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Spatial and Temporal Distribution Characteristics of Agricultural Non-point Source Pollution in Xixi Watershed of Jinjiang Basin

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Abstract The SWAT model was applied to analyze the temporal-spatial distribution patterns of non-point source pollution loads and the difference of pollution loads of different land use types in Xixi Watershed of Jinjiang Basin. The results showed that both yearly nitrogen and phosphorus pollution loads were evenly distributed during 1973 to 1979, the annual TN pollution from non-point source was 1530 t, or 6.3 kg/ha, and the annual TP pollution from non-point source was 270 t, or 1.1 kg/ha during 1973 to 1979 in the watershed. Considerable differences were identified on both monthly nitrogen and phosphorus pollution loads. The TN and TP pollution loads during the flood season (from April to September) accounted for 76.2% and 75.8% of the annual load respectively. There were great differences in both TN and TP pollution loads of different land use types in the study area, and the pollution load of both farmland and orchard was higher than that of the other land use types. TN and TP pollution loads of farmland accounted for 66% and 83% of total watershed. There was a great spatial difference in the non-point source pollution load of the study area. The critical source areas of non-point source pollution are mainly located at Guanqiao Town, Longmen Town, Changkeng Town, Shangqing Town and Dapu Town, where the efforts of controlling pollution should be made.

Key words Non-point source pollution, Temporal distribution, Spatial distribution, Land use type, SWAT model, Xixi Watershed of Jinjiang Basin

1 Introduction

Jinjiang Basin is located in Quanzhou City with developed economy along the southeast coast, and as the point source pollution such as industrial sewage is effectively controlled, the impact of non-point source pollution on water quality has loomed large. Previous studies have shown[1-3] that Jinjiang Basin is one of the regions with the most serious soil erosion and non-point source pollution in Fujian Province. A lot of agricultural nitrogen and phosphorus nutrients enter into the river along with soil erosion, increasing the hazardous substances in Xixi Watershed and decreasing dissolved oxygen in water. However, currently, it lacks studies on the spatial and temporal distribution of non-point source pollution in Xixi Watershed. SWAT (Soil & Water Assessment Tool) is a river basin scale model developed to quantify the impact of land management practices in large, complex watersheds. SWAT is a public domain model actively supported by the USDA Agricultural Research Service at the Grassland, Soil and Water Research Laboratory in Temple, Texas, USA. It is a hydrology model with the following components: weather, surface runoff, return flow, percolation, evapotranspiration, transmission losses, pond and reservoir storage, crop growth and irrigation, groundwater flow, reach routing, nutrient and pesticide loading, and water transfer. SWAT model has been widely used in USA[4] and other countries, and some domestic scholars employ SWAT model to analyze the spatial and temporal distribution of non-point source pollution in the Chaohu Lake area[5], Liaoning Taizi River Basin[6], Danjiangkou reservoir basin[7] and Chongqing Chenjiagou small watershed[8], and achieve good results. In this study, on the basis of previous non-point source pollution SWAT simulation[9], we further analyze the spatial and temporal distribution of non-point source pollution in Xixi Watershed of Jinjiang Basin.

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2 Overview of the study area

Xixi Watershed is located in Quanzhou City of southeastern Fujian Province. Xixi is the main source of Jinjiang River, flows from the northwest to the southeast and flows together with Dongxi into the sea via Quanzhou Bay. In this study, we choose the area controlled over by Hydrological Station of Anxi County (23°03′N, 118°10′E) as the study area. The Xixi within the study area flows 105 km, with basin area of 2451 km^2 and elevation range of 50 – 1500 m, and the landscape is dominated by mountains and hills[10]. Xixi Watershed features a subtropical monsoon climate, with the average temperature of 22 – 29℃ and annual average rainfall of 1715 mm. The rainfall mainly happens from July to September, accounting for nearly 40% of year-round rainfall, and the average annual runoff is 2.63 billion m^3. Three kinds of soil account for 85%: paddy soil (44%); yellow red soil (23%); red soil (18%). Various types of land use in the study area in 1985 included forest land (54%), shrubbery (17.3%), paddy field (9.7%), dry land (9.6%), middle coverage grassland (6.9%), garden plot (1.2%), low coverage grassland (1.1%), and public transportation land (0.2%)[11].

