doi:10.2489/jswc.69.4.121A

FEATURE

Worldwide performance and trends in nonpoint source pollution modeling research from 1994 to 2013: A review based on bibliometrics

Sisi Li, Yanhua Zhuang, Liang Zhang, Yun Du, and Hongbin Liu

Water quality deterioration as a consequence of nonpoint source (NPS) pollution or diffuse pollution has been documented around the world (Davis and Koop 2006; Ma et al. 2011; Novotny 1999; Smith 2003). This deterioration not only damages the social and ecological functions of water bodies as water supply, fisheries, ecosystem maintenance, and recreation (Pretty et al. 2003), but also largely raises water treatment and policy response costs (Novotny 1999; Pretty et al. 2003). Understanding and evaluating the processes of pollution generation, transport, and transformation are continuous challenges for scientists and engineers. Modeling as a way to simplify the complex natural processes has been widely used in NPS pollution research (Zhuang et al. 2012). There are various NPS pollution models available now, which were summarized and compared in different previous studies (Alexander et al. 2002; Borah and Bera 2003; Shen et al. 2012). These reviews of available models are meaningful, though they hardly provide a direct overview of worldwide research efforts and the general trends in NPS pollution modeling. Since researchers have conducted research in this field for several decades, a comprehensive and quantitative review of past efforts, including influencing researchers and their performance, participating regions and their activity, and general shift of key issues, will provide an informed perspective on future research.

Bibliometrics, which utilizes visual and quantitative analysis to summarize trends in selected research fields (Pritchard 1969), can reveal research patterns of certain field, such as publication output, author performance, geographical distribution of publications, scientific cooperation, and temporal variation of hot issues (Liu et al. 2011; Zhuang et al. 2012). The quantitative and visual characteristics of bibliometric analysis are important supplements to traditional literature reviews. This paper presents worldwide performance and trends in NPS pollution modeling from 1994 to 2013 based on bibliometric methods.

Sisi Li is a graduate student, **Yanhua Zhuang** is an assistant professor, **Liang Zhang** is an associate professor, and **Yun Du** is a professor at the Key Laboratory of Environment and Disaster Monitoring and Evaluation, Hubei, Institute of Geodesy and Geophysics, Chinese Academy of Sciences, Wuhan, China. **Hongbin Liu** is a professor at the Key Laboratory of Nonpoint Source Pollution Control, Institute of Agricultural Resources and Regional Planning, Chinese Academy of Agricultural Sciences, Beijing, China.

BIBLIOMETRIC DATABASE AND ANALYSIS

The bibliometric database of this review was built with articles related to NPS pollution modeling from Science Citation Index (SCI) via Web of Science, published from 1994 to 2013. Nearly all phrases representing nonpoint source pollution ("non point source*," "non-point source*," "diffuse pollut*," "diffuse source*," etc.) and words representing modeling (including "model*," "simulate," and "simulation") were used as search terms to obtain all articles that contain these words in titles, abstracts, or keywords. The citations of articles used to evaluate authors' academic influences were updated to January 1, 2014.

A total number of 2,179 articles related to NPS pollution modeling during the past two decades (1994 to 2013) were found in SCI database. All the articles were analyzed with the following aspects: (1) author performance and cooperation, (2) geographical distribution of institute-publication activity, and (3) temporal evolution of keywords. The author cooperation network was drawn using NetDraw. The institutes' locations and their publication activity were extracted from author addresses using CiteSpace (Chen 2006) and visualized in ArcGIS software.

AUTHOR PERFORMANCE AND COOPERATION

Table 1 lists the 30 most productive authors in NPS pollution modeling. Among them, the first 27 ranked top 27 with total articles (TA), and the other 3 authors ranked top 10 with articles as first author or correspondence author (FCA). Besides article productivity (TA and FCA), the academic impacts of the authors were also shown with three indices: total citations (TC), citation per publication (CPP), and *h*-index (an impact factor developed by Hirsch [2005] that incorporates both quantity [publications] and quality [citations] of a researcher's scientific outputs). The cooperation clusters of the 30 authors are depicted in figure 1. The size of the nodes represents the *h*-index of the authors, and the thickness of the ties between nodes represents the numbers of coauthored articles.

