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ORIGINAL PAPER

Effectiveness of vegetative filter strips in abating fecal coliform based on modified soil and water assessment tool

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Abstract Pathogenic bacteria are a serious public health concern. Exposure to these microorganisms can result in illnesses or even death. Therefore, it is important to control pathogenic bacteria sources, transport mechanisms and fate. Best management practices proved to be very effective in the control of non-point source pollution. In this study, the soil and water assessment tool (SWAT) was modified and used to simulate the fecal coliform in Chao River of Miyun Reservoir watershed, China. The model was then used to explore the effectiveness of vegetative filter strips (VFS) in reducing fecal coliform abundance throughout the watershed. The water temperature equation within the SWAT was modified to align the model more closely with the characteristics of the study area and generate a more accurate simulation. The $DAFS_{ratio}$ (20, 50, 80, 120 and 150) and DF_{con} (0.25, 0.4, 0.6 and 0.75) parameters were considered for VFS to see their effects on removal efficiency. The results show that calibration and validation results for fecal coliform and flow can be accepted. Different values for $DAFS_{ratio}$ and DF_{con} have great influence on VFS. Increasing values resulted in a decrease in the removal efficiency of VFS.

Keywords Hydrologic model · Miyun Reservoir watershed · Water quality · Watershed management

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Introduction

Microorganisms found in non-point source pollution are a serious threat to human health. Harmful microbial pathogens can be spread through drinking water and other water systems, such as recreational water and aquaculture water. It is reported that approximately four billion cases of diarrhea cause 2.2 million deaths each year and 200 million people in the world are infected with schistosomiasis, of whom 20 million suffer severe consequences (WHO/UNICEF 2000). Changes in bacterial populations can directly reflect the characteristics of the habitat in which they are found. Therefore, monitoring and control of bacteria have been given increased attention in recent years. The application of manure in agricultural fields is a substantial threat to surface waters (Hyer and Moyer 2003). Research shows that the abundance of pathogenic microorganisms is increased in water bodies after a heavy rainfall. Therefore, controlling the transport mechanisms of pathogenic microorganisms especially after a storm is an important way to protect water quality.

The soil and water assessment tool (SWAT) model has been widely used in the study of bacteria. At present, studies using the model to simulate bacteria abundance and movement can be divided into the following two types: the application of the model and the specific use for the simulation. Application of the model generally includes the following aspects: a variety of models are applied to simulate bacteria (Moore et al. 1989; Benham et al. 2006; Frey et al. 2013), modifications for the existing model are researched (Kim et al. 2010; Cho et al. 2012), and a comparative study between different models is performed (Benham et al. 2006). Simulations for the model are divided into the following three categories: tracking sources of bacteria, conducting research on the impacts of multiple types of bacteria (Frey et al. 2013), and simulating the impacts of management measures (Parajuli et al. 2008).

The SWAT model has been widely applied in the study of bacteria (Benham et al. 2006; Coffey et al. 2010; Frey et al. 2013). Past research identified that the SWAT model was limited in its ability to simulate bacteria abundance and transport; therefore, additional research was performed to improve the model. Cho et al. (2012) found that solar radiation is one of the most influencing factors in the fate of fecal coliform by assessing fecal coliform contamination in the Wachusett Reservoir watershed with a modified SWAT. Kim et al. (2010) added a bacteria transport subroutine to SWAT model to evaluate the *Escherichia coli*. Baffaut and Sadeghi (2010) indicated that the simulation process of bacteria may need to be revisited after reviewing several cases in which the SWAT model was used to simulate bacteria. The values of the evaluation indices R^2 and E_{NS} used in their study were lower than the generally acceptable range identified in present SWAT-based bacteria simulation studies (Baffaut and Benson 2009; Baffaut and Sadeghi 2010; Frey et al. 2013), which was related to many factors, including runoff, sediment, temperature and even nutrient content. Other scholars believe that the existence of shortcomings in the SWAT simulation process for bacteria may lead to low calibration and validation results (Baffaut and Sadeghi 2010). This study aims to identify the major problems in the SWAT model and uses the Chao River of Miyun Reservoir watershed as a case study to modify the SWAT model and improve the calibration results to obtain a more accurate simulation of bacteria.