3 Research method

3.1 SWAT model SWAT (Soil & Water Assessment Tool) is a river basin scale model developed to quantify the impact of land management practices in large, complex watersheds. It is a hydrology model with the following components: weather, surface runoff, return flow, percolation, evapotranspiration, transmission losses, pond and reservoir storage, crop growth and irrigation, groundwater flow, reach routing, nutrient and pesticide loading, and water transfer. SWAT can be considered a watershed hydrological transport model. Hydrology sub-model uses SCS CN (Curve Number) equation to compute, and soil erosion sub-model uses MUSLE equation to predict soil erosion. For the changes in water quality within the river, QUAL2E model is used to simulate[12]. SWAT uses a two-level dissagregation scheme; a preliminary subbasin identification is carried out based on topographic criteria, followed by further discretization using land use and soil type considerations. Areas with the same soil type and land use form a Hydrologic Response Unit (HRU), a basic computational unit assumed to be homogeneous in hydrologic response to land cover change. Various sub-models are applied to calculate runoff, and amount of sediment and pollutants on HRU; by flow routing, we calculate the outlet section flow, sediment and pollution loads[13].

3.2 Data sources The terrain data required by SWAT model are from 30 m DEM in the study area. ArcView software is used to extract river system, aspect, slope and other topography parameters. The soil map and land use map are drawn based on 1:500000 soil map of the region in the upper reaches of Jinjiang Basin, and 1:100000 Fujian land use/cover remote sensing interpretation data provided by Nanjing Institute of Soil Science, Chinese Academy of Sciences. The data on soil physical and chemical properties are obtained from references. The daily precipitation data are from the 1972 – 1979 data measured by 15 rainfall stations within the watershed, and Thiessen polygon method is used to achieve spatial discretization of single-site data. Other daily data are obtained from the observed data of weather stations in Anxi County. Detailed data sources are shown in reference[14 – 15].

3.3 Parameter estimation Using the meteorological data, terrain data, soil data, land use data and agricultural management data needed for the model, we simulate the runoff generation, sediment formation and non-point source pollution in the study area from 1972 to 1979. Meanwhile, we select three indicators (relative error *RE*; efficiency factor *Ens*; coefficient of determination R^2) to evaluate the applicability of the model, and the results show that during the calibration period of runoff simulation (1972 to 1975), the monthly simulation *Ens* is 0.91 and R^2 is 0.92; during the verification period of runoff simulation 1976 to 1979), the monthly simulation *Ens* is 0.85 and R^2 is 0.9. The sediment formation simulation takes 1972 as the warm-up period, and the monthly simulation Ens of sediment formation (1973 – 1979) is 0.63, R^2 is 0.65, and 7-year mean relative error (*RE*) is −14.1%. The non-point source pollution simulation takes 1972 as the warm-up period, and the annual simulation *Ens* of ammonia nitrogen (1973 – 1979) is 0.69, R^2 is 0.95, and 7-year mean relative error (*RE*) is −18.6%. In the same period, the annual simulation *Ens* of mineral phosphorus is 0.79, R^2 is 0.85 and 7 – year mean relative error (*RE*) is −1.5%. Overall, the calibrated and verified SWAT model has good adaptability in Xixi Watershed of Jinjiang Basin, and high simulation accuracy of runoff generation, sediment formation and non-point source pollution, so we can use this model to further study the spatial and temporal distribution characteristics of non-point source pollution in Xixi Watershed.

