PRINT ISSN 1119-8362
Electronic ISSN 1119-8362

Full-text Available Online at
https://www.ajol.info/index.php/jasem
http://www.bioline.org.br/ja

J. Appl. Sci. Environ. Manage.
Vol. 26 (5) 865-870 May 2022

Non-Point Source Pollution Modelling: An Overview

[1]*ABDULKAREEM, JH; [2]SOLOMON, RI

*[*1]Department of Soil Science, Institute for Agricultural Research, Faculty of Agriculture, Ahmadu Bello University, Zaria, Nigeria.*
[2]Department of Soil Science, Faculty of Agriculture, Modibbo Adama University, Yola, Nigeria.

**Corresponding Author Email: abdulkareemjabir@yahoo.com; jhabdulkareem@abu.edu.ng*
Other Author(s) Email: solomonri@mautech.edu.ng; rejoice605@gmail.com

ABSTRACT: The objective of this paper is to provide a critical evaluation of the data available from existing studies concerning non-point source pollution (NPS). NPS pollution is complex and difficult to detect and manage when compared with point source pollution. To tackle its risk, it is vital to have precise simulations and estimations of NPS pollutants. Different modelling techniques applied to NPS pollution were reviewed and classified as either physically-based models or empirical. The physically-based models (White box models) can be used both for long-term and daily time steps. They require initial model data as well as watershed morphological and physiographic, which makes them complex and not easy to use. Empirical models on the other hand are called black-box models or metric models and can be used for both long-term, daily time steps with minimal data requirement and requires less skill to operate. Although their results are easy to interpret, these types of models are only suitable within the boundary of a certain domain. The findings of this review will serve as a guide to water resource planners in identifying the type of NPS model they need to apply to a particular catchment for a particular problem.

DOI: https://dx.doi.org/10.4314/jasem.v26i5.13

Impact factor: http://sjifactor.com/passport.php?id=21082

Google Analytics: https://www.ajol.info/stats/bdf07303d34706088ffffbc8a92c9c1491b12470

Dates: Received: 08 December 2021; Revised: 13 April 2022; Accepted: 11 May 2022

Keywords: Non-point source pollution, modelling, LULC change, overview

Non-point source (NPS) pollution is peculiar to complex mechanisms and techniques that are random and sporadic in occurrence. They also possess uncertainty with regards to discharge in channels and amounts and variability in both temporal pollution loads, which results in difficulties in monitoring, simulation, treatment as well as control. To tackle the risk of NPS pollution, it is vital to have precise simulations and estimations of NPS (Abdulkareem *et al*., 2018a; Shen *et al*., 2012). In recent times, international attention has been given to NPS pollution as a potential problem in environmental water management. Land-use changes through agriculture and urbanization as well as climate change have been notoriously recognized as the major contributing sources of NPS pollution (Abdulkareem *et al*., 2018b; Ongley *et al*., 2010; Tang *et al*., 2005; Basnyat *et al*., 2000). NPS pollution is often caused by runoff from rainfall, atmospheric deposition, seepage, drainage problems or hydrologic changes in a watershed (Tong *et al*., 2021). Climate change in particular affects the hydrological cycle by altering the physical and chemical processes, migration and transformation capacity of pollutants as well as the ability of water bodies to dilute pollutants resulting in deteriorating surface water quality (Feng *et al*., 2021). Therefore, the need to evaluate different modelling techniques applied to NPS pollution and likely changes in water quality in the future is important for informed planning and adaptive management.

Sources of non-point source pollutants: The sources of NPS pollution are diverse unlike that from industrial and sewage treatment plants, which come from the same sources. Runoff from rainfall and melting snow carry along with them contaminants from different sources known as NPS pollutants. These pollutants range from natural to man-made pollutants which are usually deposited into water bodies by runoff water (EPA, 2017). To effectively manage an NPS pollutant,

**Corresponding Author Email: abdulkareemjabir@yahoo.com; jhabdulkareem@abu.edu.ng*

such as nutrient loads from the agricultural system, Lai *et al*. (2011); Nikolaidis *et al*. (2006) opined that careful knowledge of the pollutant transport and delivery pathways in the watershed system is essential.