Best management practices (BMPs) are the primary method used to control non-point source pollution and improve water quality. BMPs can be divided into source control techniques, process control techniques and terminal control techniques, according to different classifications. Research shows that different types of BMPs used in the control of nutrients, sediment, bacteria, pesticides and other pollutants have achieved positive results (Maringanti et al. 2008; Parajuli et al. 2008). However, not all BMPs can be used to remove pathogenic microorganisms. Vegetated filter strips (VFS) are recommended as one of the BMPs to prevent nutrients, manure-borne microorganisms and other contaminants from reaching surface water resources (Parajuli et al. 2008; Lewis et al. 2010; Fox et al. 2011).

VFS has proven to be effective in the removal of pathogenic microorganisms (Entry et al. 2000; Cardoso et al. 2012). At present, study of the removal of pathogenic microorganisms using VFS is focused on plot scale scenarios and model simulations. Research shows that many factors affect the removal efficiency of VFS, including type of vegetation used, strip length and width, and slope of the strip (Parajuli et al. 2008). The economics and optimization of VFS placement are the focus of current study (Shen et al. 2013).

The SWAT model not only simulates the fate and transport of nutrients and pathogens but also simulates management measures. At present, the application of VFS in the SWAT model is primarily associated with the removal of nutrients and bacteria. Existing studies mainly focus on the efficiency of bacteria removal using different VFS widths in the SWAT model. Parajuli et al. (2008) found out that 15-m lengths of VFS reasonably reduced fecal bacteria concentrations in the watershed when the SWAT model was applied to the removal of fecal coliform and sediment. This indicates that the parameters used to describe VFS in the SWAT model are an important consideration. The drainage area to VFS area ratio ($DAFS_{ratio}$) is used in SWAT instead of buffer width (White and Arnold 2009). However, little research has been performed correlating $DAFS_{ratio}$ with bacteria removal efficiency.

In this paper, a modified SWAT model was used to simulate flow and fecal coliform in the Chao River of Miyun Reservoir watershed, China. The water temperature equation of the SWAT was modified to align the model more closely with the characteristics of the study area. The $DAFS_{ratio}$ (20, 50, 80, 120 and 150) and the fraction of the Hydrologic Response Unit (HRU in SWAT model) which drains to the most concentrated 10 % of the VFS area defined as DF_{con} (0.25, 0.4, 0.6 and 0.75) were considered for VFS to explore their effects on bacteria removal efficiency. The primary objectives of this research were (1) to modify the SWAT model to obtain more accurate results and in combination with other researchers studying bacterial model modifications make the simulation more complete; (2) to investigate the influence of different parameter values on the bacteria removal efficiency of VFS based on the VFS module of SWAT. The study area is the Chao River of Miyun Reservoir watershed, China. The fecal coliform samples were collected in 2013.

Materials and methods

Watershed and data

The Chao River is located between North China Plain and eastern Inner Mongolia Axis with an area of 6155 km^2 (Fig. 1). The research area and Bai River are two main tributaries to the Miyun Reservoir, which is located in the northeast of Beijing. The Municipality of Beijing consists of the city of Beijing together with several rural counties that surround it. The Miyun Reservoir is located in the rural counties of Beijing. The Miyun Reservoir is the most important drinking water source for Beijing. Approximately, 60 % of the research area is covered by mountain. The major land use types are: forest (50.90 %), pasture (25.45 %) and agricultural land (19.39 %). The climate belongs to