Generally, the 30 authors were from three regions: North America, Europe, and Asia. As can be seen from figure 1, author cooperation was mainly confined to their institutes and weak across the three continents. United States and Europe accounted for 13 and 9 authors of the top 30, respectively. Furthermore, 5 of the 13 authors in the United States and 5 of the 9 authors in Europe had very high academic impacts, ranking top 10 in either TC, CPP, or *h*-index. Besides United States and Europe, China also had 7 authors in the list. Four of them ranked top 10 in FCA, while none of them were in the top 10 for academic impact indices (TC, CPP, and *h*-index).

In terms of individuals, J.G. Arnold, an agricultural engineer from USDA Agricultural Research Service (USDA-ARS), was the most productive and influential researcher in NPS pollution modeling in last two decades. Among the 30 authors, Arnold had most cooperators and ranked first for all indices except FCA. Arnold and his closest cooperator, R. Srinivasan from Texas A&M University, are two main developers of Soil and Water Assessment Tool (SWAT), a process-based model to simulate the quality and quantity of surface and ground water and to predict impact of land management practices and climate change on water, sediment, and chemical yields (Arnold et al. 1998). F. Bouraoui had only 15 articles, but a high *h*-index of 11. Bouraoui added chemi-

Table 1

Thirty most productive authors and their academic impacts.

Author/institute	TA	FCA(R)	TC(R)	CPP(R)	*h*-index(R)
Arnold, J.G./USDA ARS	30	4(22)	2415(1)	80.5(1)	17(1)
Srinivasan, R./Texas A&M University	27	4(22)	2097(2)	77.7(2)	13(3)
Steenhuis, T.S./Cornell University	22	9(5)	486(3)	22.1(7)	14(2)
Wendland, F./Forschungszentrum Julich	21	7(11)	183(17)	8.7(23)	8(13)
Walter, M.T./Cornell University	20	6(14)	399(6)	20(10)	11(6)
Heathwaite, A.L./Lancaster University, The University of Sheffield	19	6(14)	401(5)	21.1(9)	12(4)
Bingner, R.L./USDA ARS	19	0(30)	186(16)	9.8(21)	9(11)
Engel, B.A./Purdue University	18	7(11)	397(7)	22.1(8)	10(8)
Shen, Z.Y./Beijing Normal University	18	15(1)	120(22)	6.7(26)	7(19)
Kronvang, B./Aarhus University	17	6(14)	447(4)	26.3(5)	12(4)
Behrendt, H./Swedish University Agriculture Sciences	16	3(24)	249(11)	15.6(12)	10(8)
Kunkel, R./Forschungszentrum Julich	16	5(19)	165(21)	10.3(19)	8(13)
Huang, G.H./University of Regina	16	10(4)	194(14)	12.1(17)	7(19)
Bouraoui, .F/Commission of European Communities	15	6(14)	379(8)	25.3(6)	11(6)
Yuan, Y./US EPA, University Mississippi, USDA ARS	15	13(2)	176(19)	11.7(18)	8(13)
Loague, K./Stanford University	14	8(8)	179(18)	12.8(16)	8(13)
Mostaghimi, S./Virginia Tech	14	3(24)	198(13)	14.1(14)	7(19)
Tsihrintzis, V.A./Democritus University Thrace	13	13(2)	194(14)	14.9(13)	8(13)
Hao, F.H./Beijing Normal University	13	6(14)	111(23)	8.5(24)	8(13)
Billen, G./University Paris 06	12	3(24)	354(9)	29.5(3)	10(8)
Chaubey, I./Purdue University	12	7(11)	238(12)	19.8(11)	7(19)
Easton, Z.M./Cornell University	12	5(19)	169(20)	14.1(15)	7(19)
Garnier, J./University Paris 06	11	2(28)	312(10)	28.4(4)	9(11)
Ouyang, W./Beijing Normal University	11	9(5)	90(26)	8.2(25)	7(19)
Srivastava, P./Auburn University, Academy of Natural Sciences of Philadelphia	11	5(19)	111(23)	10.1(20)	6(25)
Hong, Q./Beijing Normal University	11	1(29)	97(25)	8.8(22)	5(26)
Liu, R.M./Beijing Normal University	11	3(24)	45(28)	4.1(29)	4(28)
Cho, J./USDA ARS, Virginia Tech	10	8(8)	64(27)	6.4(27)	5(26)
Lu, J./Zhejiang University	10	9(5)	35(29)	3.5(30)	4(28)
Chen, D.J./Zhejiang University	8	8(8)	35(29)	4.4(28)	4(28)

