen orchard, Exb: Exotic broad-leaved plantation, Ext: Exotic tree plantation, Fwc: Field weeds communities, Mul: Mulberry garden, Nur: Nursery garden, Pwc Paddy-field weed communities, The: Thea sinensis garden, Wcf: Weed communities in uncultivated field, Wcp: Weed communities in uncultivated paddy field, Wcr: Weed communities of the roadside

For: Forest, Gra: Grassland, Oth: Others

Urban land use/cover:

Con: Concrete pavement site, Fac: Factory/industrial areas, Lan: Land constructed for residence/factories, Urm: Urban/residential districts with many trees, Urf: Urban district with a few trees

Table 48. Multiple linear regression between water quality and detailed land use/cover in the Tama River basin

Water Quality	1 Predictor	r^2	2 Predictors	r^2	3 Predictors	r^2	4 Predictors	r^2	5 Predictors	r^2	6 Predictors	r^2
pH	The	0.216	The, Wcf	0.396	The, Wcf, Fwc	0.476						
DO	The	0.536	The, For	0.611								
BOD	Con	0.262	Con, Wcp	0.457	Con, Wcp, The	0.540						
COD	The	0.345	The, Con	0.490	The, Con, Urm	0.533	The, Con, Urm, Nur	0.589				
SSC	The	0.168	The, Pwc	0.465								
Coliform	The	0.122	The, Pwc	0.188								
TN	Urm	0.295	Urm, The	0.434	Urm, The, Wcp	0.533	Urm, The, Wcp, Con	0.588	Urm, The, Wcp, Con, Pwc	0.619		
TP	The	0.441	The, Pwc	0.693	The, Pwc, Nur	0.715	The, Pwc, Nur, For	0.738				

Agricultural land use/cover:

Cul: Cultivated meadow, Dec: Deciduous orchard, Eve: Evergreen orchard, Exb: Exotic broad-leaved plantation, Ext: Exotic tree plantation, Fwc: Field weeds communities, Mul: Mulberry garden, Nur: Nursery garden, Pwc Paddy-field weed communities, The: Thea sinensis garden, Wcf: Weed communities in uncultivated field, Wcp: Weed communities in uncultivated paddy field, Wcr: Weed communities of the roadside

For: Forest, Gra: Grassland, Oth: Others

Urban land use/cover:

Con: Concrete pavement site, Fac: Factory/industrial areas, Lan: Land constructed for residence/factories, Urm: Urban/residential districts with many trees, Urf: Urban district with a few trees

Table 49. Multiple linear regression between water quality and detailed land use/cover in the Tone River basin

Water Quality	1 Predictor	r^2	2 Predictors	r^2	3 Predictors	r^2	4 Predictors	r^2	5 Predictors	r^2	6 Predictors	r^2
pH	Oth	0.067	Oth, Wcf	0.122	Oth, Wcf, Exb	0.148	Oth, Wcf, Exb, Fwc	0.169	Oth, Wcf, Exb, Fwc, Fac	0.191	Oth, Wcf, Exb, Fwc, Fac, Ext	0.208
DO	For	0.055	For, Fac	0.077	For, Fac, Oth	0.093	For, Fac, Oth, Lan	0.104	For, Fac, Oth, Lan, Wcf	0.112	For, Fac, Oth, Lan, Wcf, Urm	0.120
BOD	Urf	0.100	Urf, Urm	0.152	Urf, Urm, Wcf	0.176	Urf, Urm, Wcf, Cul	0.193	Urf, Urm, Wcf, Cul, Dec	0.202	Urf, Urm, Wcf, Cul, Dec, Lan	0.206
COD	For	0.219	For, Pwc	0.251	For, Pwc, Wcf	0.275	For, Pwc, Wcf, Oth	0.284	For, Pwc, Wcf, Oth, Urf	0.288		
SSC	For	0.160	For, Oth	0.193	For, Oth, Pwc	0.209	For, Oth, Pwc, Con	0.225	For, Oth, Pwc, Con, Wcf	0.234	For, Oth, Pwc, Con, Wcf, Mul	0.244
Coliform												
TN	Wcf	0.167	Wcf, Urm	0.261	Wcf, Urm, Oth	0.314	Wcf, Urm, Oth, Fwc	0.346	Wcf, Urm, Oth, Fwc, Mul	0.375	Wcf, Urm, Oth, Fwc, Mul, Urf	0.396
TP	Urf	0.060	Urf, Oth	0.067	Urf, Oth, Fac	0.073						

Agricultural land use/cover:

Cul: Cultivated meadow, Dec: Deciduous orchard, Eve: Evergreen orchard, Exb: Exotic broad-leaved plantation, Ext: Exotic tree plantation, Fwc: Field weeds communities, Mul: Mulberry garden, Nur: Nursery garden, Pwc Paddy-field weed communities, The: Thea sinensis garden, Wcf: Weed communities in uncultivated field, Wcp: Weed communities in uncultivated paddy field, Wcr: Weed communities of the roadside

For: Forest, Gra: Grassland, Oth: Others

Urban land use/cover:

Con: Concrete pavement site, Fac: Factory/industrial areas, Lan: Land constructed for residence/factories, Urm: Urban/residential districts with many trees, Urf: Urban district with a few trees

4.6. Case studies at a monitoring site level

In the studied river basins, the changes in land use/cover during the studied periods were generally limited. Therefore, it is generally unrealistic to ascribe temporal changes in water quality to changes in land use/cover. However, observations on data for each monitoring site and its upstream area indicate that land use/cover changes were relatively large in some areas, which may have contributed to water quality changes. The following two typical examples show the relatively clear contribution of land use/cover changes to water quality changes.