NPS Pollution from agricultural runoff: NPS pollution from agricultural runoff is among the major causes of pollution found in water bodies. This type of pollution usually results from agrochemicals transferred during heavy rainfall events as well as via soil erosion (Ahmad *et al*., 2015). The occurrence of NPS pollution from agricultural runoff is a threat to water quality, aquatic animals and other uses associated with water resources. Some of the pollutants associated with NPS from agriculture include nutrients, pesticides, herbicides, disease pathogens, sediment, heavy metals etc. This has, therefore, become imperative for farmers who release runoff water from agriculture to act following water quality guidelines set by relevant authorities and to carry out best management practices that will control NPS pollution (Abdulkareem *et al*., 2018a; O'Geen *et al*., 2010).

Several studies on NPS pollution from agricultural runoff have been conducted around the world in recent years. Chang *et al*. (2017) used SWAT and a two dimensional and hydrodynamic model to monitor total N (TN) and total P (TP) at Yuqiao Reservoir, China. From their results, it was observed that Liu Xiangying and Wu Baihu were the main TN inlets. They were observed to be the major point of entry for TN and the mean TN concentration in the reservoir reach the highest level in September (3.74 mg/L). TP concentration in the eastern region of Yuqaio Reservoir was observed to exceed that in the west and the mean TP concentration was at its peak in August (1.56 mg/L). In another research carried out in Korea, SWAT was also used to examine NPS pollution changes of TN, TP and sediment for 30 years (2011-2040) giving regard to uncertainties in climate change scenario data (Cho *et al*., 2016). The results showed that sediment and TP loads are more likely to be affected by the features of climate variables by presenting an increasing trend in most sub-basins. Uncertainty ranges from sediment and TP recorded higher loads during the wet season (June-September).

De Girolamo *et al*. (2017) used a correlation coefficient to determine the contribution of human input of nitrogen (N) in agriculture dominated watersheds and to estimate the amount of nitrate estimated from the catchment to Celone River, Italy. They observed variations in nitrate concentrations in surface waters across the seasons. Furthermore, nitrate was estimated to be around 14 kg N ha^{-1} $year^{-1}$ around the riverine areas and NPS inputs obtained through agricultural activities mainly fertilizers and animal manure are equivalent to 68.2 and 24 kg N ha^{-1} $year^{-1}$, respectively. The Annualized Agricultural Non-Point Source Pollution (AnnAGNPS) model was used to simulate TN, TP and sediment in East-Central Mississippi, USA (Karki *et al*., 2017). The model effectively simulated runoff, sediment, and P but not N due to data scarcity in the study area. Assessment of on-farm water storage indicated 220,000 m^3 of runoff was captured by the system from the monitored catchment, which can be utilized for irrigation. The model simulated that the on-farm water storage system was able to save up to 46 tons of sediment and 558 kg of P during the surveillance period. Hence, averting pollution of downstream areas with nutrients and sediment.

Nitrate-N, P and sediments were simulated by Kollongei and Lorentz (2015) using The Agricultural Catchment Research Unit-Nitrates, Phosphorous and Sediments (ACRU-NPS) model in Mkabela catchment, South Africa. The research was carried out to develop and integrate algorithms for simulating crop growth and NPS pollution changes and to estimate nutrients and sediment for different land uses. The model was successfully utilized in simulating NPS pollutant load in the area. Results from the model indicated that the decrease in nutrient and sediment load was due to best management practices (BMPs) carried out by introducing buffer strips, wetland maintenance and flood control. In a different study, new methods for simulating potential loadings of manure and chemical fertilizers in water from different sources of land use types, animal production, fertilizers and other agricultural chemicals as well as combined sewage overflows were developed (He, *et al*., 2008). The study which was conducted in Saginaw Bay Basin, USA focused on TN, TP and Atrazine and utilized Distributed large basin runoff (DLBRM) model for the simulation. The simulated model results obtained will serve in the provision of information to researchers and decision-makers for the development of total maximum daily load programs for abating NPS pollution in the study area.