Notes: TA = total articles. FCA = articles as first author or correspondence author. TC = total citations. CPP = citations per publication. R = rank in the list. ARS = Agricultural Research Service.

cal simulation modules to ANSWERS and improved it from a single-event model to a long-term continuous model (Bouraoui and Dillaha 1996). T.S. Steenhuis and M.T. Walter from Cornell University, both of whom had high *h*-indices, combined microscale biogeochemistry and macroscale management of water and soil resources in their research. Compared with Arnold, Srinivasan, and Bouraoui, Steenhuis and Walter do not greatly contribute to specific models, but use models as tools to understand natural processes and to manage hydrological and ecological systems. A.L. Heathwaite from Lancaster University, United Kingdom, ranked fourth in *h*-index although she had no cooperation with the other authors in the list. Heathwaite used empirical models to estimate NPS pollution in her early research (Johnes and Heathwaite 1997) and later worked to incorporate process-based knowledge into empirical models to make them useable for end users to make appropriate, effective, and economically viable mitigation decisions (Heathwaite 2003).

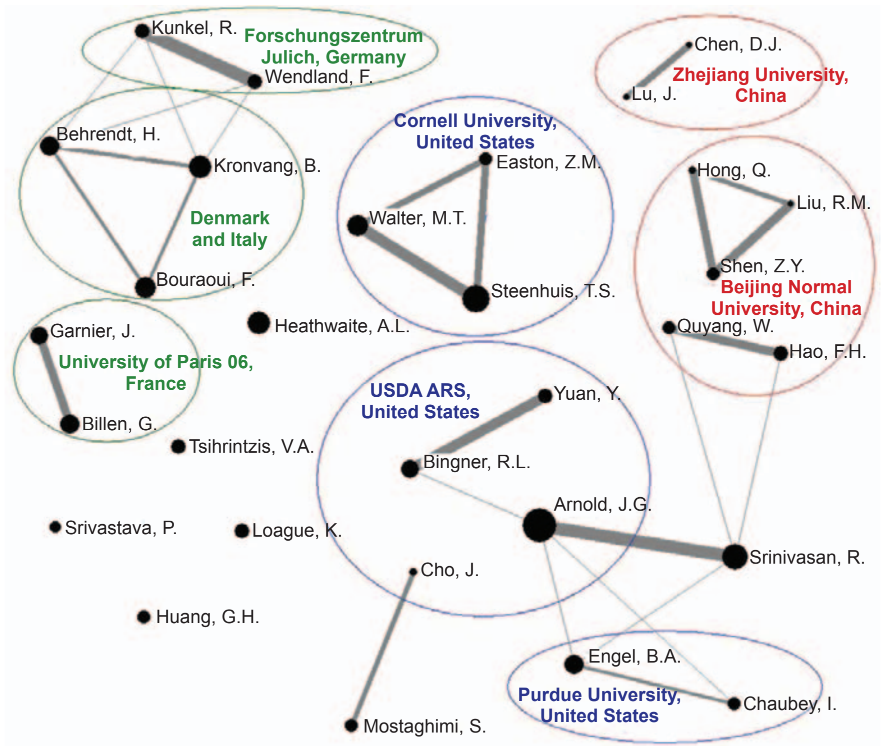
GEOGRAPHIC DISTRIBUTION DYNAMICS OF INSTITUTE PUBLICATION ACTIVITY

Based on author addresses, the geographical distribution of institute-publication activity in NPS pollution modeling was plotted (figure 2). Here, institute-publication activity refers to the frequency that a site occurred in author addresses; it is high in sites with many research institutes and/or a large quantity of publications. Here, sites with high institute-publication activity are referred to as research "hot spots."

Figure 2 showed a significant expansion of research activity in NPS pollution modeling over the world during last two decades. From 1994 to 1998, research in NPS pollution modeling was mainly limited to the United States and western Europe, and Fort Collins, Colorado, United States, was the only research hot spot. Only 264 articles were published during this period. From 1999 to 2003, research in the field expanded to most continents of the world. However, in Asia, Oceania, Africa, and South America, participating institutes were still sparse and their publication activity was generally low. The period from 2004 to 2008 witnessed the greatest geographical expansion of NPS

Figure 1

Cooperation among the 30 most productive authors from 1994 to 2013.



pollution modeling research, when more institutes participated and three hot spots, Beijing, Nanjing, and Seoul, appeared in Asia. Furthermore, the TA increased from 418 papers published from 1999 to 2003 to 677 papers published from 2004 to 2008. From 2009 to 2013, there were more participating institutions, and the TA continued growing at a slower speed (820 publications during this span).