4.6.1. Monitoring site 1110830 in the Ara/Edo River basin

Monitoring site 1110830 is one of the 85 monitoring sites in the Ara/Edo River basin. The site is located near Kurihashi City in Saitama Prefecture. Although it is near the Tone River, its 13.82 km^2 drainage basin falls under the Ara/Edo River basin (Figure 30). In relation with the City Planning Law, 83% of the drainage basin was UCA, and the rest (17%) was UPA in 2006. The changes in the composition of land use/cover in the drainage basin are presented in Table 50. The paddy field weed communities decreased by 3.92% between the fourth and fifth periods, which were converted into the land constructed for residence/factories (3.86%) and the urban district with a few trees (0.05%).

These land use changes corresponded to changes in water quality at the site 1110830 (Figure 31). Prior to the land use/cover changes, DO fluctuated around 8.0 mg/l. However, after the land use/cover changes, DO decreased to 5 mg/l in 2005. COD was relatively low prior to the land use/cover changes, but increased significantly after the changes. A similar correlation can be observed for SSC, where it had increased significantly since the fifth period. Nutrient concentrations (TN and TP) also show a slight increase since the fifth period.

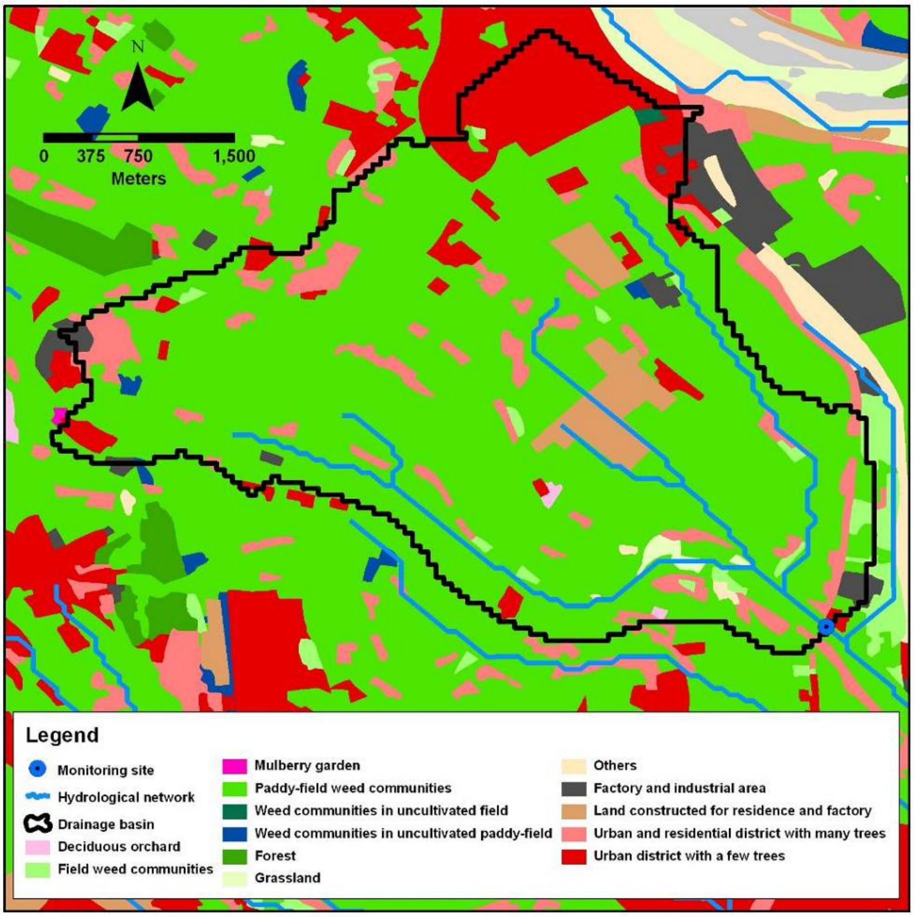


Figure 30. Drainage basin of monitoring site 1110830

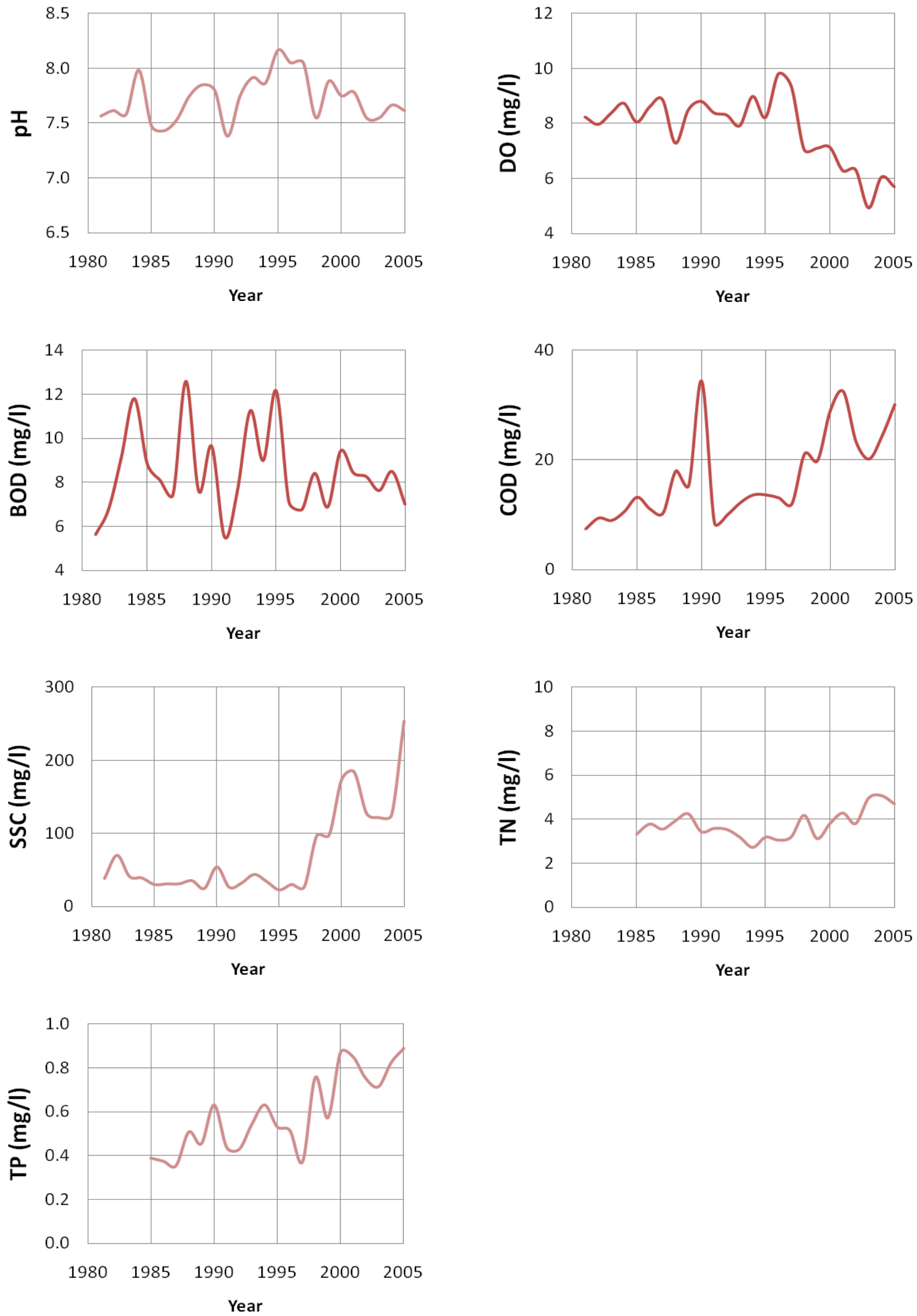


Figure 31. Water quality trend at monitoring site 1110830

Table 50. Detail land use/cover changes in the watershed of monitoring site 1110830

Land use/cover	Third period	Fourth period	Fifth period
Deciduous orchard	0.16	0.16	0.16
Field weeds communities	1.25	1.25	1.25
Paddy-field weed communities	79.73	79.73	75.81