NPS pollution from urban runoff: Rapid increase in urbanization has led to the geographical modification of most watersheds, thereby increasing pollutant load build-up due to an increase in impervious surfaces. An accurate description of such pollutants is necessary for land-use planners, environmental managers and policymakers alike (Chen *et al*., 2015). Li *et al*. (2016) used a long-term hydrologic impact assessment model (L-THIA) to evaluate the spatial and temporal variation of NPS pollutant loads as well as the relationship between NPS pollution and the level of urbanization in Baoan District, Shenzhen, China. They were able to observe significant changes in NPS pollutant loads both spatially and temporally. While chemical oxygen demand (COD), total suspended solids (TSS), TN and TP loads were found to be influenced by the relationship between EMC, spatial distribution as well as the degree of changes in land use.

The treatment and performance of infiltration trench based on stormwater runoff quality data collected from long-term measurements in the rainy seasons from June 2006 to September 2008 was assessed by Maniquiz *et al*. (2010) in Yong-in city, Korea. Results obtained demonstrated high treatment efficiencies for total suspended solids (89%); biochemical oxygen demand (BOD), COD, and dissolved organic carbon (89–93%); oil and grease (100%); cadmium, lead, and zinc (89–93%); TN (84%); and TP (82%). The monitored data can be used to enhance effective forecasting of NPS pollution effects on the environment and for the national development of BMPs for sustainable management of the studied watershed.

Nazahiyah *et al*. (2007) used EMC to interpret the behaviour of pollutant loads regarding rainfall intensity and size as well as to estimate pollutant loads in an urban catchment (Skudai, Johor, Malaysia). The stormwater quality in the urban catchment was found to be highly polluted based on National Water Quality Standards for Malaysia and a variation was observed between storms with regards to EMC values of all parameters. In another research, the environmental effects of land use/cover (LULC) change due to urbanization, long-term runoff and NPS pollution was fully assessed in the Muskegon River watershed, Michigan, USA (Tang *et al*., 2005). Pollutants such as N, P, Cr, Cu, Ni, Pb, oil and greases were monitored during the research using Land Transformation Model (LTM). Results indicated that the watershed has the probability to be influenced by the impacts of runoff and some NPS pollutant loads. An increase in runoff volume was caused by urbanization, which is dependent on the rate of development, increase in nutrient losses due to runoff as well as loss of oil and grease and heavy metals during runoff.

Effect of NPS pollution on LULC changes: Control measures for NPS pollution has been fully implemented in most watersheds in the past. However, the issue of water quality deterioration is still posing a challenge mainly due to the deposition of NPS pollutants into water bodies and LULC changes. NPS pollution being not from the same source is usually spatially deposited into water bodies by surface and subsurface runoff from rainfall events and by irrigation return flows. NPS pollution is a complex and difficult problem to detect, isolate and manage when compared with point source pollution (Dzikiewicz, 2000; Lai *et al*., 2011; Ouyang *et al*., 2014). The major NPS pollutants that cause significant pollutant loading to water bodies and deteriorate their quality are suspended solids, N, P, fertilizers, pesticides, herbicides as well as other organic and inorganic materials. Watershed characteristics such as LULC change, soil, topography and rainfall intensity have been proven to affect the quantity and quality of NPS pollution (Abdulkareem *et al*., 2018a).