4 Results and analysis

4.1 Inter-annual distribution characteristics of non-point source pollution The simulated annual output of TN and TP in river course, measured rainfall, and measured amount of sediment in Xixi Watershed during 1973 – 1979 can be shown in Fig. 1. The figure shows that in the simulation period, there is little change in the annual amount of TN and TP in the river, and it is evenly distributed in different years. The maximum TN (1975, 2538.1 t) is 1.68 times as large as the minimum TN (1977, 1506.4 t); the maximum TP (1975, 323.4 t) is 1.67 times as large as the minimum TP (1977, 193.1 t). Fig. 1 also shows that the sediment discharge, TN and TP in the river is closely related to rainfall in different years. For example, the rainfall in 1975 was larger than in 1978, and the sediment discharge, TN and TP were also more than in 1978; the rainfall in 1977 was smaller than in 1976, and the sediment discharge, TN and TP were also less than in 1976. The reason is that rainfall is the main driving force of soil erosion and non-point source pollutant loss[16]; runoff and sediment are the carriers of non-point source pollutant loss, and when the underlying surface conditions remain unchanged, soil erosion and non-point source pollution are greatly affected by rainfall, for example, R2 between the annual rainfall in Xixi Watershed and sediment discharge, TN or TP in the river is 0.52, 0.61 and 0.45, respectively.

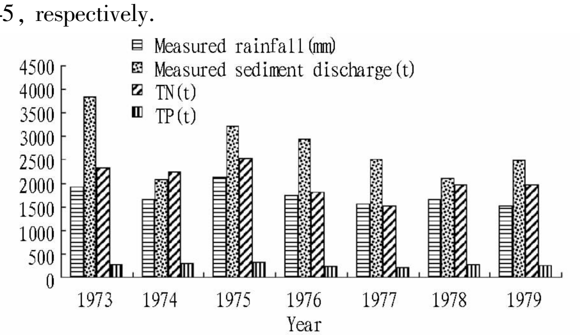

Fig.1 The yearly measured rainfall, sediment discharge and simulated TN and TP in Xixi Watershed from 1973 to 1979

4.2 Inter-monthly distribution characteristics of non-point source pollution The change in the monthly average value of non-point source TN and TP pollution with the monthly rainfall in Xixi River during 1973 – 1979 can be shown in Fig. 2. The non-point source pollution is often accompanied by rainfall runoff and especially heavy rain, so non-point source pollution loading is mainly concentrated in flood season[17]. Fig. 2 shows that in the flood season with great rainfall in Xixi Watershed (April to September), the non-point source TN, TP pollution loads are high, and the TN, TP proportion in August is 16.34% and 17.33%, respectively; in the month with low rainfall, the non-point source pollution load is also low, and the TN, TP proportion in December is only 1.36% and 0.95%, respectively. In the flood season (April to September), the total rainfall accounts for 74% of total annual rainfall, and the TN, TP loads account for 76.2% and 75.8%, respectively. The above data show that rainfall is strongly correlated with non-point source pollution load, and R^2 between monthly rainfall in Xixi Watershed and monthly non-point source TN or TP load is 0.89 and 0.91, respectively. Affected by rainfall, both TN and TP loads are lowest in July, and highest in June and August. The annual TN, TP loads show irregular M-shaped changes with the season. In the 7-year SWAT model simulation results, the simulated monthly average value of runoff and sediment increases from May to June, so the rainfall decreases and pollution load increases from May to June. From the above analysis, it can be found that the period from April to September is the key to non-point source nitrogen and phosphorus pollution control in the study area.