Compared to the distributed spread of research institutes in United States and Europe, the institutes in Asia were much more geographically concentrated. Seoul had 7 participating institutes, and Beijing had more than 10. The research hot spots in United States revealed the high activity of USDA Agricultural Research Service (USDA ARS). Fort Collins, Colorado, was the hot spot in the first decade of the study period, partly because it is the location of 4 research units of USDA ARS working on NPS pollution. Some other research hot spots (Madison, Wisconsin; Temple, Texas; Ames, Iowa; and University Park, Pennsylvania) also have 1 or 2 USDA ARS research units.

TEMPORAL EVOLUTIONS OF KEYWORDS

Table 2 lists the 30 most frequently used keywords in NPS pollution modeling articles from 1994 to 2013. Since terms associated with emerging trends are of interest and could be overshadowed by commonly used terms associated with broader and more consistent themes (Chen 2006), 20 emerging keywords during a specific period with sharp increase in frequency were listed in table 3.

"Water quality" was the most frequently used keywords in NPS pollution modeling articles during the study period. Nutrients, including "phosphorus," "nitrogen," and "nitrate," were of most interest in NPS pollution modeling, followed by "sediments" and "pesticides." It should be noted that "*Escherichia coli* (*E. coli*)" and "pathogen" were emerging keywords in the past decade, which indicates an expansion in the targets of NPS pollution modeling.

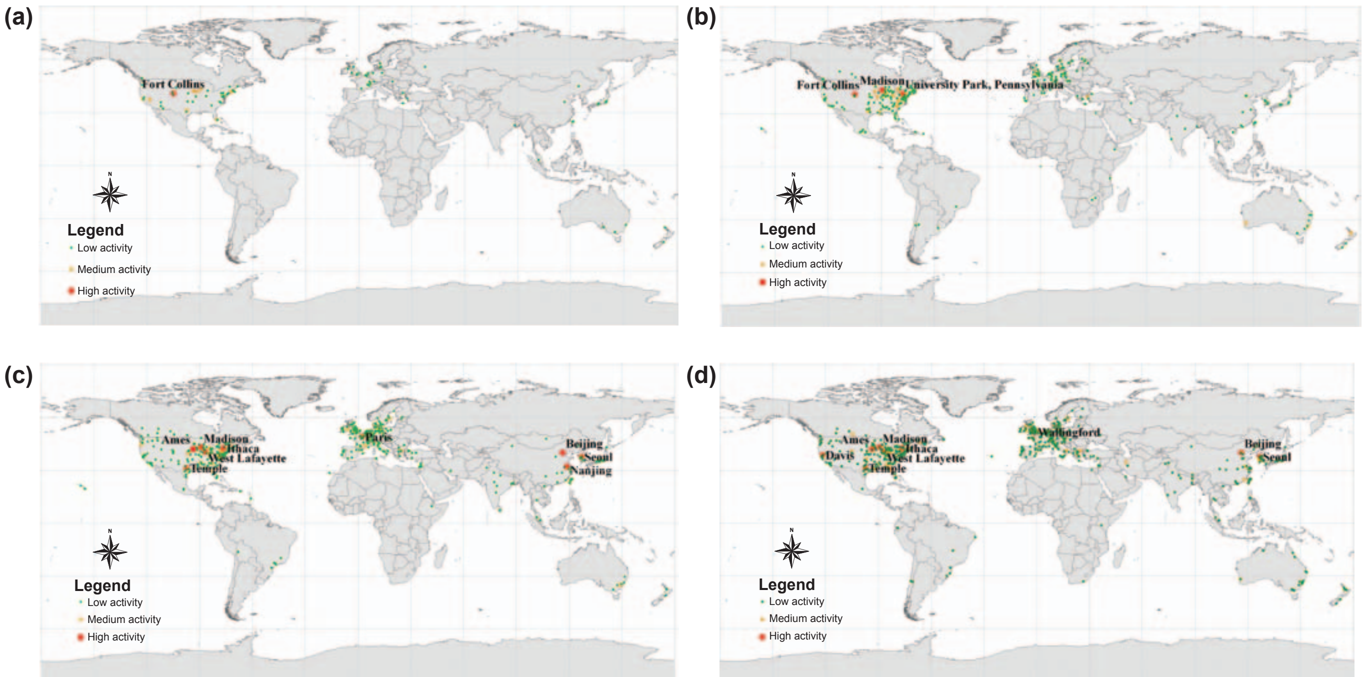
Geographic information system (GIS) and remote sensing (RS) techniques are important tools for NPS pollution modeling. However, the frequency of GIS as a keyword decreased from 1994 to 2013. This implies the maturity of the application of GIS technology in NPS pollution modeling. Actually, the integration of GIS and some mainstream NPS pollution models (including ANSWERS, AGNPS [the Agricultural Nonpoint Source pollution model], and SWAT) was accomplished in the 1990s (Mitchell et al. 1993; Rewerts and Engel 1991; Srinivasan and Arnold 1994). By contrast, RS, as an easier way to gather data important to NPS pollution models in large scales, has gained attention, with a large increase in keyword frequency during last decade.