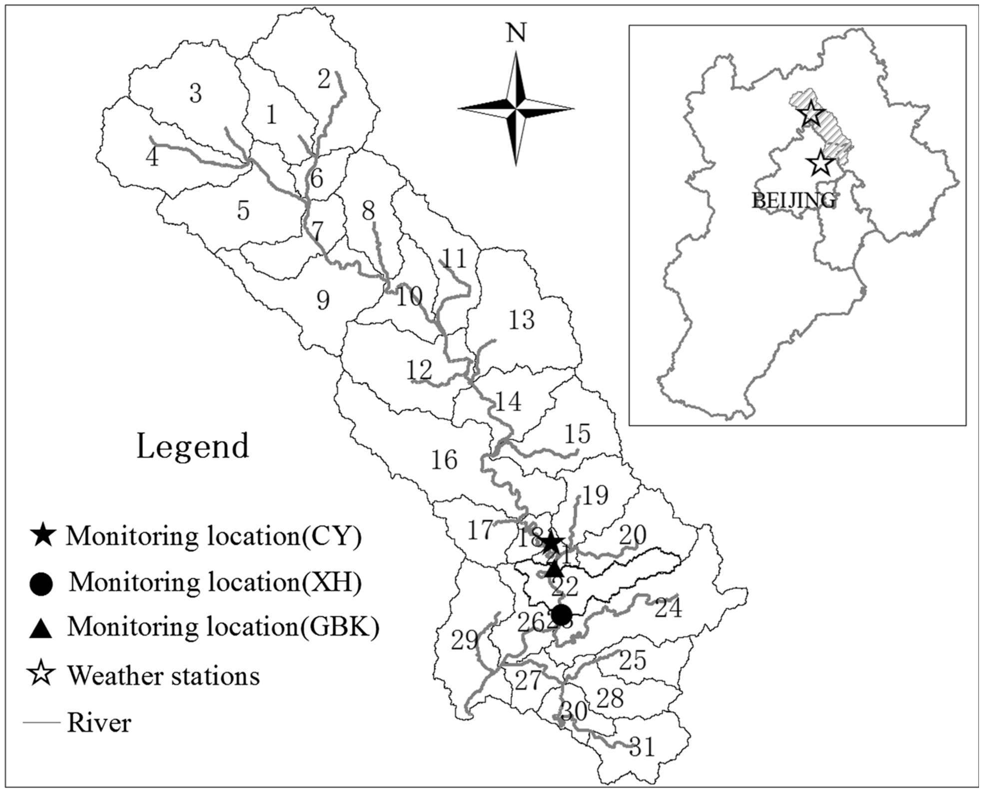

Fig. 1 Location of the study watershed and the hydrological sites

continental monsoon climate, precipitation of the Chao River more concentrated in the flood season, and the precipitation ranges from 261.4 to 750.0 mm per year (Wang et al. 2012).

The flow was calibrated and validated in Xihui (XH) and Guibeikou (GBK) from 2006 to 2010, and fecal coliform presence was calibrated and validated at three sites (CY, GBK and XH) in 2013. There are 22 rainfall stations and two weather stations in the watershed. The key data needed for this study were obtained from the following organizations:

(a) DEM: The National Geomatics Center of China.
(b) Land use: Institute of Geographical Sciences and Natural Resources Research, Chinese Academy of Science.
(c) Soil properties: Institute of Soil Science, Chinese Academy of Science.
(d) Weather data: China Meteorological Administration.
(e) Hydrology: Hydrological yearbook.
(f) Water quality: Fecal coliform samples were collected and measured at three sampling sites (CY, GBK and XH).

