Temporal Analysis of Water Quality of the Kaname River Basin Using GIS

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Abstract
The authors analyzed the water quality of five rivers in the Kaname River basin and correlated it with the sewerage system and land use. The development of a sewerage system and reduction in agricultural land were found to affect water quality. The water quality of all river basins improved with time, and the improvement was seen as a gradual reduction in the pollution loads from the unsewered population and agricultural land. Temporal variations in the water quality of each river could be used to characterize them in terms of the expansion of the sewerage system and decrease in agricultural land use. Multiple regression analysis revealed that, in most cases, the unsewered population had a greater impact on water quality; nevertheless, the change in agricultural land use also had some influence. Unlike total nitrogen (TN), chemical oxygen demand and total phosphorus exhibited good correlations with the pollution loads from the unsewered population and agricultural land. Atmospheric nitrogen (N) was presumed to impact the TN concentration in rivers. To maintain the water quality in the Kaname River basin, the development of a sewerage system could be a crucial factor; however, the contamination due to atmospheric N also needs to be considered.

Keywords: water quality; unsewered population; agricultural land; atmospheric nitrogen; GIS

1. Introduction
Water is one of the most abundant elements found on Earth and forms an essential component of the ecosystem (Millennium Ecosystem Assessment, 2005). However, because of modernization, there is an increasing and concurrent prevalence of water environment problems. In Japan, remarkable improvements in water quality have been observed over recent years because of the strict regulations imposed on industrial wastewater and the development of a sewerage system. However, nonpoint sources such as households and agricultural lands still produce large pollution loads (Ministry of Environment homepage; UNESCO, 2003). Furthermore, the extent of the sewerage system is still inadequate in small and medium cities (Kohata and Mizuochi, 2007; Overseas Environmental Cooperation Center, 1998).

Hadano City, where the Kaname River basin lies, is known for its abundant water resources (Hadano City, 2003). However, it had a water quality degradation problem in the past, and the problem continues to persist with just a slight difference in the degree of pollution. Hadano City contains various types of land, varying from urban to rural. This city has expanded on account of newly developed areas; however, the sewerage system has been developed at a pace slower than that of urbanization. The present study on the temporal analysis of river water quality and its relationship with nonpoint pollution sources, that has not been conducted yet in the Kaname River basin; can be used to effectively and practically implement proper water quality management of not only this basin but also other watersheds with similar characteristics. Hence, as a research area in this study, the Kaname River basin in Hadano City is significant and has socio-economic value regarding water quality management.

With the start of the sewerage system in 1978 and its subsequent development, the river water quality in the Kaname River basin improved with time. Nevertheless, improvements have not yet been observed in the areas where its installation is still in progress. The discharge of agricultural and urban runoffs also impacted the river water quality in this basin (Fujino et al., 1997). Further, it was reported that the deposition of atmospheric nitrogen (N) had been increasing gradually in forested watersheds such as the
Tanzawa Mountains in Hadano City (Fujimaki et al., 2008). Therefore, nonpoint pollution sources such as areas without a sewerage system, land use change, as well as the atmospheric N deposition loads could be considered as determining factors concerning the water quality in this basin.

Understanding the dependence of water quality on the development of a sewerage system and change in land use is necessary for proper water quality management. Hence, the present study was undertaken to temporally analyze the water quality in the Kaname River basin and clarify the relative impacts of the sewerage system dispersion and land use changes on the river water quality. Studies conducted until now have been limited to only some rivers of the Kaname River basin, and the relationship of the water quality with the sewerage system and land use has not been clarified for this basin until now. Therefore, in this study, the authors have used a holistic approach to understand the pollution scenario of the entire basin by performing a water quality analysis for all the rivers in the basin. The consideration of atmospheric N deposition loads, as one of the factors impacting water quality is unique to this study.

