Chapter 6
Scale and Seasonal-Dependent Impacts of Land-Use Types on River Water Quality of Multiple Watersheds in Southern China

Dayang Sun, Jianfeng Li, Wei Jun, Huabin Li, Sheng Sheng, and Fenfei Chen

Abstract Knowledge of how land-use types influence riverine water quality is fundamental for watershed pollution mitigation and city land planning. Based on seasonal water quality data from 82 monitoring sections in 20 watersheds in Jinjiang, we reveal scale and seasonal-dependent impacts of land-use types on river water quality in the multi-watershed perspective, using kriging and redundancy analysis (RDA). Results from kriging analysis demonstrate that sections of the urban district areas have the worst water quality, and the rivers generally have better water quality in winter. RDA results suggest that the degree of interpretation and significance of correlations generally increase as the scale enlarges. Urban construction lands and farmlands show obvious seasonal and scale-dependent effects regarding their influence on stream water quality. Urban construction lands are the primary sources of pollution in summer, mainly influencing COD concentrations through surface runoff pollutions in riparian buffer zone scales, while influencing NH_3-N concentrations through sewage pollutions in the watershed scale. Farmlands in the watersheds show a positive influence on river water quality, while farmlands distributed within 100 m and 200 m buffer zone in winter show negative influences. Projects for runoff pollution reduction, sewage treatment capacity enhancement in urban areas, and sewage collection system improvement in rural areas are urgently needed for mitigation of water quality.

Keywords Water quality · Multi-watershed · Land-use

6.1 Introduction

Water quality of streams can be influenced by both natural factors (i.e., topography, rainfall, temperature, plant and soil types, etc.) and human activities (i.e., damming, agriculture activities, urbanization, etc.) in watersheds (Khatri and Tyagi 2015; Park

D. Sun (✉) · J. Li · W. Jun · H. Li · S. Sheng · F. Chen
Power China Huadong Engineering Corporation Limited, Hangzhou 311122, China
e-mail: sun_dy@hdec.com; dylan_1991@163.com

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and Lee 2020; Hooper and Hubbart 2016). Land-use changes within the watersheds have been paid much attention in the last few decades due to its substantial influence on water quality of streams (Hooper and Hubbart 2016). Land-use changes in watersheds can influence stream water quality by altering physical, biochemical and ecological stream characteristics, including stream geomorphology, sediment regime, water temperature, nutrient/pollutant concentrations, aquatic habitat, and ecological biodiversity (Wertz and Shank 2019; Giri and Qiu 2016; Johnson et al. 1997; Su et al. 2016). Understanding how land-use types influence riverine water quality is fundamental for watershed pollution mitigation and city land planning.

Previous studies suggest that impervious surfaces in urban areas relates to water quality degradation (Gyawali et al. 2013; Pratt and Chang 2012; Sliva and Williams 2001), while farmlands can be important sources of non-point pollution to streams (Wertz and Shank 2019; Pratt and Chang 2012; Sliva and Williams 2001; Huang et al. 2016; Gonzales-Inca et al. 2015). Forests, on the other hand, are often found to effect positively on water quality of streams (Oliveira et al. 2016; Singh and Mishra 2014). However, how these land-use types influence riverine water quality in different scales and different seasons are still under debates, considering different results from studies with different regional background (Pratt and Chang 2012; Sliva and Williams 2001). Moreover, current studies mainly focused on single watersheds. How land-use types in a city influence riverine water qualities in a multi-watershed scale is still not clear. To investigate the scale and seasonal-dependent impacts of land-use types on river water quality in the multi-watershed perspective can provide key information for city land planning and watershed pollution mitigation projects.

Jinjiang has undergone rapid urbanization and economic developments in the last few decades and has endured serious deterioration of stream water quality. Here we collected seasonal water quality data from 82 sections in 20 watersheds in Jinjiang and investigated scale and seasonal-dependent impacts of land-use types on river water quality in the multi-watershed perspective, using kriging and redundancy analysis (RDA). Hopefully, this study can provide useful suggestions for better pollution control strategies for watersheds in Jinjiang and other similar cities.