Fecal coliform source characterization

Classification of bacterial origin is very important and is primarily based on watershed characteristics. Current research classifies bacterial origins in the following categories: livestock, human, wildlife, grazing operations, manure applications and failing septic systems (Table 1). A region's size and location greatly influence the number and type of bacterial sources. For example, Table 1 identifies Little Cove Creek watershed as a small watershed with only one bacterial source. There is an obvious difference between the planting structures, livestock breeding practices and other land management practices in China and other countries. As a result, the sources of bacteria are also different. Sources of bacteria can also be related to the seasons. Bacteria source tracking performed by Benham et al. (2006) indicated that the contribution of animal manure on fecal pollution in summer was much higher than in winter. In the present study, identified differences in bacterial concentrations may greatly influence the bacterial content of the watershed. Bougeard et al. (2011) set the fecal bacteria concentration as 8.96×10^5 *E. coli*/g in the manure, while Parajuli et al. (2008) set a concentration of fecal coliform in the manure as 13×10^{10} cfu/day/AU (wet-weight-basis). In this study, the source of fecal coliform mainly considers the following source (Table 2), which presents the concentrations of fecal coliform from related research. As the watershed area is large, diversity of wild animal species is very rich. The primary wild animal species are listed in Table 2. In this study, sheep, cattle and duck were considered grazing animals, as identified through field investigations and a literature review.

Table 1 Summary of the source classification of bacteria in application of SWAT model

	Shoal Creek watershed[a]	Little Cove Creek watershed[b]	Upper Wakarusa watershed[c]	Payne River watershed[d]	Sac River watershed[e]
Area	367 km^2	68 km^2	950 km^2	178 km^2	726 km^2
Source	Septic tanks and illegal connections	–	Failing septic systems	Septic system	Septic tanks, permitted and facilities storm runoff from urban areas
	Poultry litter	–	Livestock	Manure and fertilizer	Livestock
	Wildlife	–	Wildlife	Wildlife	Wildlife
	Grazing cattle	Grazing operation	–	–	Horses
Country	USA	USA	USA	Canada	USA
Bacteria types	Fecal bacteria	*E. coli*	Fecal bacteria	Cryptosporidium, Salmonella, Giardia Campylobacter, fecal coliform, *E. coli*	Fecal coliform

[a] Benham et al. (2006), [b] Kim et al. (2010), [c] Parajuli et al. (2008), [d] Frey et al. (2013), [e] Baffaut (2006)

Table 2 Sources of fecal coliform in the Chao River watershed

Source	Typical sources	Bacteria Production Information
Fertilization	People and livestock manure	Parajuli et al. (2008), Bougeard et al. (2011), ASAE (2000)
Wild animal	Mongolian Sky Lark	Moyer and Hyer (2003), Middleton and Ambrose (2005), ASAE (2000)
	Lark	Moyer and Hyer (2003), Middleton and Ambrose (2005), ASAE (2000)
	Ring necked pheasant	ASAE (2000), Moyer and Hyer (2003)
	Shelduck	ASAE (2000), Moyer and Hyer (2003)
	The magpie duck	ASAE (2000), Moyer and Hyer (2003)
Grazing	Sheep	ASAE (2000), Moyer and Hyer (2003)
	Cattle	ASAE (2000), Moyer and Hyer (2003)
	Duck	ASAE (2000), Moyer and Hyer (2003)
Point source	Urban wastewater treatment plant discharge water	Zheng and Zhou (2013), Yang et al. (2008); cities sewage treatment plant pollutant discharge standard in China

The modified SWAT model

The SWAT is one of the most widely used distributed models and simulates long-term flow, sediment and nutrient losses in rural watersheds. The SWAT model is suitable for complicated large watersheds with different soil types and land use, and by setting the catchment area threshold, the basin can be divided into sub-basins and these sub-basins are further discretized into HRUs. Non-persistent pathogens and persistent pathogens are the two different populations of enteric organisms that can be simulated by the SWAT model. The microbial survival and transport sub-model was first added in SWAT 2000 and was modified in the 2005 and 2009 versions. Many scholars have used the SWAT model to simulate pathogenic microorganisms (Parajuli et al. 2008; Cho et al. 2012; Frey et al. 2013).