2. Methods
2.1 Study area and rivers
The Kaname River basin is located in Hadano City, which is situated in the western region of Kanagawa Prefecture and has an area of 103.61 km$^2$. In this city, the Tanzawa Mountains are situated in the north and the Shibusawa Hill is in the south. The authors studied five rivers that flow into the Kaname River basin the Muro, Mizunashi, Kuzuha, Kaname, and Ohne. The Mizunashi flows in the central region and to the east of this river are the Kuzuha and Kaname rivers, forming an alluvial fan in the plains. The Muro flows along the Shibusawa faults in the south and the Ohne flows in the southeastern portion of the basin (Fig.1.). With the exception of Ohne River, all the remaining rivers merge toward the southern end of the basin and then flow as the Kaname River.

2.2 Delineation of drainage basins
The drainage basin of each river, based on their water quality monitoring stations (Table 1.), was delineated (Fig.2.) with the help of the Spatial Analyst tool of ArcGIS; using a digital elevation model (Kawasaki, 2006; Maidment, 2002). Subsequently, the prepared data were modified on the basis of the detailed rainwater drainage area map of Hadano City.

2.3 Data collection and preparation
Water quality data for the years from 1972 to 2007 were collected from annual water quality survey reports for Kanagawa Prefecture and Hadano city. Sewerage system data such as sewered area and the corresponding year of installation were acquired from Hadano city in the form of paper based data and maps.

These data were prepared digitally in ArcGIS (Fig.3.a). Land use data from 1974 to 1994 in sets of five-year intervals were obtained from the Detailed Digital Information of Japan Map Center and those of 2000 and 2005 were obtained from Kanagawa Prefecture's city planning survey data. The land use data for each river basin was extracted using the GIS and the area for each type of land use was computed (Fig.3.b). The available data were interpolated to obtain the data for each year. Population data were obtained from national census data and the data for each river basin were computed in the GIS (Fig.3.c).

The unsewered population data were calculated in the GIS by overlaying layers of prepared sewered
areas, the residential building data obtained from the land use data and the population data for each basin. First, the buildings that were not connected to the sewerage system were identified on the basis of the data of sewered areas and buildings (Fig. 4.). Next, the unsewered population data was determined using unsewered buildings and population data.

2.4 Unit loads of pollution
To calculate the pollution loads from the unsewered population and agricultural land, unit loads (Table 2.) reported by the Ministry of Construction in Japan were considered (Ministry of Construction, 1999). In the case of agricultural land, the pollution loads from paddy fields and cultivation land were added.

2.5 Atmospheric nitrogen deposition load
The atmospheric N simulation conducted by the National Institute of Advanced Industrial Science and Technology under collaborative research was considered in this study (Kondo, 2008). Active nitrogen compounds impacting the water system and ecosystem that have been emitting into the atmosphere as a result of anthropogenic activities are mainly ammonia and nitrogen oxides. These compounds, diffused from their respective sources, are carried by the wind, and are again deposited to the Earth's surface either directly as a dry deposition or as a wet deposition after merging into rain water. On the basis of these deposition mechanisms, the simulation was undertaken using the EAGrid2000-JAPAN data to calculate the distribution of anthropogenic nitrogen deposition in a 1 km² mesh in Kanagawa Prefecture.

The simulation results were first converted into GIS layer data and overlaid by GIS maps of delineated drainage basins (Fig. 5.). Next, the data of atmospheric N deposition load in each basin was extracted using GIS tools and considered in the analysis to determine the effect of the deposition on the total nitrogen (TN).

3. Results and Discussion
3.1 Temporal variation of water quality
In every river basin, the water quality was found to
improve with time. The water quality parameters of all river basins, except the Ochiai-bashi drainage basin of the Kaname River, showed almost similar decreasing trends with passing time. The Ohne River basin was found to be the most polluted with a high fluctuation in the water quality parameters. In the Ochiai-bashi drainage basin, the water pollution was the least and the water quality parameters remained almost the same as the previous values (Fig.6.).