Weed communities in uncultivated field	0.14	0.14	0.14
Weed communities in uncultivated paddy field	0.25	0.25	0.25
Grassland	0.47	0.47	0.47
Others	0.19	0.19	0.19
Factory/industrial areas	1.09	1.09	1.09
Land constructed for residence/factories	0.00	0.00	3.86
Urban/residential districts with many trees	7.63	7.63	7.63
Urban district with a few trees	9.07	9.07	9.12
Figure in percentage from total area of 13.82 km^2			

4.6.2. Monitoring site 811810 in the Tone River basin

The monitoring site 811810 is one of the 245 monitoring sites in the Tone River basin. It is located near Miho Village in the southwest of Lake Kasumigaura (Figure 32). The 4.86 km^2 drainage basin of this monitoring site consists of 91.5% UCA and 8.5% UPA in 2006. The drainage basin experienced various land use/cover changes as presented in Table 51. The field weeds communities, paddy field weed communities, and forest decreased with time. On the other hand, the cultivated meadows, the factory/industrial areas, the land constructed for residence/factories and the urban/residential districts with many trees increased throughout the periods.

In this monitoring site, water quality fluctuated throughout the years (Figure 33). However, notable fluctuations are observed for BOD, COD, SSC, and TN prior to the fifth period. While various land use/cover changes occurred prior to the fifth period, a notable one was a conversion into the land constructed for residence/factories, which accounted for 10.92% of the total drainage basin. The conversion was likely responsible for the increase of BOD into 8 mg/l, COD into 8 mg/l, SSC into 34 mg/l, and TN into 6 mg/l in 1995. However, in comparison to the first case study, the effects of the land use conversion on water quality were lower, especially on COD and SSC.