NPS Pollution Modelling: For better planning and control of non-point source (NPS) pollutants, accurate predictions and estimations are required using NPS models. The use of models in NPS pollution control is regarded as the most essential and direct technique for quantifying spatial and temporal differences in NPS pollution and managing NPS pollutants. NPS models are used for the identification of origin and transport pathways, prediction of pollutant load as well as its effect on the environment. They are also used to assess different LULC planning and control strategies for NPS pollution (Zhang *et al*., 2010; Shen *et al*., 2012). Owing to the rapid increase in knowledge of the effect of NPS pollution is damaging water quality, several models were developed over the last three decades that predict the behaviour, migration and fate of NPS pollution. Such models are useful in evaluating the environmental effect of nutrients, sediments, heavy metals etc. on water bodies. These models vary in their complex nature to their simplicity, ranging from simple empirical to process-based that integrate complex physical, chemical, and biological approaches that govern NPS pollutant transport. Examples of NPS models include the export coefficient model (ECM), L-THIA, SWAT, Areal, and Nonpoint Source Watershed Environmental Response Simulation (ANSWERS). The characteristics of NPS pollution models are presented in Table 1.

Physically Based and Process-based NPS Pollution Models: The use of physically-based, distributed, and empirical models is common in most developed countries. Although the use of such models is not common in most developing countries around the world. Examples of these models include L-THIA, SWAT, SWRRB (Simulator for Water Resources in Rural Basins), BASINS (Better Assessment Science Integrating Point and Non-point Sources), and AGNPS (Agricultural Non-Point Source Pollution).

Table 1: Summary characteristics of NPS pollution models

Description/Criteria	Physically-based model	Empirical model
Example	L-THIA, SWAT, SWRRB (Simulator for Water Resources in Rural Basins), BASINS (Better Assessment Science Integrating Point and Non-point Sources), AGNPS (Agricultural Non-Point Source Pollution).	Numeric integration, Export coefficient model, Mean concentration method, Rainfall deduction method, Correlation method of water quality and quantity
Component	White box model or mechanistic	Black box model or metric
Temporal scale	Long term, daily steps.	Long term, daily steps.
Process-driven	Spatial distribution is driven, by the assessment of parameters outlining physiographic features.	Mathematical equations with values derived from time series.
Data requirement	Initial model data required as well as watershed morphological and physiographic features	Minimal data requirement
Outputs	comprehensive and precise	Simple with less information
Operational capability	Often complex and not easy to use. Computational capability is high.	Requires less skill to operate and the results are easy to interpret.
Watershed representation	Suitable for several conditions	Suitable within the boundary of a certain domain.

(Adopted from Borah & Bera, 2003; Shen et al. 2012)

Long-term Hydrologic Impact Assessment (L-THIA) model: The L-THIA model is broadly applied for the evaluation of the influence of LULC change on the environment. The model techniques are easy to use for the prediction of runoff and NPS pollution caused by LULC changes. It uses long-term rainfall data to give predictions of NPS pollution according to the LULC of the area. The rationale behind using long-term is that the model can emphasize changes in the environment thereby reducing statistical variance resulting from extreme rainfall events due to climate variability. The NRCS-CN methodology just like many other hydrological models is the core component of the L-THIA model. Runoff and NPS pollution prediction in the model is based on distributed CN approach (Harbor, 1994; Ma, 2004). Several studies from different parts of the world applied L-THIA for NPS pollution modelling. The L-THIA model was applied by Zhang *et al*. (2010) to produce an effective and actual NPS pollution model for local water resources in Qingdao Watershed, China. The NPS pollutants monitored during the study are nitrate-N, dissolved P, BOD and COD. The results showed that the developed model was found to be reliable in projecting an increase in pollution levels. Hence, it can be adopted for the provision of information on land use and environmental protection planning. Jang *et al*. (2013) carried out a study to improve the reliability of the L-THIA model by developing a genetic algorithm-based automatic calibration module and to test the performance of the developed algorithm in estimating runoff and pollutant loads in the Paldang watershed, South Korea. The results showed that the web-based auto-calibration module integrated with L-THIA 2012 could be utilized to reliably estimate surface runoff and NPS pollutions not only in the study area but also in the entire globe. They also found that the developed algorithm can be used to provide a tool for BMPs that can be adopted by decision-makers. The combined use of the export coefficient model (an empirical model) and L-THIA was utilized to evaluate the influence of a future increase in urbanization on runoff, TN, TP and total suspended particles in the Richland Creek watershed, USA (Choi, 2007). An increase in the direct runoff by 7% and total suspended particles by 4% was projected by the model to occur by 2030 while a rapid increase in urbanization will result in low changes in TN and TP. Changes in the watershed were a result of the predicted increase in LULC change, precisely conversion of agricultural lands to industrial areas or low-intensity residential areas that will increase imperviousness which favours runoff and NPS pollution build-up. The results of the study indicated the influence of urbanization on water quality, hence providing possible solutions on how effective planning and control can be carried out on the rapid increase in urbanization for impact assessments in the watershed. In another research, the Spatio-temporal changes of NPS pollutants were assessed in the Nansi Lake basin, China by Zhang *et al*. (2016). Results of the study showed that COD, TN and TP loads recorded loads of 260017.5, 111607.7 and 6372.0 t with a greater percentage of the load (approximately 90%) obtained during the rainy season (June to September). The land use pattern in the study area is taken by about 80% cultivated land and construction land with their proportion exceeding 98%. Furthermore, an increase in COD, TN and TP loads was observed from 2000-to 2010, which is the influencing factor governing water quality in the watershed.