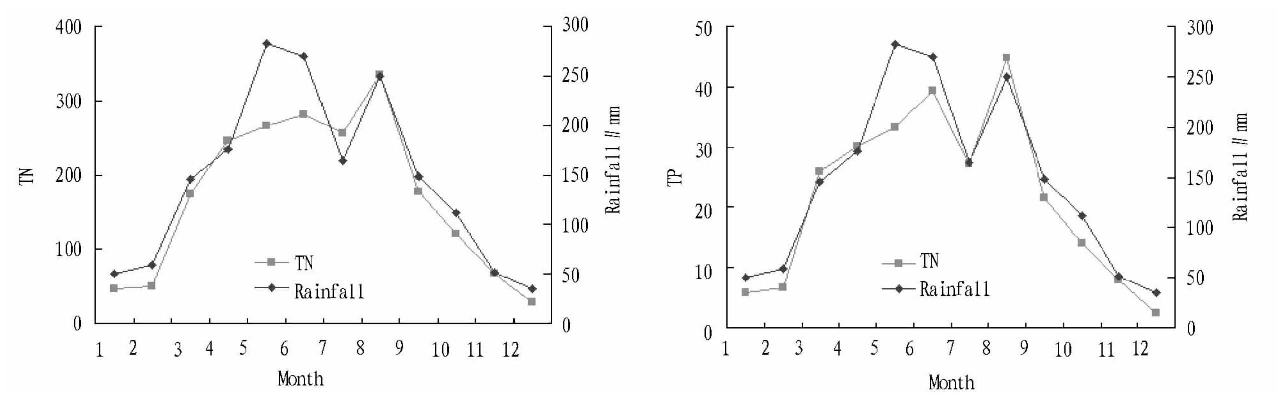

Fig. 2 Relationship between rainfall and TN or TP in the study area

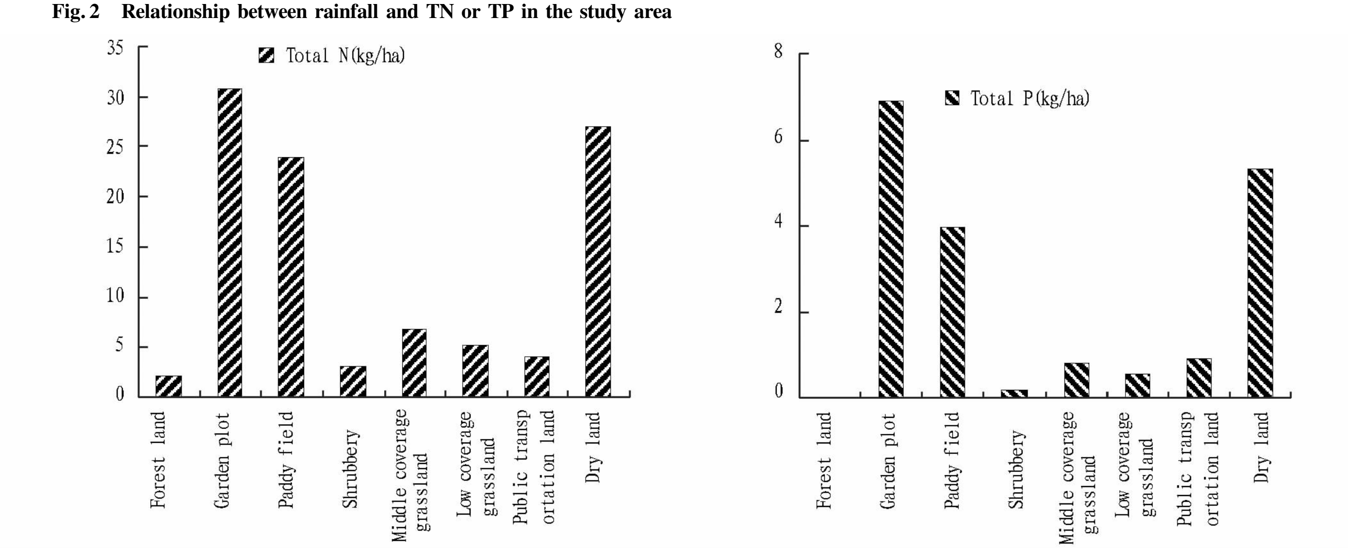

Fig. 3 Non-point source TN and TP loss for different land use types

4.3 Non-point source pollution distribution characteristics of different land use types The non-point source TN, TP loss for different land use types in Xixi Watershed is shown in Fig. 3. The figure shows that there is a large difference in non-point source TN, TP loss per unit area between eight types of land use. For example, the non-point source TN, TP loss per unit area of dry land is 9 and 30 times that of shrubbery, respectively, and there is a similar phenomenon between paddy field and shrubbery. The non-point source pollution is greatly affected by land use, so great fertilizer consumption and lack of forest cover for paddy field and dry land have caused serious soil erosion and non-point source nitrogen and phosphorus loss, while the nitrogen and phosphorus loss is smaller for forest land. Fig. 3 also shows that garden plot has the greatest non-point source TN, TP loss per unit area among eight types of land use. In the process of planting fruit tree, more nitrogen and phosphorus fertilizers are artificially applied, and a considerable part of these fertilizers are carried away by rainfall runoff to form non-point source pollution, thus the non-point source TN, TP loss per unit area is large for garden plot. The proportion of non-point source TN and TP loss for different land use types in Xixi Watershed can be shown in Fig. 4. The figure shows that most of non-point source pollution for seven years is produced by paddy field and dry land, accounting for 66% and 83% of non-point source TN, TP pollution, respectively; due to large area, forest land produces 15.05% of non-point source TN pollution in the study area; the remaining five land use types produce a low percentage of non-point source. Therefore, controlling the nitrogen and phosphorus pollution loading of paddy field and dry land is the key to non-point source pollution control in the study area.

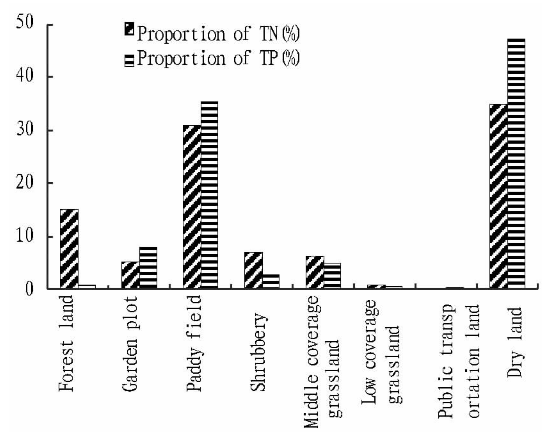

Fig. 4 Proportion of non-point source TN and TP loss for different land use types