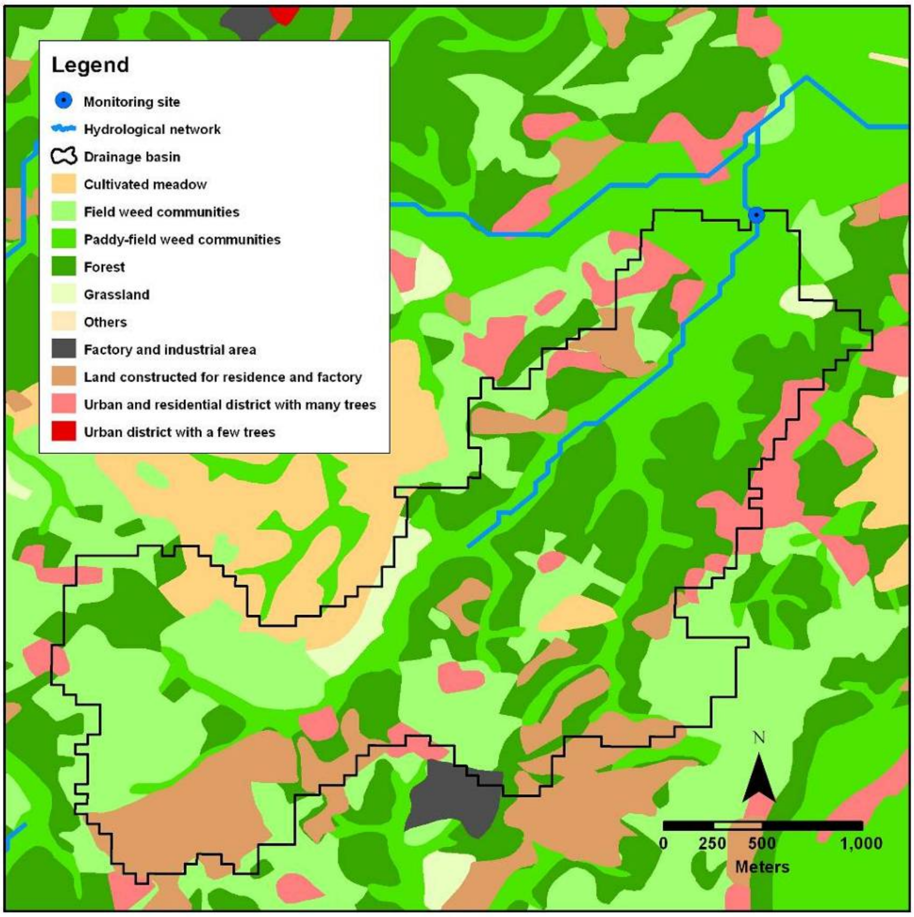


Figure 32. Drainage basin of monitoring site 811810

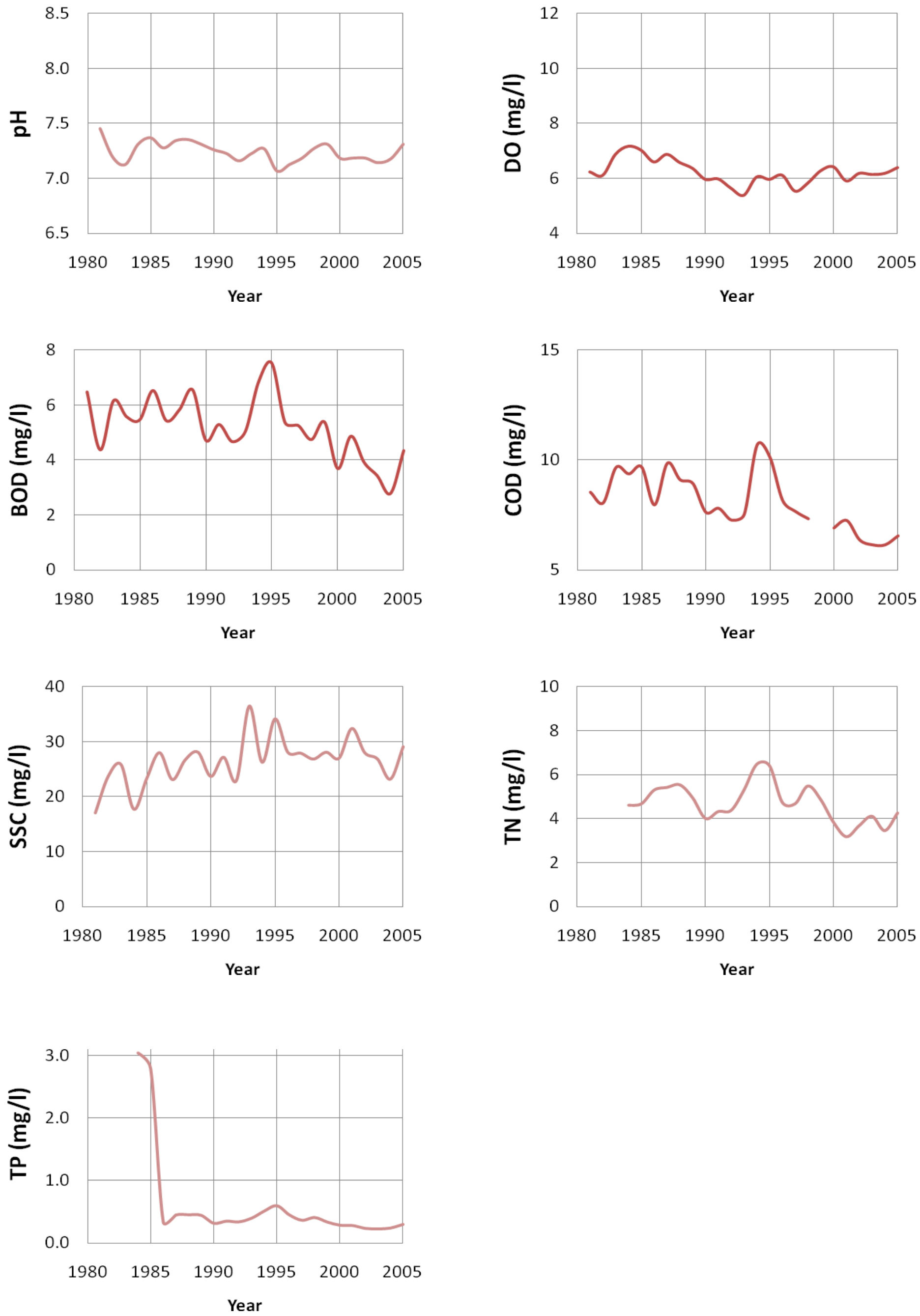


Figure 33. Water quality trend at monitoring site 811810

Table 51. Detail land use/cover changes in the watershed of monitoring site 811810

Land use/cover	Third period	Fourth period	Fifth period
Cultivated meadow	2.79	3.59	3.59
Field weeds communities	29.31	28.71	25.22
Paddy-field weed communities	22.31	22.04	21.11
Forest	36.58	35.19	28.75
Grassland	2.20	2.20	2.20
Factory/industrial areas	0.00	0.20	0.20
Land constructed for residence/factories	2.13	2.76	13.68
Urban/residential districts with many trees	4.67	5.30	5.24
Figure in percentage from total area of 4.86 km^2			

Chapter 5 Discussion

5.1. Land use/cover changes

Section 4.1 describes the trend in land use/cover changes in the Kanto region. These results provide several points to be discussed. The number of changes was somewhat lower in the latter periods. However, the larger average size of changes in the latter periods made the overall areas of changes similar to the earlier periods (Table 3). In terms of spatial distribution, Figures 15 and 16 show that changes were more dispersed in the latter periods. The situation likely relates to the rapid trend of motorization in the 1990s that enabled people to commute from rural areas in the surroundings of major cities, even if the distance of commute is long (Himiyama, 1998). The different development thresholds applied by the government may also contribute to the dispersed changes in the latter periods. According to the City Planning Law, development less than 1,000 m^2 in UPA has been exempted from the requirement to obtain development permission, while the threshold is 3,000 m^2 in the areas not classified into UPA/UCA (Sorensen, 1999, 2000). Thus, it may encourage developers to build more houses in the areas not classified into UPA/UCA, especially with the increased demand from the commuters.