3.2 Relationship among water quality, sewerage system and agricultural land

From an analysis of the sewerage system data and variation of land use, it was found that the unsewered population and agricultural land in every basin declined with passing time (Fig.7. and 8.). Similarly, water quality was also found to improve with time (Fig.6.). It was considered that the sewerage system and agricultural land had a significant role in the improvement of the river water quality. Thus, the relationship of the improvement in water quality with the expansion of the sewerage system, and the change in agricultural land was analyzed in this study.

The temporal variation of water quality parameters and the respective pollution loads from the unsewered population and agricultural land were compared, as shown in Fig.9. Pollution loads from the unsewered population and agricultural land were calculated using unit loads (Table 2.) from the Ministry of Construction.

In this paper, the analyses of the Muro and Ohne Rivers have been presented in detail. In the Muro River basin, a sewerage system was installed in 1983. In contrast, a sewerage system was installed in the Ohne River basin as recently as the year 2000, which was much later than in other river basins. Thus, the late installation of the sewerage system coupled with the growing rate of urbanization (Fig.8.) could be the reason why the Ohne River was highly polluted (Fig.6.).

The analyses of the water quality of the Muro and Ohne Rivers were therefore used, in order to compare river basins where the sewerage system was installed early and late, respectively.

In the Muro River basin, a sewerage system was built in 1983. Therefore, from the 1980s, both the development of the sewerage system and the reduction in the agricultural land could have played an important role in the improvement of water quality in this basin (Fig.9.a).

In the Ohne River basin, after the year 2000, a sharp decrease in COD and TP could be observed as a result of the decrement in the corresponding unsewered population's pollution loads; TN was observed to decrease slightly. However, a slight improvement in water quality could be observed during the late 1980s before the start of the sewerage system (Fig.9.b). This improvement could be attributed to a decrease in agricultural pollution loads. Thus, it could be
considered that both the expansion of the sewerage system and decrease in agricultural land contributed to the improvement in water quality in this basin, although the period during which this occurred was different from that for the Muro River.

A gradual decrement in the TN was not observed as in the case of COD and TP (Fig.9.a and 9.b). It was rather found to increase again in later years, in the case of the Mizunashi and Kuzuha Rivers. In Mizunashi River, TN started to increase again from 2004 onwards and in Kuzuha River, from 2000 onwards (Fig.10.).

Water pollution in the Ochiaibashi basin of the Kaname River was not much compared with that in other basins (Fig.6.). Hence, an analysis of this basin was not considered. The Shinsaibashi basin of the Kaname River was not analyzed separately because it encompasses the basins of the Muro, Mizunashi, and Kuzuha Rivers.

3.3 Multiple regression analysis

The temporal variation of water quality was somewhat in accordance with the decreasing trends of the unsewered population and agricultural pollution loads (Fig.9.). Hence, to determine the relative impact of these factors on water quality, multiple regression analysis was performed using COD (mg/l), TP (mg/l), and TN (mg/l) as objective variables, and unsewered population and agricultural pollution loads (kg/day) as explanatory variables. The unit loads (Table 2.) used for calculating pollution loads were published by the Ministry of Construction, Japan, in 1999. Hence, the pollution loads that were calculated might be different than the actual pollution loads generated during different time periods. As unit loads were based on the annual average runoff during rainfall, and because rainfall also influences the dilution of pollutants, the calculated pollution loads were calibrated by dividing them by the annual rainfall data (Fig.11.) of the respective years and then used in the regression analysis.

Each river had its own distinctive results that depended on the temporal variations of water quality, expansion of the sewerage system, and decrease in the agricultural loads. In most cases, it was found that the unsewered population's pollution load had a relatively high impact on water quality; however, agricultural pollution loads were also found to have some effects on the water quality (Table 3.). In the case of the Mizunashi River basin, the influence of agricultural pollution loads was found to be higher as compared to those of other rivers. Thus, it could be said that both the development of a sewerage system and the reduction in agricultural pollution loads affected the water quality positively.