The existing SWAT model is based on the experience and procedures of foreign countries and may not apply as well in response to the actual condition of this watershed. Water temperature data were used during the water quality simulation; however, due to the untimely determination, the equation proposed by the Stefan and Preud'Homme (1993) was used in the SWAT model to calculate the daily average temperature, where T_{water} is the water temperature in °C; $\bar{T}_{\mathrm{av}}$ is the day's temperature in °C.

$$T_{\mathrm{water}} = 5.0 + 0.75\bar{T}_{\mathrm{av}} \quad (1)$$

The water temperature equation was given by Stefan and Preud'Homme (1993) after calculating water temperatures for the tributaries to the Mississippi River in the USA. There are great differences between the Mississippi River watershed and the Miyun Reservoir watershed, with respect to both climatic conditions and geographical location. Therefore, this research will focus on the actual conditions of this watershed, and the water temperature formula will be recalculated to align the model more closely with the watershed, increasing the reliability of results during the calibration and validation processes.

The daily average temperature data of the Fengning station (2006–2009) in the Chao River watershed and daily water data of the Dage hydrologic station (2006–2009) are analyzed in this study. The Fengning station and Dage hydrological station are located in the upper reaches of Chao River watershed closely.

The indices of R^2 and S_{p} (Pilgrim et al. 1998) were used to calculate the equation's efficiency. Generally, $R^2 = 1$ and $S_{\mathrm{p}} = 0$ denote the best fit equation. The ratio $S_{\mathrm{p}}/S_{\mathrm{e}}$ should be close to 0 and R^2 close to 1 in order for an equation to be a good fit. The equations are as follows:

$$R^2 = 1 - \frac{S_p^2}{S_e^2} \quad (2)$$

$$S_p = \sqrt{\frac{\sum_{i=1}^{n} (y_i - x_i)^2}{n-1}} \quad (3)$$

$$S_e = \sqrt{\frac{\sum_{i=1}^{n} (y_i - \bar{y})^2}{n-1}} \quad (4)$$

$$\bar{y} = \frac{\sum_{i=1}^{n} y_i}{n} \quad (5)$$

where S_p is the standard error of the prediction value, y_i is the measured value of water temperature, x_i is the water temperature calculated by the temperature equation. By calculating water temperature and air temperature of this watershed, the new equation is:

$$T_{water} = 4.57 + 0.42\bar{T}_{av} \quad (6)$$

The values of R^2 and S_p were 0.87 and 1.91, respectively. Pilgrim et al. (1998) analyzed the relationship between water temperature and air temperature using daily, weekly, monthly and mean annual temperatures in the state of Minnesota. The ranges of R^2 and S_p were 0.133–0.991 and 0.21–4.86. Therefore, the conclusions of this study conform to standard statistical requirements.

Comparing (1) and (6), the intercept of (1) is 5, and the intercept of (6) is 4.57. This is not a large gap; however, the slope of (1) is 0.75, and the slope of (6) is 0.42, which is an obvious difference. Therefore, when the temperature is high, the values of the two equations are different. When the temperature is 30 °C, the gap between the two equations is approximately 10 °C. Temperature played an important role in the process of simulating bacteria; therefore, changes in water temperature may have an important impact on bacterial simulation.

The VFS module of SWAT

The VFS module in the SWAT 2009 model is used to simulate the removal of pollutants from the water in agricultural and urban regions. VFS were implemented at the HRU level with three parameters: $DAFS_{ratio}$, DF_{con} and CF_{frac}. $DAFS_{ratio}$ is the ratio of drainage area to VFS area, and CF_{frac} is the fraction of the flow through the most heavily loaded 10 % of the VFS which is fully channelized. The fraction of the HRU which drains to the most concentrated 10 % of the VFS area is defined as DF_{con}. The related formulas can refer to White and Arnold (2009). The $DAFS_{ratio}$ and DF_{con} are the most important parameters affecting removal efficiency compared to the CF_{frac}. Hence, a large number of SWAT simulations were performed to evaluate the effects of $DAFS_{ratio}$ and DF_{con} on VFS effectiveness. However, few similar studies exist for bacteria. In this study, the coefficient of determination (R^2) and the Nash–Sutcliffe efficiency (E_{NS}) were used to evaluate the performance of the model (Shen et al. 2013).