6.2 Materials and Methods

Jinjiang located in the southeastern China (118°24′56″–118°41′10″ E, 24°30′44″–24°54′21″ N). There are 20 main watersheds in Jinjiang, most of which are seagoing streams (Fig. 6.1). The topography of Jinjiang mainly consisting of plains and hills, with the elevation ranging from 0 to 469 m (Fig. 6.1). Jinjiang has a subtropical monsoon climate. The average temperatures in Jinjiang range from 17 to 24 °C and the average precipitation is ~1147 mm.

The data of monthly water quality indicators (COD, NH_3-N and TP) from 82 monitoring section of 20 watersheds in 2018–2019 were provided by Quanzhou Municipal Ecology and Environment Bureau. The average concentrations of COD, NH_3-N and TP in June, July and August were calculated to represent the summer

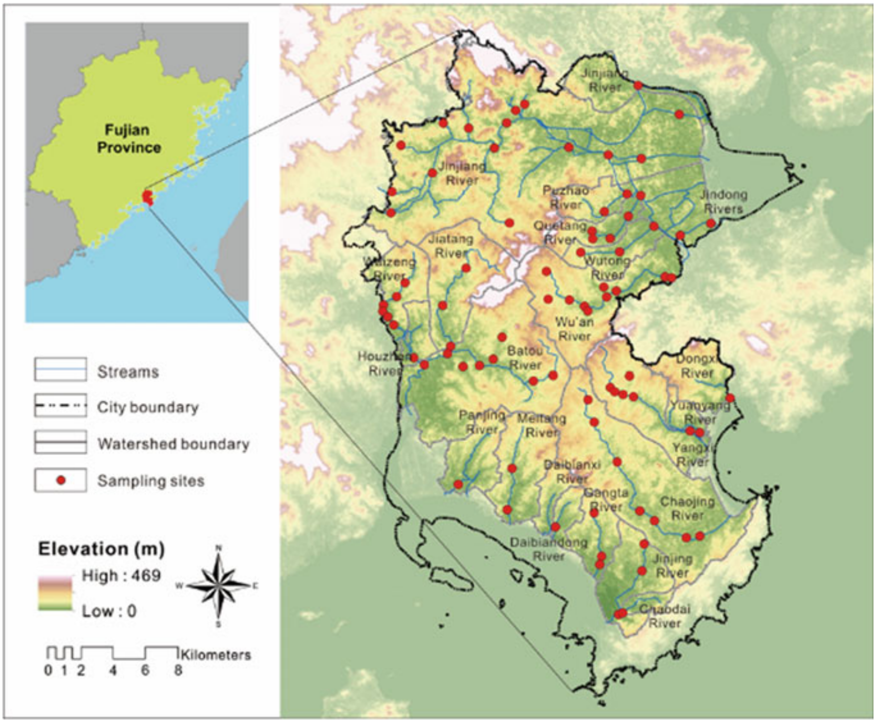

Fig. 6.1 Topography and sampling sites in 20 watersheds in Jinjiang

water quality, while those of November, December and January were calculated to indicate the winter water quality.

The land-use types of Jinjiang were provided by Quanzhou Land and Resources Bureau. The percentage of land-use types in riparian buffer zone scales (100 m, 200 m, and 500 m) were calculated using buffer tools in ArcGIS. The effect of different land-use types on riverine water quality in different scales and different seasons were further estimated using redundancy analysis (RDA) in Canoco for Windows.

6.3 Results and Discussion

6.3.1 Distributions of COD, NH_3-N and TP

In the spatial perspective, the urban centre is the area with worst stream water quality. In summer, three water quality indicators have similar distributions, with their highest values in the upper streams of Puzhao River, Quetang River and Wutong River. The distribution of the worst water quality sites highly coincides with the location of urban centre. In these areas, concentrations of NH_3-N, TP and COD are higher than 25 mg/L, 2.5 mg/L and 120 mg/L, respectively, which is lower than the V-class standard (i.e. NH_3-N < 2.0 mg/L, TP < 0.4 mg/L, COD < 40 mg/L). In winter, the highest concentrations of NH_3-N and TP occur in the upper reaches of Quetang River and Yangxi River, while the highest concentrations of COD the upper reaches of Quetang River, Wutong River and the middle reach of Jiatang River. The urban centre is still one of the areas that have worst water quality.

In the seasonal perspective, the stream water quality in winter is generally better than that in summer. The average concentration of COD in winter (59.4 mg/L) is 28.2% lower than that in summer (82.7 mg/L). Considering the influence of seawater may reduce COD concentrations in summer months, the actual difference may be even higher. The average concentration of TP in winter (0.84 mg/L) is 11.3% lower than that in summer (0.95 mg/L). The seasonal difference of NH_3-N concentrations is unobvious.