4.4 Spatial distribution characteristics of non-point source pollution The seven-year (1973 – 1979) average non-point source TN and TP loss in various sub-watersheds of Xixi Watershed can be shown in Fig. 5. From Fig. 5 and SWAT model output results, it can be found that the average annual loss of TN on slope was about 1530 t or 6.3 kg/ha in Xixi Watershed from 1973 to 1979; while the average annual loss of TP on slope was 270 t or 1.1 kg/ha. There is a large difference in spatial distribution of TN and TP loss on slope among 21 sub-watersheds. TN pollution load varies from 1.6 kg/ha to 8.5 kg/ha, while TP pollution load varies from 0.04 kg/ha to 1.7 kg/ha. The nitrogen and phosphorus loss is great in No. 8, No. 12, No. 15, No. 18 and No. 20 sub-watersheds, mainly located in Guanqiao, Longmen, Changkeng, Shangqing, Chengxiang, Penglai and Huqiu of Anxi County and Dapu of Yongchun County, which is consistent with Lin Hezhen's conclusion that Guanqiao and Longmen are the towns with the most serious soil erosion in Xixi Watershed[2]. The reason is that the forest coverage rate is low, high proportion of arable land results in excessive application of nitrogen and phosphate fertilizer per unit area, and a lot of fertilizers are washed away by rainfall to lead to non-point source pollution. According to the studies of Levanon D[18], Chen Liding *et al.*[19], due to the plowing, with strong mineralization, the nitrate leaching effect of farmland soil is significantly greater than that of woodland no-tillage soil, thereby increasing TN loss; low forest cover makes it more prone to soil erosion under the same other conditions, and there will be a greater loss of nitrogen and phosphorus. The nitrogen and phosphorus loss of various sub-watersheds also shows that the loss is small in No. 1, No. 4, No. 6, No. 10 and No. 17 sub-watersheds located in the upper reaches of Xixi; small runoff, sparse river net, and weak erosion effect of water contribute to small soil and water loss as well as nitrogen and phosphorus loss. In addition, the proportion of arable land is small in these sub-watersheds while the forest coverage rate is high, leading to small migration amount of nitrogen and phosphorus[20]. From the above analysis, it is found that the key towns that need to control non-point source nitrogen and phosphorus pollution, include Guanqiao, Longmen, Changkeng and Shangqing in Anxi County, and Dapu in Yongchun County.