SWAT was the most commonly used model in last decade, with 8.2% and 12.8% of the articles listing it as a keyword from 2004 to 2008 and 2009 to 2013, respectively. Hydrological Simulation Program-Fortran, which was recognized as a promising model for mixed agricultural and urban watersheds (Borah and Bera 2003), also drew attention in the last decade. However, the percentage of articles listing it as a keyword dropped from 3% to 1.1% between 2004 to 2008 and 2009 to 2013. AGNPS (Young et al. 1989) developed by USDA ARS, had a decreasing trend in keyword occurrence frequency. To some extent, AGNPS has been replaced by its long-term continuous version, AnnAGNPS (Bingner and Theurer 2001). EPIC, Erosion-Productivity Impact Calculator (Williams and Singh 1995), which is a field-scale model, had a decreasing trend in occurrence frequency and nearly disappeared during the last decade in NPS pollution modeling research. By contrast, the keywords related to watershed-scale (including "watershed management," "watershed modeling," "catchment/s," and "watershed model/s") were consistent common keywords or emergent keywords in recent years. This phenomenon implies that researchers in NPS pollution modeling focus more on watershed-scale modeling than field-scale modeling in recent years. "Urbanization" was an emerging keyword from 2004 to 2008, and "event mean concentration (EMC)" jumped to rank 28th during 2009 to 2013, mainly co-occurring with urban runoff. This indicates more recent attention on urban NPS pollution modeling.

Management was a consistently key issue in NPS pollution modeling as illus-

Figure 2

Geographical distribution of institute publication activity during (a) 1994 to 1998, (b) 1999 to 2003, (c) 2004 to 2008, and (d) 2009 to 2013.



trated by many keywords in tables 2 and 3: "watershed management;" "river basin management;" "best management practices;" "decision support;" "mitigation;" "total maximum daily load," a standard required by the Clean Water Act of United States; and "Water Framework Directive," a European Union legislation set to drive the establishment and implementation of management strategies to protect water bodies. Furthermore, the emerging trends of "cost-effectiveness" and "critical source areas" in recent years indicated that evaluation and selection of cost-effective management strategies by modeling was a research frontier of the field.

OVERALL TRENDS

General Trends in Nonpoint Source Pollution Modeling Research. In the field of NPS pollution, the role of modeling can be generally classified as two purposes: for the initial stage, modeling is a way to understand the problem (simulating the complex processes of pollution generation and transformation); for the ultimate stage, modeling serves as an assisting tool to meet the need of end users (assessment and selection of management practices). The results of keyword evolutions indicate that the main role of modeling in NPS pollution research has been shifting from its initial stage to its ultimate stage. Meanwhile, the research interests of NPS pollution modeling have expanded during 1994 to 2013 in three aspects: (1) the targets of NPS pollution modeling from sediments and nutrients to pathogens, (2) the scales of modeling from field-scale to watershed-scale and river basin–scale, (3) the interested source areas from agricultural lands to urban lands or mixed lands.