Sensitivity analysis and calibration of hydrologic parameters

Based on the actual conditions within the research area, the Chao River watershed was divided into 31 sub-basins, with XH selected as the outlet in the SWAT model. Obtaining optimum parameters for the hydrological models through calibration and validation was a very important process. The SWAT Calibration and Uncertainty Programs (SWAT-CUP) were used to calibrate the sensitive parameters and calibrate and validate the SWAT model in this paper (Abbaspour 2011). The SWAT-CUP method was selected because of its consideration of uncertainties and its high calibration efficiency (Shen et al. 2014). Table 3 summarizes the bacterial sensitivity parameter values from previous studies. In Table 3, the value of BACTKDQ (the soil partitioning coefficient in surface runoff) is generally set to 175, while THBACT (temperature adjustment factor for bacteria) is 1.07 in the watershed. WDLPS and WDPS represent the die-off factors for less persistent and persistent bacteria adsorbed by soil particles at 20 °C, respectively, both of which are lower than the values of WDLPQ and WDPQ, which represent the die-off factors for less persistent and persistent bacteria in soil solution at 20 °C. Study of the application of the SWAT model in simulating bacteria reflects that a reasonable value for THBACT is 1.07. BACTKDQ influences the number of organisms transported by surface runoff. The recommended value for this variable is 175.

The parameters sensitivity analysis result showed that the sensitivities of the two parameters (THBACT and BACTKDQ) are not very high in this paper; therefore, the values of the two parameters were set at 1.07 and 175. BACT_SWF can be specified as the fraction of manure containing organisms.

Table 3 Summary of bacterial parameter values in different studies

	Wachusett Reservoir[a]	Daoulas estuary[b]	Little Cove Creek[c]	Upper Wakarusa watershed[d]	Fergus catchment[e]
BACTKDQ	166.14	90	175	175	175
BACT_SWF	0.61	1	0.97	–	–
THBACT	–	1.070	–	1.07	1.07
WDLPQ	–	2.01	–	–	–
WDLPS	–	0.023	–	–	–
WDPQ	–	–	–	0.4	–
WDPS	–	–	–	0.04	–

[a] Cho et al. (2012), [b] Bougeard et al. (2011), [c] Kim et al. (2010), [d] Parajuli et al. (2007, 2009), [e] Coffey et al. (2010)

Related research indicates that the value of BACT_SWF is different in different stages of the animal's growth. Referencing relevant studies, as outlined in Table 3 and the actual conditions of this area, the value of the BACT_SWF was set at 1. WDLPQ and WDLPS had the highest sensitivity of all of the parameters. The values of these two parameters were set at 0.54 and 0.016 determined by the SWAT-CUP model.

Results and discussion

Results of the calibration and validation

Flow calibration and validation results are shown in Table 4. Flow was calibrated and validated at two sites (XH and GBK). The calibration period ran from 2006 to 2008, and the validation period ran from 2009 to 2010. The index values for calibration and validation at GBK and XH were no significantly different, because these two sites are relatively close geographically. The calibration and validation results for flow at the two sites are acceptable. Fecal coliform was calibrated and validated at three sites (XH, GBK and CY). Generally, $E_{NS} = 0.5$ is recommended as a lower limit; evaluation values were summarized using the SWAT model for bacterial simulation research and shown in Table 5. E_{NS} values during calibration and validation ranged from −6 to 0.63. In some watersheds, the results were very good; in other watersheds, the results are difficult to accept. In addition to the Shoal Creek watershed, the calibration results of other watersheds were <0.5. The differences in calibration results mainly resulted from the characteristics of the watershed, including land use, soil, runoff, sediment and so on (Coffey et al. 2010; Cho et al. 2012; Frey et al. 2013). In this respect, the results of this study are basically identical to other researchers' results. Therefore, so the E_{NS} of fecal coliform was acceptable during the calibration and validation period. Calibration and validation results of fecal coliform were better in this study compared with other similar studies.