Additionally, although vacant land was still available in the latter periods, the higher land price in urbanized areas during and soon after the Bubble Economy may have forced development to take place either in the fringe of urban areas or in the forested hillslopes in the upper reaches, where land prices were lower (Abe, 1996; Mori, 1998). A study by Iwata & Oguchi (2009) in Kamakura City shows similar development problems. In general, topographical factors and nature conservation activities limited the rapid development in the forested hillslopes in the upper reaches. However, it is clear that in the latter periods these areas were subject to land use/cover changes.

The results related to general land use/cover changes in the Kanto region as presented in Tables 4 and 5 show that the region was characterized by rapid urbanization and deforestation, as well as modest agricultural expansion. Like many other parts of Japan, rapid urbanization in the Kanto region is attributed to fast economic growth and improvement in the transportation network (Himiyama, 1998). Rapid population growth in the Kanto region particularly increased urban development in the rural-urban fringes, to fulfill a high demand of residential areas because of high land prices in city centers and requirement for higher housing standards (Abe, 1996; Himiyama, 1998; Mori, 1998). As a consequence, many rural areas especially forested and agricultural areas were urbanized. Despite the conversion of agricultural areas into urban areas, their extent remained similar due to the expansion of agricultural areas into forest.

Figure 34 illustrates the most dominant patterns of the general land use/cover changes in the Kanto region, based on Tables 4 and 5. Relatively broad forest and agricultural areas were converted into urban areas. At the same time, forest was also often converted into agricultural areas. It is clear that forest was the main source of other land use/covers. It is likely that its percentage will continue to decrease in the future as current development and conversion are observed in the forested upper reaches. Grassland and others, despite their small numbers of changes, are regarded as transitional land use/covers before being converted into various land use/covers as shown in Figure 34.

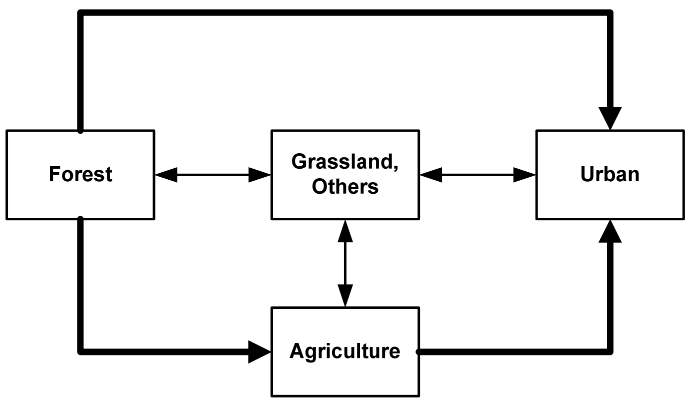


Figure 34. Trend in general land use/cover changes in the studied river basins

The results of the analysis of the detailed land use/cover changes show that urbanization generally comes in the form of the land constructed for residence/factories, and the urban districts with a few trees (Tables 8 and 9). As discussed earlier, these changes likely correspond to population growth and a high demand of residential areas with high housing standard (Abe, 1996; Himiyama, 1998; Karan, 2005). The two tables also show that the percentages of land constructed for residence/factories increased with time. While this indicates ongoing development in the Kanto region, it also implies that the amount of actual development was smaller than that of the land constructed for development (Hebbert, 1994). Although deforestation itself gives impacts on the environment, the undeveloped land constructed for residence/factories could further affect the environment, including possible effects on surface water quality.

Further, on the detailed land use/cover changes, Tables 8 and 9 show that the field weeds communities and the paddy field weed communities are the two main agricultural land use/covers that were converted into urban areas. Conversion of the less managed field weeds communities to urban areas might be beneficial for the reduction of environmental problems caused by weeds such as loss of desirable species through long-term competitive exclusion/succession and interference with commercial activities (Cousens & Mortimer, 1995). On the other hand, the conversion of the paddy field weed communities should be minimized. Land suitable for agricultural activities, especially the paddy field weed communities is limited in the Kanto region. Therefore, by preserving them, agricultural expansion in forested areas, as seen in Tables 4 and 5, can be minimized. Additionally, in the last 50 years, Japan has seen a reduction in its food self-sufficiency (Sato, 2001). Therefore, it is important to maintain and efficiently use the limited amount of agricultural land not only to reduce the conversion of forest into the agricultural area, but also to improve food self-sufficiency. Close relationships between paddy fields and socio-culture of Japanese people also mean that preservation of the areas to some extent will maintain the vitality of rural societies (Karan, 2005; Sato, 2001).

In relation to the City Planning Act, land use/cover changes in the Kanto region are characterized by higher percentages of urbanization in UCA. Tables 6 and 7 show that higher percentages of forest and agricultural areas were converted outside UPA. This conversion occurred despite the availability of space for urbanization within UPA. As noted above, this can be explained from the development of transportation systems and lower land prices in the suburbs. Loopholes in the City Planning Law such as the exemption from the requirement to obtain development permission for urban development less than 1,000 m^2 further fostered urbanization in the agricultural area (Sorensen, 1999). Another loophole that contributed to the urbanization is the rights given to farmers to develop additional residential areas for family members, but in reality these areas were sold to general housing market (Millward, 2006). Furthermore, in 1984 a revision of the Arrangements of Regional Agricultural Promotional Law enabled more urban development to be established in the area where UCA is overlapped with APA (agricultural promotion area) (Alden & Abe, 1994).