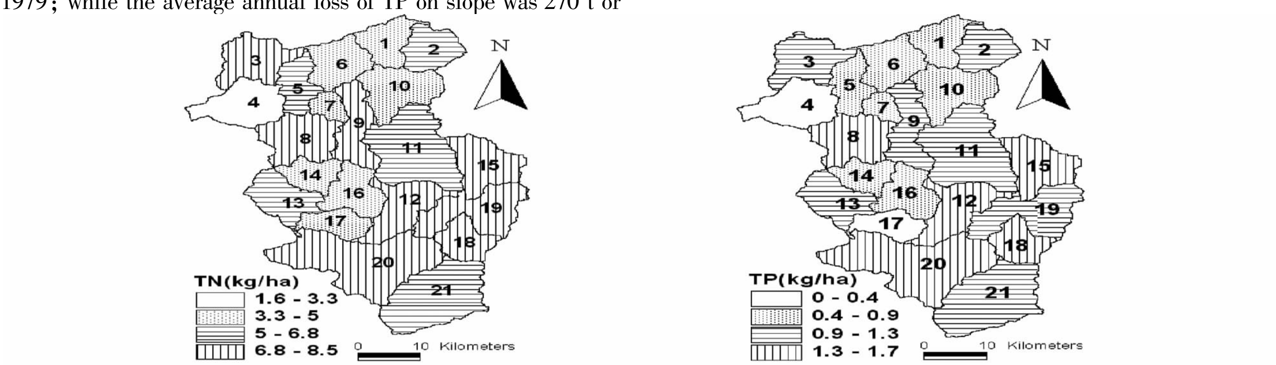

Fig. 5 The average non-point source TN or TP loss distribution in various sub-watersheds from 1973 to 1979

5 Conclusions

Using SWAT model, we analyze the spatial and temporal distribution characteristics of non-point source nitrogen and phosphorus pollution as well as the differences in pollution load between different land use types in Xixi Watershed of Jinjiang Basin. The results show that the annual distribution of non-point source nitrogen and phosphorus pollution loads was even during 1973 – 1979; the average annual non-point source TN loss was about 1530 t or 6.3 kg/ha, and the average annual TP loss was about 270 t or 1.1 kg/ha. There are great changes in monthly non-point source TN, TP loads, and TN, TP loads show irregular M-shaped changes with the season. In the flood season (April to September), the total rainfall accounts for 74% of total annual rainfall, and the TN, TP loads account for 76.2% and 75.8%, respectively. There is a large difference in non-point source TN, TP load per unit area between different types of land use. The pollution load of paddy field, dry land and garden plot is significantly higher than that of other land types. Most of non-point source pollution for seven years is produced by paddy field and dry land, accounting for 66% and 83% of non-point source TN, TP pollution, respectively. There is a large difference in spatial distribution of non-point source pollution, and Guanqiao, Longmen, Changkeng and Shangqing in Anxi County and Dapu in Yongchun County, have serious non-point source pollution, so they are the key towns to control non-point source pollution.

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