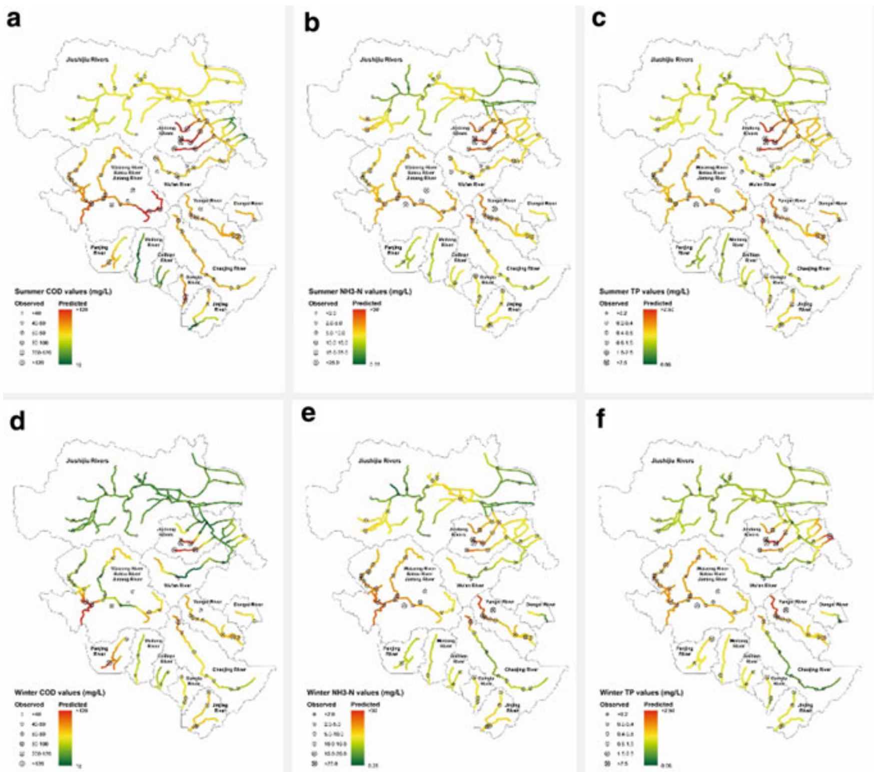

Fig. 6.2 Influence of land-use types on water quality Fig. 6.2. Distributions of observed and predicted water quality indicators in Jinjiang. **a**: summer COD; **b**: summer NH_3-N; **c**: summer TP; **d**: winter COD; **e**: winter NH_3-N; **f**: winter TP indicators

6.3.2 Influence of Land-Use Types on Water Quality Indicators

RDA results in summer. RDA results that indicate influence of land-use types on concentrations of COD, NH_3-N and TP in riparian buffer zone scales in summer are shown in Fig. 3a. The degree of interpretation of land-use types in riparian buffer zones to concentrations of COD, NH_3-N and TP reaches 47.6%. Garden lands in all riparian buffer zones correlate positively to TP concentrations. Garden lands in 100 m riparian and transportation lands in all riparian buffer zones correlate positively to NH_3-N concentrations. Urban construction lands in all riparian buffer zones and woodland in 100 and 200 m riparian correlate positively to COD concentrations. Other land-use types are not or negatively correlated with water quality indicators. Most interestingly, farmlands and grasslands in all riparian buffer zones negatively correlate to COD concentrations, while rural construction lands negatively correlate to TP concentrations.

RDA results that indicate influence of land-use types on concentrations of COD, NH_3-N and TP in the watershed scale in summer are shown in Fig. 3b. The degree of interpretation of land-use types in watersheds to water quality reaches 79.4%. Urban construction lands and transportation lands in the watersheds correlate positively to all three indicators. Farmlands and industry lands in watersheds correlate negatively to all three indicators. Rural construction lands correlate negatively to TP concentrations, while unused lands (including bare land, salt marsh and other unused land types) and grasslands correlate negatively to COD concentrations.