Gap between Asia and Western Countries in Nonpoint Source Pollution Modeling Research. Based on the results of author performance and institute-publication activity, we can see a gap between Asia and western countries in NPS pollution modeling research. Asia became active in the field in last decade, which was obviously later than the United States and Europe. Moreover, the distribution of research authors and institutes were concentrated in big cities in Asia, such as Beijing and Seoul. By contrast, the research activity in western countries started earlier and was more widely distributed. Specifically, in the United States, universities cooperated with research units of USDA ARS in local areas, forming multiple research hot spots. Considering the local needs and research advantages, each of these research hot spots had its own research focus. For instance, in Temple, Texas, the home of SWAT, research focused on the development, improvement, and application of the SWAT model. Meanwhile, in Ames, Iowa, where Iowa State University and National Soil Tilth Lab of USDA ARS are located, research focused on the effects of grazing and tile drainage on nutrient loss and related mitigation practices. The division of research aspects in NPS pollution modeling is important since there is no universal model that can be used across regions with various geographic, climatic, and anthropogenic backgrounds. However, most NPS pollution models used in China were directly derived from models developed by several other countries, especially the United States (Shen et al. 2012). This gap can also be seen in author performance. For example, most authors in the top 30 list are from western countries while only

Table 2

Thirty most frequent keywords in nonpoint source pollution modeling articles from 1994 to 2013. Arrows indicate an increasing (upward arrow) or decreasing (downward arrow) trend in frequency and rank.

Author keywords	TA(R)	R(%) 1994 to 1998	1999 to 2003	2004 to 2008	2009 to 2013
Water quality	303(1)	1(21.7)	1(20.6)	1(16.9)	2(12.7)
Geographic information system (GIS) ↓	158(2)	2(12.8)	2(11.3)	3(10.6)	8(4.5)
Phosphorus	157(3)	3(8.3)	5(7.7)	2(11.0)	5(7.0)
Soil and Water Assessment Tool (SWAT)	148(4)	26(1.7)	37(1.4)	4(8.2)	1(12.8)
Nutrient/s ↑	116(5)	26(1.7)	9(4.9)	5(7.2)	3(7.4)
Nitrogen	112(6)	9(3.9)	4(8.0)	8(5.9)	6(5.8)
Best management practices (BMPs) ↑	109(7)	15(2.8)	13(3.3)	7(6.6)	3(7.4)
Watershed management	107(8)	8(4.4)	3(9.3)	6(6.8)	13(3.6)
Watershed/s	95(9)	6(5.6)	7(5.8)	11(4.5)	7(5.2)
Runoff	88(10)	9(3.9)	6(6.9)	9(5.8)	14(3.2)
Sediment/s	85(11)	15(2.8)	12(3.8)	9(5.8)	8(4.5)
Eutrophication	80(12)	5(6.1)	11(4.4)	13(4.0)	11(4.1)
Nitrate	77(13)	9(3.9)	10(4.7)	12(4.2)	12(4.0)
Total maximum daily load (TMDL) ↑	64(14)	96(0.6)	14(3.0)	15(3.3)	8(4.5)
Agriculture	59(15)	15(2.8)	8(5.2)	14(3.5)	20(2.1)
Land use	56(16)	9(3.9)	27(1.9)	15(3.3)	14(3.2)
Watershed modeling	54(17)	22(2.2)	14(3.0)	17(3.1)	16(2.9)
Groundwater	50(18)	4(7.2)	23(2.2)	20(2.4)	20(2.1)
Uncertainty	43(19)	46(1.1)	23(2.2)	22(2.1)	16(2.9)
Hydrology	38(20)	26(1.7)	18(2.5)	19(2.8)	28(1.4)
Water Framework Directive ↑	34(21)	595(0)	93(0.5)	20(2.4)	18(2.5)
Pesticide/s	34(21)	22(2.2)	16(2.7)	25(1.9)	35(1.2)
Remote sensing (RS) *	33(23)	26(1.7)	31(1.6)	32(1.6)	20(2.1)
Calibration	31(24)	26(1.7)	31(1.6)	27(1.7)	25(1.7)
Erosion ↓	31(24)	7(5.0)	18(2.5)	27(1.7)	110(0.4)
Climate change *	30(26)	96(0.6)	37(1.4)	40(1.2)	19(2.3)
Point source/s	29(27)	96(0.6)	18(2.5)	49(1.0)	23(1.8)
Catchment/s	29(27)	595(0)	41(1.1)	22(2.1)	23(1.8)
Soil erosion	28(29)	46(1.1)	27(1.9)	32(1.6)	28(1.4)
Hydrological Simulation Program-Fortran	28(29)	96(0.6)	93(0.5)	18(3.0)	39(1.1)

*Emerging keywords during the last decade.