While conversion into the less managed grassland is not a main land use/cover change in the Kanto region, Tables 6 and 7 show that small percentages of forest and agricultural areas in UPA were converted into grassland. Factors such as high price of land in UPA and low land taxes including inheritance taxes encourages landowners in UPA to maintain their land for future development, even though it also means no profitable activities carried out on the land (Sorensen, 2001). This behavior and the higher percentages of urbanization outside UPA indicate that the existing land use control in Japan has not been effective.

5.2 Water quality trend and spatial distribution

On the water quality trends, Figure 19 shows the ongoing improvement in water quality of most river basins in the Kanto region, especially in the urbanized river basins such as the Ara/Edo and Tama River basins. This improvement relates to the enforcement of the Environmental Pollution Prevention Act since the 1970s (Yoshimura et al., 2005). Combination of several pollution controls such as stringent effluent control, construction of public sewage systems in populated areas, and improvement of wastewater treatment technology contributed to these improvements. According to Japan Sewage Works Association (2002), all WWTPs (Waste Water Treatment Plants) in Japan have adopted a secondary treatment, and the coverage of population served by the public sewage system that collects and treats wastewater from the household increased from 30% in 1980 to 63.5% in 2001.

Figure 19 also shows that the trend of nutrient concentration in the Fuji, Kuji, and Naka River basins indicates the deterioration of water quality. Among the three river basins, deterioration in the Fuji River basin is the most notable. According to Shrestha & Kazama (2007), the deterioration in the Fuji River basin is likely related to agricultural and orchard plantations. Tables 21 and 35 support this inference. In Table 35, agricultural land use/covers positively correlate with nutrient concentration (TN and TP), with the highest correlation coefficient for the deciduous orchard. However, changes in the nutrient concentration around 1995 in the Fuji River basin are likely due to the conversion of various land use/covers into the cultivated meadow as shown in Table 21.

Based on the water quality state in the earlier years and trend on the improvement of water quality, river basins in the Kanto region are classified into three groups. The first group includes the Kuji and Naka River basins. Figure 19 shows that the initial water quality state of these river basins is better in comparison to the other river basins. Large percentages of forest contributed to this. The second group consists of the Fuji, Sagami, and Tone River basins. The initial state of water quality in these river basins was generally lower than that of the first group, and modest improvements of water quality are observed in these river basins. The third group consists of the Tama and Ara/Edo River basins. They are characterized by the low initial water quality state that underwent a subsequent remarkable improvement with time.

The percentages of forest, urban, and agricultural areas are considered as the main factors explaining the differences in initial water quality among the river basins of the Kanto region. However, the dominance of a certain land use/cover is not necessarily reflected in water quality. For example, although the percentage of forest in the Sagami River basin is higher than that in the Naka River basin, the initial water quality in the former is lower than the initial water quality in the latter. The combination of more than one land use/covers seems to play a higher role in determining the initial state of water quality. On the other hand, the improvement of water quality is likely affected by the percentages of urban areas, for example in the Ara/Edo and Tama River basins. A higher coverage of public sewage systems in urbanized areas accounted for this improvement.

The spatial distribution of water quality in the Kanto region presented in Figures 20 to 27 provides additional information on regional water quality. Monitoring sites with better water quality are usually located in the upper reaches, where forest is largely dominated. On the other hand, monitoring sites with lower water quality are distributed within the urban and agricultural areas. However, the effects of other land use/covers should also be considered. Indeed, the figures show that better water quality is sometimes found in the lower reaches where urban and agricultural areas dominate. While water quality improvement in urban areas might reflect the availability of public sewage systems and better wastewater treatment technology, the improvement in urban areas may not be as clear as in agricultural areas. This indicates that engineering control of water quality does not surpass the positive effect of the semi-natural environment in agricultural areas.

Accumulation of pollutant substances from the upper reaches may also obscure the improvement of water quality in the urban areas. Figure 35 illustrates this situation. In general, urban areas are located in the lower reaches of the river basins, receiving water from the upper reaches dominated by forest and agriculture. Despite most of the monitoring sites in the upper reaches shows improvement in water quality, some of them remained in poor quality (Figures 20 to 27). Pollutants from urbanization and agricultural activities in the upper reaches are accumulated and then transported to the lower reaches. Thus, it may affect the overall water quality in the lower reaches.

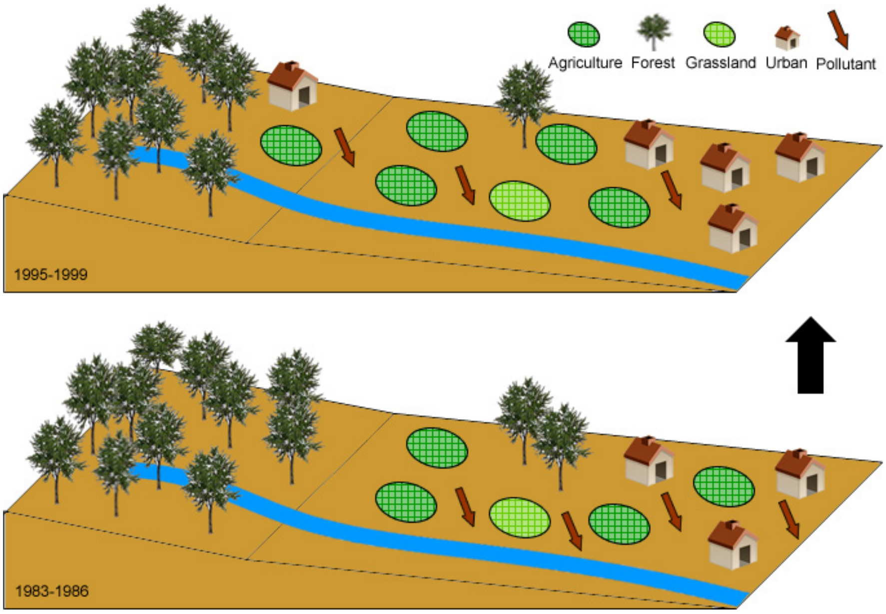


Figure 35. Relations between water quality in the upper and lower reaches for different periods

5.3 Correlation analysis and predictors of water quality

Correlation and predictor analyses show that land use/covers in the river basins in the Kanto region are related to surface water quality. Several implications of the results are discussed below.