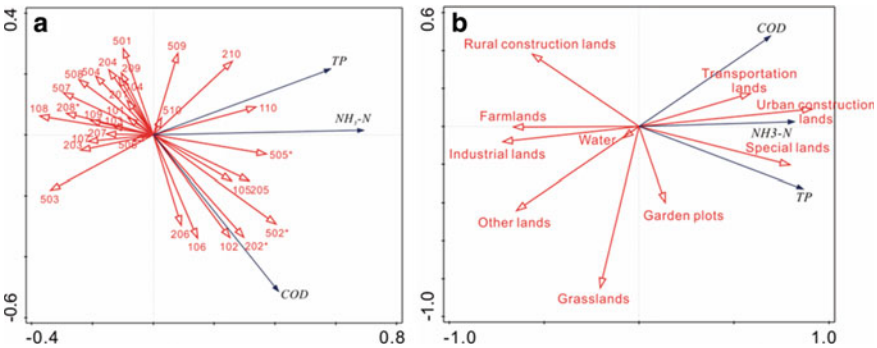

Fig. 6.3 RDA results of influences of land-use types on concentrations of COD, NH_3-N and TP in summer at buffer scales (**a**) and at watershed scales (**b**). In Fig. 3a, the first digits of numbers represent the widths of riparian buffer zones: 1–100 m, 2–200 m, 5–500 m. The second and third digits represent land-use types: 01-grasslands, 02-urban construction lands, 03-rural construction lands, 04-farmlands, 05-trasportation lands, 06-woodlands, 07-other lands (bare land, salt marsh and other unused land types), 08-water, 09-special lands (military lands, consulate lands, prison lands, religion activity lands), 10-garden lands. Stars after the land-use types represent that the influences of these land-use types on water quality indicators are significant ($p < 0.05$)

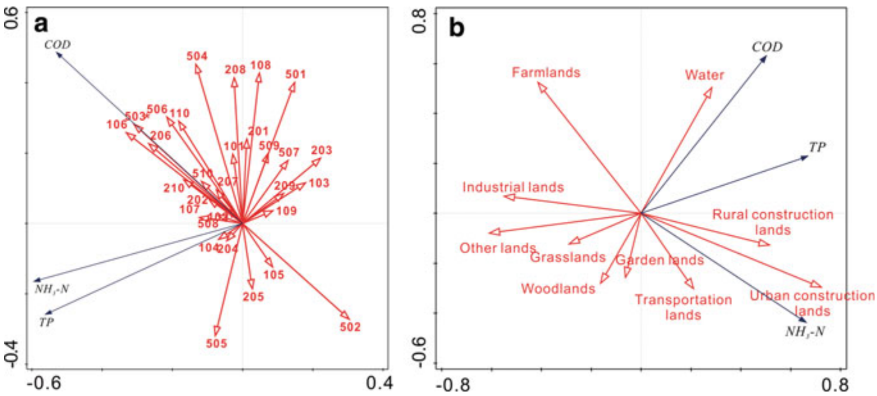

Fig. 6.4 RDA results of influences of land-use types on concentrations of COD, NH_3-N and TP in winter at buffer scales (**a**) and at watershed scales (**b**). The numbers in Fig. 4a have same meanings as those in Fig. 3a

RDA results in winter. RDA results that indicate influence of land-use types on concentrations of COD, NH_3-N and TP in riparian buffer zone scales in winter are shown in Fig. 4a. The degree of interpretation of land-use types in riparian buffer zones to water quality reaches 46.4%. The land-use types that correlate positively to COD concentrations including garden lands and woodlands in all riparian buffer zones, rural construction lands in 500 m riparian, and urban construction lands in 100 and 200 m riparian. Farmlands in 100 and 200 m riparian show positive correlation to NH_3-N and TP concentrations. The influences of other land-use types on concentrations of COD, NH_3-N and TP in riparian buffer zone scales in winter are unobvious or insignificant.

RDA results that indicate influence of land-use types on concentrations of COD, NH_3-N and TP in the watershed scale in winter are shown in Fig. 4b. The degree of interpretation of land-use types in watersheds to concentrations of COD, NH_3-N and TP reaches 62.4%. Urban construction lands and transportation lands in the watershed correlate positively to NH_3-N concentrations. Rural construction lands correlate positively to NH_3-N and TP. Farmlands correlate negatively to NH_3-N concentrations; other lands and grasslands correlate negatively to TP concentrations; woodlands and garden lands correlate negatively to COD concentrations.