Notes: TA = total articles where the keywords occurred. R = rank during the specific period. % = keyword occurring frequency.

7 are from Asia. These 7 authors also had weaker academic impact than the authors from western countries.

SUMMARY

A systematic review of NPS pollution modeling from 1994 to 2013 based on bibliometric analysis revealed the worldwide research performance and the temporal evolutions of hot issues, which can be summarized as follows:

1. United States was the most active and influential country in NPS pollution modeling. USDA ARS played a critical role. Division of research aspects has been developed in multiple research hot spots around leading authors and institutes.
2. Asia participated in NPS pollution modeling later than western countries, and the research activity in Asia was more concentrated in specific big cities. While some leading authors appeared in China, their academic impacts around the world were limited.
3. Water quality and nutrients were consistent main concern of NPS pollution modeling, while pathogens became the emerging interest in last decade. SWAT was the dominating model in last decade partly because it satisfied the growing needs of watershed-scale management. GIS and RS techniques played important roles in NPS pollution modeling, and RS tends to be increasingly applied in recent years.
4. The role of modeling in NPS pollution research has generally been shifting from a way to understand the problem to a tool to assist management. Evaluation of pollution control practices and selection of cost-effective management strategies are research directions in the field.

ACKNOWLEDGEMENTS

The authors thank the support by the National Natural Science Foundation of China (No. 41001333), Key Laboratory of Nonpoint Source Pollution Control, Ministry of Agriculture (20130102), and the National Key Technology R&D Program of China (2012BAC06B03).

REFERENCES

Alexander, R.B., P.J. Johnes, E.W. Boyer, and R.A. Smith. 2002. A comparison of models for estimating the riverine export of nitrogen from large watersheds. Biogeochemistry 57(1):295-339.

Arnold, J.G., R. Srinivasan, R.S. Muttiah, and J.R. Williams. 1998. Large area hydrologic modeling and assessment part I: Model development. Journal of the American Water Resources Association 34(1):73-89.

Bingner, R., and F. Theurer. 2001. AnnAGNPS technical processes: Documentation version 2. Oxford, MS: USDA Agricultural Research Service.

Borah, D., and M. Bera. 2003. Watershed-scale hydrologic and nonpoint-source pollution models: Review of mathematical bases. Transactions of the American Society of Agricultural Engineers 46(6):1553-1566.

Bouraoui, F., and T.A. Dillaha. 1996. ANSWERS-2000: Runoff and sediment transport model. Journal of Environmental Engineering 122(6):493-502.

Chen, C. 2006. CiteSpace II: Detecting and visualizing emerging trends and transient patterns in scientific literature. Journal of the American Society for Information Science and Technology 57(3):359-377.

Davis, J.R., and K. Koop. 2006. Eutrophication in Australian rivers, reservoirs and estuaries: A southern hemisphere perspective on the science and its implications. Hydrobiologia 559(1):23-76.

Heathwaite, A.L. 2003. Making process-based knowledge useable at the operational level: A framework for modelling diffuse pollution from agricultural land. Environmental Modelling & Software 18(8-9):753-760.

Table 3

Twenty typical emerging keywords in nonpoint source pollution modeling articles. Arrows indicate an increasing (upward arrow) or decreasing (downward arrow) trend in frequency and rank.