5.3.1. Urban land use/cover

The results of the correlation analysis for urban areas show that their high proportions could degrade water quality, despite some indications of improved water quality in the urban and agricultural areas. The results of correlations for the detailed land use/covers could provide information on the possible mechanism of urban land use/cover effects on water quality as follows.

The percentage of the factories and industrial areas correlate with pH and TN (Table 33). Dissolved carbonate in the industrial effluent, as well as higher effluent's temperature could increase the hydrogen ion activities and thus reduces pH of the surface water (Hem, 1985; Jain & Singh, 2003). Industrial effluent that contains a high concentration of organic matter could cause an anaerobic condition in the rivers. This will produce ammonia and organic acids that reduce pH (Shrestha & Kazama, 2007). Apart from ammonia produced in an anaerobic condition, urban areas contribute to increase in TN through the discharge of wastewater. Although atmospheric deposition from vehicles and industrial activities also contribute to increase in nitrogen in surface water, its contribution is generally very low as compared to discharged wastewater (Markich & Browna, 1998).

The proportion of the urban district with a few trees correlates with DO, coliform concentration, and TP (Table 33). The urban land use/covers that signify higher population density are generally served by sewage systems and WWTPs. Therefore, water pollution in urban areas is generally suppressed into a low level. However, in comparison to natural water, effluent of WWTPs is generally more polluted. According to Jain & Singh (2003), a typical concentration of phosphorus in surface water is around 0.05 mg/l, but that in treated wastewater effluent is around 1.4 mg/l. This significant difference may contribute to the correlations of the proportion of the urban district with few trees with DO, coliform concentration, and TP.

The proportion of the urban/residential district with many trees correlates with BOD, COD, and SSC (Table 33). Significant differences of this land use/cover from the urban district with a few trees lie in their locations and available infrastructures. Generally, the urban/residential district with many trees is located in rural areas and not within the coverage of the major sewage system. Instead, detached or individual wastewater treatment called "johkaso" is served as a household WWTP. Even if a sewage system is present, it is likely that its efficiency is lower than that of a WWTP in the urban district with a few trees, because of different technologies used. Additionally, small-scale agricultural activities such as vegetable gardens for self-consumption generally occur in the urban/residential district with many trees. These contribute to the higher BOD, COD, and SSC.

However, the obtained results also indicate differences among river basins (Tables 34 to 40). For examples, the higher pH correlations are found with the proportion of the urban district with a few trees in the Ara/Edo River basin, that of the urban/residential district with many trees in the Fuji, and that of the concrete pavement sites in the Tama. These differences may reflect differences in the composition and distribution of the urban land use/covers. The result also shows that not all urban land use/covers have a potential to degrade water quality. In several river basins the land constructed for residence/factories has a potential to improve DO (Ara/Edo and Kuji), reduce BOD, COD, SS, TN, and TP (Ara/Edo), and reduce coliform concentration (Fuji). The previous land use/cover of the land constructed for residence/factories may provide a possible explanation. For example, in the Ara/ Edo River basin, part of the land constructed for residence/factories was originally the urban district with a few trees, where degradation of water quality is often observed.

5.3.2. Agricultural land use/cover

The correlation of the weed communities (weed communities of the roadside, those in uncultivated paddy fields, and field weeds communities) and water quality is higher than that of the other agricultural land use/covers. This indicates that the unmanaged weed communities hold a significant position in determining water quality in the studied river basins. The conversion of the weed communities might be beneficial for the reduction of the environmental problem caused by this land use/cover. For example, resuming agriculture on the unmanaged weed communities can improve water quality (Feng et al., 2004). According to Anbumozhi et al. (2005), paddy fields possess a capability on nutrient retention. Therefore, its presence significantly reduces the nutrient loading to surface water. Additionally, in comparison to other agricultural land use/covers, the paddy field has less significant correlations, indicating that it contributes less to water pollution. However, it should be noted that the proportion of the paddy field weeds communities has a higher correlation with SSC. Therefore, resuming agricultural activities, especially paddy cultivation could lead to increase in SSC.

The correlation analysis also identifies several other agricultural land use/covers that have a potential to improve water quality: e.g., cultivate meadow (DO), mulberry garden (DO, BOD), exotic broad-leaved plantation (COD), evergreen orchard (Coliform), and exotic tree plantation (Coliform, TN, and TP). A possible explanation for this is that these land use/covers are dominated by woody vegetation, which provides better surface cover and may reduce the eroding effect of rainfall and potentially runoff. This in the end will reduce the amount of sediment, and sediment borne pollutant entering surface water (Lowrance et al., 1997).

Like the case of the urban land use/covers, the correlation analysis for individual river basins has revealed different information from that at the Kanto region scale. In general, agricultural land use/covers have significant correlations with water quality. In the Ara/Edo and Kuji River basins, the cultivated meadow has a potential to improve DO. Furthermore, in the Ara/Edo River basin, the mulberry garden potentially affects DO, BOD, COD, SSC, TN, and TP, while the *Thea sinensis* garden also potentially affects DO, COD, and SSC. The fact that these land use/covers are dominated by woody vegetation, as well as the effects of the land use/covers prior to the conversion, may contribute to these unusual correlations.