6.3.3 Scale and Seasonal-Dependent Effects

RDA results show that the degree of interpretation of influences of land-use types on concentrations of COD, NH_3-N and TP in the watershed scale is remarkably higher than that in riparian buffer zone scales. In riparian buffer zone scales, the significance of influences of land-use types on concentrations of COD, NH_3-N and TP generally increases as the buffer widths increase. This result is inconsistent with the studies on a single stream or watershed, where land-use types near the river usually have a greater influence on the water quality. This indicate that, in a multi-watershed scale, the scale effect of influence of land-use types on riverine water quality will also be enlarged.

Urban construction lands, transportation lands and rural construction lands show highly negative influence on stream water quality, which is in consistence with former studies (Zhang et al. 2009). The influence of urban construction lands on water quality show obvious scale-dependent effects. In riparian buffer zone scales, urban construction lands mainly influence COD concentrations, while in the watershed scale, urban construction lands mainly influence NH_3-N concentrations. COD concentrations and NH_3-N are often related to sewed contamination. COD concentrations are also highly related to runoff pollution. This suggests that urban construction lands influence water quality through surface runoff pollutions in riparian buffer zone scales, while through sewage contamination in the watershed scale.

The farmlands also show scale-dependent effects on riverine water quality. In the watershed scale, farmlands have positive influence on stream water quality, in both summer and winter. However, farmlands within 100 m and 200 m riparian buffers show negative influence on stream water quality in winter, as indicated by the positive correlation between farmlands and TP concentrations. Positive influence of farmlands on water quality are rarely reported in watersheds in foreign countries, probably because the foreign watersheds are usually dominated by farmlands, which become the primary source of contamination. In Jinjiang, however, the urban construction lands are the primary source of contamination in the watersheds, especially in summer when the runoff pollution increases due to the elevated rainfall. The farmlands in watershed can probably mitigate runoff pollution and thus have positive influence on stream water quality. Similar phenomenon has also been reported in Chinese cities such as Wujiang (Zhang et al. 2009). In winter, the runoff pollution from urban construction lands decreases as the rainfall reduces. The farmlands near the streams become a primary source of contamination instead.

In seasonal perspective, the riverine water quality in winter is generally better than that in summer. Two main reasons main explain the seasonal variations in the stream water quality. Firstly, streams in Jinjiang are mostly in eutrophication status. The algae blooms in summer may cause anaerobic conditions in streams, which is often followed by elevated concentration of COD (Hu et al. 2001; Gu 2012). Secondly, the increased sewage and runoff pollution may also cause deteriorated water quality.

RDA results demonstrate that the degree of interpretation of land-use types to water quality in a watershed scale is significantly higher to that in riparian buffer zone scales, indicating more intense influence of land-use types on water quality in summer. In summer, urban construction lands are the most significant factor that control stream water quality. On one hand, the productions of domestic and industrial sewage are significantly higher in summer than those in winter. This may reflect the insufficient capacity of urban sewage treatment in summer. On the other hand, the surface runoff pollutions are higher in summer, due to the elevated rainfall. In winter, both sewage and runoff pollution reduced. The urban construction lands therefore no longer influence the stream water quality significantly. The farmlands and rural construction lands within buffer zones became the primary sources of contamination, probably reflecting that the wastewater collection systems are still not completed in rural areas.

6.4 Conclusions

This study investigated the influences of land-use types on water quality indicators from a multi-watershed perspective and revealed scale and seasonal-independent effects of influence of land-use types on stream water quality. The main conclusions of this study are as follows.

- In the spatial perspective, the urban centre is the area with worst stream water quality, while in seasonal perspective, the stream water quality in winter is generally better than that in summer.
- In the multi-watershed perspective, the degree of interpretation and significance of correlations generally increase as the scale enlarges. Urban construction lands and farmlands show obvious scale-dependent effects in regarding to their influence on stream water quality. Urban construction lands mainly influence COD concentrations through surface runoff pollutions in riparian buffer zone scales, while influence NH_3-N concentrations through sewage contamination in the watershed scale. Farmlands show positive influence to water quality in the watershed scale, while have negative influence on water quality within 100 m and 200 m buffer zone in winter.
- The degree of interpretation and significance of correlations in summer generally higher than those in winter. Urban construction lands are the primary sources of pollution in summer, while rural construction lands and farmlands are the primary sources of pollution in winter.

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