Empirical NPS Pollution Models: Empirical models are primarily produced for analyzing both water quantity and quality data in hydrology. The main aim of this technique is to carefully focus on the pollutant migration pathway by carefully calculating the amount produced from water quality at the delivery pathway (Shen *et al*., 2012). Empirical models built with large data capability can be suitable for watersheds with reasonable background information and can be used for the prediction of NPS pollution at the local level with reliability. However, the use of these models should be done with caution, as they are only applicable to certain watersheds due to their limited utilization productivity. As the basin characteristics changes, the efficiency of model results is hindered. (Shen *et al*., 2012).

Export coefficient model (ECM): The export coefficient model (ECM) is one of the most widely used empirical NPS pollution models due to its reliability and ease of use. The model uses the concept of pollutants load migrating from a watershed as the total of all losses from different sources such as LULC, agricultural fields, livestock etc. In addition, the model adopts a large time interval (monthly, seasonal or annual), which allows the use of temporal and spatial lumped data instead of measured data and agricultural data from census instead of field measured data. The ECM has been applied in several parts of the world for NPS pollution modelling e.g., Fleifle, *et al*. (2014), Salerno *et al*. (2014) Wang *et al*. (2015), Palviainen *et al*. (2016), Hou, *et al*. (2017), (Abdulkareem *et al*. (2018b) etc.

*Conclusions***:** Suspended solids, N, P, fertilizers, pesticides, herbicides as well as other organic and inorganic materials are observed to be the major NPS pollutants that cause significant pollutant loading to water bodies and deteriorate their quality. NPS models are classified as either physically-based models such as L-THIA, SWAT, etc. or the empirical models such as Numeric integration, Export coefficient model etc. The findings of this review will serve as a guide to water resource planners in identifying the type of NPS model they need to apply to a particular catchment for a particular problem.

REFERENCES

Abdulkareem, JH; Sulaiman, WNA; Pradhan, B; Jamil, NR (2018a). Long-Term Hydrologic Impact Assessment of Non-point Source Pollution Measured Through Land Use/Land Cover (LULC) Changes in a Tropical Complex Catchment. *Earth Syst. Environ.* 2, 67–84.

Abdulkareem, JH; Jamil, NR; Sulaiman, WNA (2018b). Non-Point Source (NPS) Simulation in a Tropical Complex Catchment. International *J. App. Environ. Sci.* 3, (2). 145-160

Ahmad, ZU; Sakib, S; Gang, DD (2016). Nonpoint source pollution. *Water Environ. Res.*, 88(10), 1594-1619.

Basnyat, P; Teeter, LD; Lockaby, BG; Flynn, KM (2000). The use of remote sensing and GIS in watershed level analyses of non-point source pollution problems. *For. Ecol. Manage.* 128(1–2), 65–73.

Borah, DK; Bera, M (2003). Watershed-scale hydrologic and nonpoint-source pollution models: Review of mathematical bases. *T. ASABE*, 46(6), 1553.