5.3.3. Change in land use/cover and case studies at particular sites

The exploratory analysis shows no valuable correlation between land use/cover changes and water quality changes. There are several reasons for this. First, changes in land use/covers are generally very small. The average size of the changes are less than 0.02 km^2, and total areas of the changes only account for 1.4% of the total area of the studied river basins. Second, water quality changes have generally been very subtle. For example, average change in DO is only around 0.48 mg/l. The small changes in both land use/cover and water quality results in the low correlation.

Nonetheless, in some of the monitoring sites, especially those with small drainage basins, changes in land use/covers are accompanied by changes in one or more water quality parameters as shown in the two case studies. The first case study (Monitoring site 1110830) provides an example where changes in single land use/cover affect water quality, while the second case study (Monitoring site 811810) provides an example where changes in multiple land use/cover affect it. While the major land use/cover change is similar, i.e. conversion into the land constructed for residence/factories, the level of response in water quality is different. In the latter case, changes in multiple land use/covers seem to obscure the impacts of change in one type of land use/cover to water quality. This reiterates the previous indication that while an individual land use/cover might affect water quality, the combination of more than one land use/covers seems to play a more important role.

5.3.4. Predictors

The result of multiple regression presented in Tables 41 to 49 shows that as a single predictor, the urban district with a few trees and forest, could accounts for larger variations in water quality in the Kanto region. Again, this indicates that anthropogenic activities largely determine water quality in the Kanto region, despite the presences of sewage system and WWTPs in the urban district with a few trees. Relatively low quality water discharged by WWTPs and runoff carrying pollutants from roofs, pavements, streets, etc. in the urban district with a few trees are responsible for this situation.

On the other hand, higher r^2 values for correlations of forest with COD and SSC indicate the importance of forest in regulating water, protecting land surface from erosion and the transport of pollutant. Some agricultural land use/covers, especially the field weed communities, the weed communities in uncultivated field, and the weed communities in uncultivated paddy fields, account for fewer variations in water quality. However, these land use/covers are still considered important in predicting water quality in the studied river basins. Especially the paddy field weeds communities underwent rapid conversion into urban areas. Furthermore, as Feng et al. (2004) indicate, the paddy field weed communities produce less pollutants compared to the other agricultural land use/covers. Therefore, their conversion into urban areas increases the possibility of water quality degradation.

No predictor is found for coliform concentration in the studied river basins, indicating that it is affected by a factor other than land use/covers. Additionally, the method used to analyze coliform in Japan might also explain this situation. According to Okada & Peterson (2000), Japan still uses the total coliform method instead of the fecal coliform method. Therefore, its value may not clearly reflect the actual fecal coliform due to human activities. Additionally, Kuhn et al. (1997) state that the concentration of coliform may not solely originate from fecal contamination, but also come from other sources such as soil, decaying vegetation, or industrial processes.

Similar to the correlation analysis, altering the spatial scale of the multiple regression has also revealed different predictor(s) for water quality in each river basin. This confirms the uniqueness of relationships between land use/covers and water quality for each spatial scale. Therefore, development planning should consider the use of multiple spatial scale approaches to minimize the potential impact of the development on surface water quality.

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Chapter 6 Conclusion

This paper has discussed the distribution and changes of land use/covers in the Kanto region, Japan, and their impacts on surface water quality in the drainage basins of eight major rivers. Although literature review shows that in many river basins water quality is affected by land use/covers, there have been disputes on the contradicting findings in one river basin to another. This research has also observed such unique relationships between land use/covers and water quality, whereas some insights common to most river basins have been obtained. The following general conclusions have been reached:

1) The trend of land use/cover change in the Kanto region indicates more conversion of forested areas in the upper reaches into urban and agricultural areas. It is also observed that the urbanization rate is higher outside UPA. This indicates the potential water quality problems due to the loss of forest that regulates water, and urbanization outside UPA not followed by the development of sewage systems.

2) Ongoing improvement of water quality is observed in most river basins. This trend will likely to continue thanks to more water pollution control, especially the expansion of sewage systems in urbanized areas. However, despite the general improvement, degradation in nutrient concentrations has been occurring in the Fuji, Kuji, and Naka River basins, and other types of water quality degradation due to human activities still can be observed in several monitoring sites, especially those with small upstream areas.

3) Correlation analysis has revealed that at the Kanto region level, water quality is mostly affected by the percentages of the factory/industrial area, the urban district with a few trees, and the urban/residential district with many trees. Additionally, despite lower correlations, the weed communities (weed communities of the roadside, those in uncultivated paddy fields, and paddy field weeds communities) affect water quality. Several agricultural land use/covers have a potential in improving water quality due to their similarity to woody vegetation; for example mulberry gardens, exotic broad-leaved plantation, evergreen

orchards, and exotic tree plantation. At each river basin, although the ratios of urban and agricultural areas generally remain correlated with water quality, there are significant differences in the level of correlation from one river basin to another, indicating unique relationships between land use/covers and water quality at the river basin level.

4) Multiple regression analysis at the Kanto region level has revealed that the ratio of urban areas, especially the urban district with a few trees, provides a better prediction for water quality in comparison to the other land use/covers. This implies that water quality in the Kanto region is largely affected by anthropogenic activities. On the other hand, forest is found to be essential to maintain better water quality in the Kanto region. For each river basin, the multiple regression has revealed more predictors of water quality, confirming specific relationships between land use/covers and water quality for different river basins. This may reflect details of the spatial distribution of land use/covers in each river basin.

5) Analyses of r^2 values either at the Kanto region level or at the individual river basin indicate that while an individual land use/cover may strongly affect water quality, the combination of some land use/covers seems to play a more important role in determining water quality.

To conclude, because of the unique relationships between land use/cover and water quality at different spatial scales, future plannings of sustainable development should consider the use of multiple spatial scale approaches to minimize the potential impact of development on surface water quality.

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