Table 4 Model performance indicators of flow

Name	Calibration		Validation	
	R^2	E_{NS}	R^2	E_{NS}
XH				
Flow	0.72	0.49	0.78	0.61
GBK				
Flow	0.67	0.42	0.74	0.64

Table 6 Results of calibration and validation of fecal coliform

Name	Period	Sites	R^2	E_{NS}
The no-modified SWAT model	Calibration	CY	0.00	−1.38
		GBK	0.38	0.27
	Validation	XH	0.58	0.47
The modified SWAT model	Calibration	CY	0.11	−0.20
		GBK	0.34	0.19
	Validation	XH	0.69	0.46

The results of the modified model

The fecal coliform results of calibration are shown in Table 6. The value of E_{NS} was −0.20 at CY in the modified model, which was greatly improved compared with the −1.38 value obtained in the unmodified model. The results form GBK and XH are basically the same in both models. In the modified model, the model was recalibrated to change parameters. The parameters were adjusted, the sensitivity of WDLPQ, BACTKDQ and THBACT was not high in the SWAT-CUP model, but the sensitivity of WDLPS was very high; additionally, an increase or decrease of 0.01 units for this variable had a strong impact on the results. In the modified model, the value of WDLPS was 0.020 compared with 0.016 in the original model in the SWAT-CUP model. Thus, changing the temperature affects temperature model migration, and the change made to bacteria is essential. Thus, changing the temperature equation has a significant influence on bacteria.

Water temperature is the most important factor in the growth and survival of bacteria because it can affect

Table 5 Summary of calibration and validation goodness-of-fit criteria in different studies

	Upper Wakarusa watershed[a]			Payne River watershed[b]		Shoal Creek watershed[c]		James River basin[d]	
	Rock Creek	Deer Creek	Auburn	Calibration	Validation	Calibration	Validation	Calibration	Validation
R^2	0.42	0.41	0.36	0.002	0.030	0.7 (monthly) 0.40 (daily)	0.66 (monthly) 0.61 (daily)	0.00–0.09	0.01–0.26
E_{NS}	0.20	0.31	−2.20	−0.154	−0.192	0.63 (monthly) 0.21 (daily)	0.61 (monthly) 0.54 (daily)	−6 to 0.03	−0.08 to 0.21
p_{bias}	–	–	–	88.870 %	69.942 %	–	–	−56 to 92 %	20 to 80 %

[a] Parajuli et al. (2009), [b] Frey et al. (2013), [c] Benham et al. (2006), [d] Baffaut and Benson (2009)

bacterial enzymes. After the SWAT model was modified, seasonal changes (i.e., from winter to summer), the elevated level of water temperature is less than the original model; therefore, modeled enzymatic activity is decreased, and the death rate of fecal coliform was slowed down. The fecal coliform concentration in water increased; therefore, the values of parameters were altered.

As seen in the equation of bacteria equation in the SWAT model, water temperature plays an important role in the bacterial growth/death process. The THBACT (0–10) parameter was designed to adjust the influence of water temperature in this equation. This parameter is a regulator in the equation and can adjust the water temperature values within a certain range. However, the results of this study indicate that there is a significant gap between Eqs. (1) and (6). The temperature regulating factor cannot completely erase this gap, which may lead to a large error during the adjustment process. As a result, it is necessary to modify the model produce a better simulation.

At present, the bacteria module of the SWAT model was modified; however, some researchers still think the SWAT simulation is limited in its ability to simulate bacteria. The studies of modified SWAT models mainly focus on two aspects: sediment release and radiation. However, many factors influence bacteria, including temperature, runoff, sediment and radiation. In this study, temperature factors were considered based on previous research. Combined with the results of other studies, this research can provide some reference for improving the simulation precision of SWAT.