Chang, D; Lai, Z; Li, S; Li, D; Zhou, J (2021). Critical source areas' identification for non-point source pollution related to nitrogen and phosphorus in an agricultural watershed based on SWAT model. *Environ Sci and Poll Res*, *28*(34), 47162-47181.

Chang, C; Sun, D; Feng, P; Zhang, M; Ge, N (2017). Impacts of Nonpoint Source Pollution on Water Quality in the Yuqiao Reservoir. *Environmental Eng Sci*, 34(6), 418–423.

Chen, Y; Xu, Y; Yin, Y (2009). Impact of land-use change scenarios on storm runoff generation in Xitiaoxi basin, China. *Quat. Int*, 208(1– 8), 121–128.

Cho, J; Oh, C; Choi, J; Cho, Y (2016). Climate change impacts on agricultural non-point source pollution with consideration of uncertainty in CMIP5. *Irrig. Drain.* 65, 209–220.

Choi, W. (2007). Estimating land-use change impacts on direct runoff and non-point source pollutant loads in the Richland Creek basin (Illinois, USA) by applying the L–THIA model. *J. Spat. Hydrol.* 7(1).

De Girolamo, A. M., D'Ambrosio, E., Pappagallo, G., Rulli, M. C: Lo Porto, A. (2017). Nitrate concentrations and source identification in a Mediterranean river system. *Rendiconti Lincei.* 28(2), 291–301.

Dzikiewicz, M. (2000). Activities in nonpoint pollution control in rural areas of Poland. *Ecol. Eng.*, 14(4), 429–434.

EPA (Environmental Protection Agency) (2022). Polluted Runoff: Nonpoint Source Pollution. Retrieved from https://www.epa.gov/nps 24/02/2022.

Feng, M; Shen, Z (2021). Assessment of the Impacts of Land Use Change on Non-Point Source Loading under Future Climate Scenarios Using the SWAT Model. *Water*, *13*(6), 874.

Fleifle, A; Saavedra, O; Yoshimura, C; Elzeir, M; Tawfik, A (2014). Optimization of integrated water quality management for agricultural efficiency and environmental conservation. *Environ Sci. Pollut. Res.*, 21(13), 8095–8111

Harbor, JM (1994). A practical method for estimating the impact of land-use change on surface runoff, groundwater recharge and wetland hydrology. *J. Am. Plan. Assoc.*, 60(1), 95–108.

He, C; Demarchi, C; Croley, TE (2008). Modeling spatial distributions of nonpoint source pollution loadings in the Great Lakes Watersheds by using the Distributed Large Basin Runoff Model 1. In Proceedings of the Papers of American Water Resources Association GIS and Water Resources 2008 Spring Specialty Conference, San Matteo, California (pp. 1–7).

Hou, Y; Chen, W; Liao, Y; Luo, Y (2017). Modelling of the estimated contributions of different sub-watersheds and sources tophosphorous export and loading from the Dongting Lake watershed, China. *Environ. Monit. Assess*. 189(12)

Jang, C; Kum, D; Jung, Y; Kim, K; Shin, D; Engel, B; Lim, K (2013). Development of a Web-Based L-THIA 2012 Direct Runoff and Pollutant Auto-Calibration Module Using a Genetic Algorithm. *Water*, 5(4), 1952– 1966.

Karki, R; Tagert, MLM; Paz, JO; Bingner, RL (2017). Application of AnnAGNPS to model an agricultural watershed in East-Central Mississippi for the evaluation of an on-farm water storage (OFWS) system. *Agric. Water Manage.* 192, 103–114.

Kollongei, KJ; Lorentz, SA (2015). Modelling hydrological processes, crop yields and NPS pollution in a small sub-tropical catchment in South Africa using ACRU-NPS. *Hydro. Sci. J.*, 60(11), 2003–2028

Lai, YC; Yang, CP; Hsieh, CY; Wu, CY; Kao, CM (2011). Evaluation of non-point source pollution and river water quality using a multimedia two model system. *J. Hydrol.*, 409(3–4), 583–595.