		R(%)			
Author keywords	**TA(R)**	**1994 to 1998**	**1999 to 2003**	**2004 to 2008**	**2009 to 2013**
AnnAGNPS	23(35)	595(0)	93(0.5)	25(1.9)	28(1.4)
AGNPS ↓	23(35)	13(3.3)	16(2.7)	61(0.9)	178(0.3)
Watershed model/s	20(41)	96(0.6)	61(0.8)	27(1.7)	56(0.8)
BASINS	19(45)	595(0)	31(1.6)	40(1.2)	56(0.8)
River basin management	16(55)	595(0)	93(0.5)	22(2.1)	178(0.3)
Cost-effectiveness * ↑	15(59)	595(0)	93(0.5)	93(0.5)	28(1.4)
Escherichia coli (*E. coli*) *	15(59)	595(0)	93(0.5)	49(1.0)	44(1.0)
Event mean concentration (EMC) *	13(67)	96(0.6)	207(0.3)	285(0.2)	28(1.4)
Urbanization	13(67)	595(0)	93(0.5)	32(1.6)	178(0.3)
Distributed model/s	13(67)	96(0.6)	23(2.2)	93(0.5)	381(0.1)
Critical source areas (CSAs) * ↑	12(73)	595(0)	207(0.3)	141(0.3)	35(1.2)
China *	11(78)	595(0)	1056(0)	93(0.5)	39(1.1)
Constructed wetland/s	11(78)	46(1.1)	207(0.3)	1624(0)	39(1.1)
Validation/model validation	11(78)	46(1.1)	207(0.3)	93(0.5)	68(0.7)
Decision support *	10(89)	595(0)	93(0.5)	285(0.2)	44(1.0)
Pathogen *	10(89)	595(0)	1056(0)	93(0.5)	44(1.0)
Mitigation *	10(89)	595(0)	1056(0)	73(0.7)	56(0.8)
EPIC ↓	10(89)	26(1.7)	37(1.4)	285(0.2)	381(0.1)
Tile drainage	10(89)	595(0)	93(0.5)	40(1.2)	381(0.1)

*Emerging keywords during the last decade.

Notes: TA = total articles where the keywords occurred. R = rank during the specific period. % = keyword occurring frequency.

Hirsch, J.E. 2005. An index to quantify an individual's scientific research output. Proceedings of the National academy of Sciences of the United States of America 102(46):16569-16572.

Johnes, P., and A.L. Heathwaite. 1997. Modelling the impact of land use change on water quality in agricultural catchments. Hydrological Processes 11(3):269-286.

Liu, X., L. Zhang, and S. Hong. 2011. Global biodiversity research during 1900–2009: A bibliometric analysis. Biodiversity and Conservation 20(4):807-826.

Ma, X.,Y. Li, M. Zhang, F.Z. Zheng, and S. Du. 2011. Assessment and analysis of non-point source nitrogen and phosphorus loads in the Three Gorges Reservoir Area of Hubei Province, China. Science of the Total Environment 412:154-161.

Mitchell, J., B. Engel, R. Srinivasan, and S. Wang. 1993. Validaion of AGNPS for small watersheds using an integrated AGNPS/GIS system. Journal of the American Water Resources Association 29(5):833-842.

Novotny, V. 1999. Diffuse pollution from agriculture: A worldwide outlook. Water Science and Technology 39(3):1-13.

Pretty, J.N., C.F. Mason, D.B. Nedwell, R.E. Hine, S. Leaf, and R. Dils. 2003. Environmental costs of freshwater eutrophication in England and Wales. Environmental Science & Technology 37(2):201-208.

Pritchard, A. 1969. Statistical bibliography or bibliometrics. Journal of Documentation 25(4):348-349.

Rewerts, C.C., and B. Engel, 1991. ANSWERS on GRASS: Integrating a watershed simulation with a GIS. Paper 91-2621. St. Joseph, MI: American Society of Agricultural Engineers.

Shen, Z.Y., Q. Liao, Q.Hong, and Y.W.Gong. 2012. An overview of research on agricultural non-point source pollution modelling in China. Separation and Purification Technology 84:104-111.

Smith,V.H. 2003. Eutrophication of freshwater and coastal marine ecosystems a global problem. Environmental Science and Pollution Research 10(2):126-139.

Srinivasan, R., and J.G. Arnold. 1994. Integration of a basin-scale water quality model with GIS. Journal of the American Water Resources Association 30(3):453-462.

Williams, J.R., and V. Singh. 1995. The EPIC model. *In* Computer Models of Watershed Hydrology, 909-1000. Highlands Ranch, CO: Water Resources Publications, LLC.

Young, R.A., C. Onstad, D. Bosch, and W. Anderson. 1989. AGNPS: A nonpoint-source pollution model for evaluating agricultural watersheds. Journal of Soil and Water Conservation 44(2):168-173.

Zhuang, Y., T. Nguyen, B. Niu, W. Shao, and S. Hong. 2012. Research trends in non point source during 1975-2010. *In* International Conference on Medical Physics and Biomedical Engineering, ed. D.Yang. Physics Procedia 138-143.