Parameter optimization of vegetative filter strips

Research shows that $DAFS_{ratio}$ and DF_{con} have a significant impact on bacteria removal efficiency. With the increase of $DAFS_{ratio}$ and DF_{con}, the removal efficiency may achieve lower values. $DAFS_{ratio}$ values from 5 to 200 and DF_{con} values from 0.2 to 0.8 were explored in nitrogen, phosphorus and sediment, and all results fit the general trend of reduced effectiveness at higher values (White and Arnold 2009). However, few studies address the impacts on bacteria levels. This study explored the impact of $DAFS_{ratio}$ (20, 50, 80, 120, 150) and DF_{con} (0.25, 0.4, 0.6, 0.75) on the removal of fecal coliform. The results are shown in Fig. 2. Similar conclusions can be drawn from Fig. 2 as from previous researchers' efforts (Cheng and Song 2009; White and Arnold 2009). There is a trend of reduced effectiveness at higher values of $DAFS_{ratio}$ and DF_{con}.

Many scholars have discussed vegetation buffer parameters. White and Arnold (2009) evaluated the effect of $DAFS_{ratio}$ and DF_{con} on VFS effectiveness with different materials, which contained part. nitrogen, nitrate nitrogen, part. phosphorus, soluble phosphorus and sediment with $DAFS_{ratio}$ values from 5 to 200 and DF_{con} values from 0.2 to 0.8. The

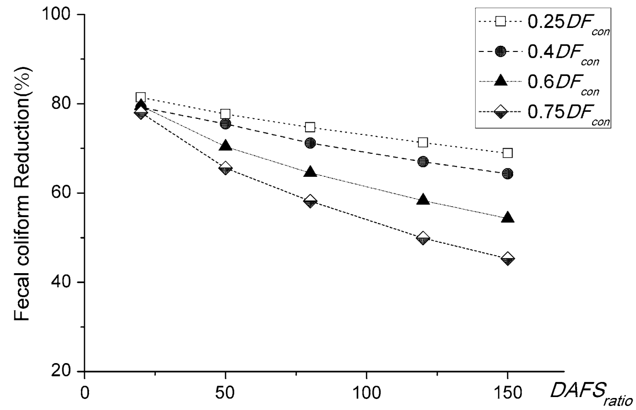

Fig. 2 Fecal coliform reduction in a vegetative filter strip

removal effect on different types of non-point source pollutants varies widely. In White and Arnold's research results, when $DAFS_{ratio}$ was 50 and DF_{con} was 0.6, the reductions of part. nitrogen, nitrate nitrogen, part. phosphorus, soluble phosphorus, and sediment were approximately 50, 85, 60, 70 and 60 %, respectively. Cheng and Song (2009) summarized effective buffer area ratio (the ratio of buffer area to field runoff area) in relation to sediment trapping efficiency. When the ratio increased, sediment trapping efficiency also increased.

Conclusion

Water flow and fecal coliform samples in the Chao River watershed of the Miyun Reservoir were calibrated and validated based on a modified SWAT model. According to the VFS module of the SWAT model, fecal coliform removal efficiency was simulated using VFS parameters. The results show that the modified SWAT in the Chao River watershed can be the more aligned with actual conditions and has good applications for simulating fecal coliform. Based on similar studies, this study modified the temperature factors of the bacterial module in the SWAT model. Combining other research on bacterial model modifications makes the simulation more complete. In this study, through the simulation of two of the most important parameters in VFS, fecal coliform removal efficiency rules were identified that may provide the basis for the future research. The present research shows that VFS have positive effects on sediments, nutrients and bacteria; however, simulation studies on fate, transport and removal efficiency are fewer for pathogenic microorganisms. The removal of nutrients and sediment using VFS are given based on are a large number of experiments; however, due to a lack of measured data, the models of pesticides and bacteria are based on assumptions. This article hopes to provide suggestions for VFS simulations based on SWAT. The hope is that more research using long-term simulations and studying pathogenic microorganism removal methods can be performed in the agricultural watersheds. More reliable information of fecal contamination can be provided by the modified SWAT model. The results of fecal contamination and VFS can provide effective watershed management information for watershed management.

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