Using partial regression coefficients and a constant
term of regression analysis, water quality parameters were calculated, and then compared with observed values (Fig.12.). The calculated values, especially for COD and TP, were found to follow a trend that was somewhat similar to that of the observed values, implying that the sewerage system and agricultural land certainly influenced the water quality of rivers.

The result of the analysis for Mizunashi River was found to be opposite to those of other rivers with a higher influence of agricultural pollution loads. In Japanese, "Mizunashi" means "no water"; therefore, as the name suggests, the water quantity was very low. As it was flowing in an alluvial plain, the riverbed geology was highly permeable throughout its length, and water easily infiltrated into the subsurface (Hadano City, 2003 and Ichikawa et al., 1978). The infiltration of surface water could be the reason for the contrasting result of the analysis.

The underground structure of the Hadano basin was formed as a groundwater dam storing about three hundred million cubic meters of water (Hadano City, 2003). The downstream portions of the Muro and Kuzuha rivers were influenced by groundwater inflow (Shrestha et al., 2009). Thus, groundwater hydrology might have been an additional factor influencing the water quality of these rivers.

In the case of the Kuzuha River, for the upstream portion, the riverbed geology was highly permeable and water easily infiltrated into the subsurface layers. In the downstream portion, groundwater sprung from the cliffs and the riverbed (Shrestha et al., 2009). Further, factory effluents were also discharged into the river. Thus, it could be said that the ground water hydrology and factory effluents could have played a significant role in the water quality and might be the reason for the rather lower correlation between water quality and impacting factors. For Ohne River, the coefficients of determination were lower than those of the Muro River; this may have been due to the late installation of the sewerage system for the Ohne River.

The COD and TP were found to be influenced by the unsewered population and agricultural land.

However, the TN did not have a good correlation with them. This might be because the decrement in the TN was quite moderate and almost constant in the later years compared to sharp decrements in the COD and TP (Fig.9.). In the Mizunashi and Kuzuha Rivers, the TN exhibited an increase in later years (Fig.10.). This might be the reason for the lower coefficients of determination concerning the TN in these rivers. Thus, it could be said that other impacting factors were also influencing the TN concentration, and atmospheric N deposition loads could be considered as one of the factors impacting the TN concentration.

### 3.4 Effect of atmospheric nitrogen

It was considered that atmospheric N also affected the TN in river water. The results of the atmospheric N simulation in fiscal year 2006 (Kondo, 2008) were taken into account. Atmospheric N deposition loads in the Muro, Mizunashi, Kuzuha, and Ohne River basins were computed by visualizing the simulation results in GIS. Next, atmospheric N deposition loads were compared with the coefficients of determination for TN (Fig.13.) obtained from the multiple regression analysis for the corresponding river basins (Table 3.). The authors expected the atmospheric N deposition load to be higher in those river basins where the coefficient of determination for TN was lower, and vice versa;
4. Conclusion

In all the river basins, the gradual improvement in water quality could be observed with time. Among the five rivers that were studied, Ohne River was found to be the most polluted.

Development of a sewerage system and reduction in agricultural pollution loads were found to influence the water quality in all river basins. The pollution loads from the unsewered population and agricultural land declined gradually with time. Correspondingly, water quality also improved gradually with time. Using multiple regression analysis, it was found that each river had distinct results in terms of the temporal variations in water quality, expansion of the sewerage system and decrease in the agricultural land use. In most cases, the unsewered population adversely affected the river water quality. Nevertheless, the influence of changing agricultural land use on the water quality was undeniable.

The COD and TP were found to be influenced by the unsewered population and agricultural land use. However, the TN concentration did not have a good correlation with these factors. From the results of atmospheric N simulation, it was found that river basins with a lower coefficient of determination for TN had a higher level of atmospheric N deposition loads and vice versa. Hence, atmospheric N could be regarded as one of the impacting factors for TN concentrations in river water, and hence, it cannot be neglected concerning proper water quality management for this basin.

A limitation of this study was that the influence of groundwater hydrology on water quality could not be considered. As a further study, the effect of groundwater hydrology on water quality will be examined in detail.
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