Li, ZHOU; LI, LZ; Huang, JK (2021). The river chief system and agricultural non-point source water pollution control in China. *J. Integr. Agric.*, *20*(5), 1382-1395.

Li, T; Bai, F; Han, P; Zhang, Y (2016). Non-Point Source Pollutant Load Variation in Rapid Urbanization Areas by Remote Sensing, GIS and the LTHIA Model: A Case in Bao'an District, Shenzhen, China. *Environ. Manage*. 58(5), 873–888

Ma, Y (2004). L-THIA: a useful hydrologic impact assessment model. *Nature and Science*, 2(1), 68–73.

Maniquiz, MC; Lee, SY; Kim, LH (2010). Long-Term Monitoring of Infiltration Trench for Nonpoint Source Pollution Control. *Water Air Soil Pollute*. 212(1–4), 13–26

Nazahiyah, R; Yusop, Z; Abustan, I (2007). Stormwater quality and pollution loading from an urban residential catchment in Johor, Malaysia. *Water Sci. Technol.*, 56(7), 1–9.

Nikolaidis, NP; Karageorgis, AP; Kapsimalis, V; Marconis, G; Drakopoulou, P; Kontoyiannis, H; Pagou, K (2006). Circulation and nutrient modeling of Thermaikos Gulf, Greece. *J Mar Syst*, 60(1), 51–62.

O'Geen, AT; Budd, R; Gan, J; Maynard, JJ; Parikh, SJ; Dahlgren, RA; (2010). Mitigating nonpoint source pollution in agriculture with constructed and restored wetlands. In *Advan. Agron*. (1st ed., Vol. 108, pp. 1–76). Elsevier Inc.

Ongley, E. D., Xiaolan, Z., Tao, Y. (2010). Current status of agricultural and rural non-point source pollution assessment in China. *Environ. Pollute*. 158(5), 1159–1168.

Ouyang, W; Song, K; Wang, X; Hao, F (2014). Non-point source pollution dynamics under long-term agricultural development and relationship with landscape dynamics. *Ecol. Indic.*, 45, 579–589.

Palviainen, M; Laurén, A; Launiainen, S; Piirainen, S (2016). Predicting the export and concentrations of organic carbon, nitrogen and phosphorus in boreal lakes by catchment characteristics and land use: A practical approach. *Ambio*, 45(8), 933–945

Salerno, F; Viviano, G; Carraro, E; Manfredi, EC; Lami, A; Musazzi, S; Marchetto, A; Guyennon, N; Tartari, G; Copetti, D (2014). Total phosphorus reference condition for subalpine lakes: a comparison among traditional methods and a new process-based watershed approach. *J. Environ. Manage. 145*, 94-105.

Shen, Z; Liao, Q; Hong, Q; Gong, Y (2012). An overview of research on agricultural non-point source pollution modelling in China. *Sep. Purif. Technol*., 84, 104–111.

Tong, X; Zhou, Y; Liu, J; Qiu, P; Shao, Y (2022). Non-point source pollution loads estimation in Three Gorges Reservoir Area based on improved observation experiment and export coefficient model. *Water Sci. Technol. 85*(1), 27-38.

Wang, J; Shao, J; Wang, D; Ni, J; Xie, D (2015). Simulation of the dissolved nitrogen and phosphorus loads in different land uses in the Three Gorges Reservoir Region - Based on the improved export coefficient model. *Environ. Sci.: Process. Impacts*, 17(11), 1976–1989.

Zhang, BL; Yin, L; Zhang, SM; Engel, B; Theller, L (2016). GIS and L-THIA based analysis on variations of non-point pollution in in Nansi Lake basin, China. *J. Donghua Univ.* (*English Edition*), 33(6), 851–858.

Zhang, J; Shen, T; Liu, M; Wan, Y; Liu, J; Li, J (2010). Research on non-point source pollution spatial distribution of Qingdao based on L-THIA model. *Math. Comput. Model.* 54(3–4), 1151–1159