RESEARCH ARTICLE

• Arch Hyg Sci 2017;6(2): 196-205
• Journal Homepage: http://jhygiene.muq.ac.ir

Modeling of Non-Point Source Pollution by Long-Term Hydrologic Impact Assessment (L-THIA) (Case Study: Zayandehrood Watershed) in 2015

Mojgan Mirzaei[a], Eisa Solgi[a*], Abdolrassoul Salman Mahiny[b]

[a]Department of Environmental Sciences, Malayer University, Malayer, Hamedan, Iran.
[b]Gorgan University of Agriculture Sciences and Natural Resources, Environmental Sciences, College of Fisheries and Environmental Sciences. Gorgan, Iran.

***Correspondence** should be addressed to Dr. Eisa Solgi, **Email**: e.solgi@malayeru.ac.ir

A-R-T-I-C-L-EI-N-F-O

Article Notes:
Received: Oct. 22, 2016
Received in revised form: Nov. 19, 2017
Accepted: Feb. 19, 2017
Available Online: Feb 28, 2017

Keywords:
Hydrology
Nitrogen
Phosphorus
water quality
Zayandehrood
Iran

A-B-S-T-R-A-C-T

Background & Aims of the Study: In this research, Long-Term Hydrologic Impact Assessment model is selected for simulation of runoff and NPS pollution. The aim of this study is modeling of non-point source pollution by L-THIA model in Zayandehrood watershed in 2015.

Materials & Methods: In this study, analytical survey and investigation of references in the context of library studies has been used. Zayandehrood watershed is located in Esfahan, Iran. Required data in this study are land use, soil and precipitation data from studied period. The first L-THIA model run and then the spatial distribution of non-point source pollution analysed within the study area. The annual average runoff volume, depth and the non-point source nitrogen and phosphorus load and the spatial distribution were estimated.

Results: According to the study, we concluded that amount of nitrogen and phosphorus load in agricultural and residential areas are more serious and the nitrogen load due to nonpoint source pollution was larger than phosphorus load in Zayandehrood basin. The maximum runoff depth in the region was calculated 501.371 cm and the maximum nonpoint source pollution obtained 24244.27 kg. The results indicated the watershed likely is affected to impacts from urbanization and agriculture.

Conclusions: The results of this study can be used for urban planning and decision making in an effort to protect water and habitat quality of Zayandehrood river. Integration of introduced model and other hydrologic models can be increased accuracy and precision of results. Also, sub-watersheds can prioritize for watershed management in in the vulnerable sections.

Please cite this article as: Mirzaei M, Solgi E, Salman Mahiny A. Modeling of Non-Point Source Pollution by Long-Term Hydrologic Impact Assessment (L-THIA) (Case Study: Zayandehrood Watershed) in 2015. Arch Hyg Sci 2017;6(2):196-205.

Background

Rivers have important roles as one of the most important sources of water supply and transport sectors of industry, agriculture and urban uses (1). Water pollution is one of the important problems in the world and Iran. Pollution sources divided into two classes: point and non-point. They differ only in the place of origin as well as their production source. Non-point pollution is defined as surface and subsurface soil, air, surface and underground water contaminants in nature that cannot be traced to its central location (2). In other words, the source of this type of pollution is widespread and often created from agricultural land. (3). Compared to the point-source pollution that caused by industrial activities, Quantify and control this type of pollution is a fairly difficult task. Typically, Population growth and urbanization and agriculture activities cause to increases in impervious surface and urban runoff, pollution of surface waters and the risk of flooding (4). Also, the underground water that are closed to the landfill, is a criteria of its effect on the water quality (5). High concentrations of natural organic matter may cause the production of harmful compounds in water and humic compounds are considered as the biggest portion of natural organic matter (6). Despite much research in recent decades of agricultural management operations to minimize water pollution, the agricultural sector remains a major source of water pollution and degradation of water quality around the world. Thus, most recently around the world, attention has been focused on pollution caused by agricultural operations. In particular, the origin of the pollution in developing countries is very critical. Integration of GIS technology with simulation models, can lead to more precise results and more comprehensive studies. Water quality assessment by GIS maps can be enhanced the speed and accuracy of water quality management (7).

Conversion of forests and grasslands to urban and agricultural areas can alter natural hydrological conditions and increase the surface runoff and river water quality degradation (8). Today, non-point source pollution is increasing in the world. Therefore, modeling approaches are necessary for simulation of runoff and NPS pollutant loads in the regional/watershed-scales (9). Water quality models with integration of Geographic Information System are developed for a simulation of the effects of land use change on watershed Hydrology and water quality. Evaluation of land use change effects on hydrology and water quality can be performed by these models.

Bhaduri and colleagues investigated the effect of land use changes on runoff and contamination of the non-point source. The results showed an increase in urban areas and the runoff volume (10). Karimi and colleagues are used L-THIA for evaluation of runoff and NPS in Gorgan and Aliabad watersheds in Golestan province. The results showed that the volume of runoff and pollutants in the northern area is more than the southern areas due to development of urban and agricultural areas in this section (11).

Tang and colleagues are evaluated impacts of land use changes on Muskegon River watershed using the L-THIA model. They concluded that over time with the development of urban area, some non-point pollution in the region is increased (12). Jinheng analyze the spatial distribution of NPS pollution in Qingdao by L-THIA model, and found that the impact of agricultural land on NPS pollution is more than other land uses, and following residential areas are more important (13). Wilson and Weng simulate the surface water quality due to urban areas using L-THIA model in the Lake Calumet area, Greater Chicago (14). Mahiny and colleagues are used L-THIA for estimating runoff from land use changes in Noshahr and Chalus. Runoff modeling results showed that in 14 years the runoff average has increased 17.3 mm (15). Yang and colleagues are used L-THIA To determination of the long term effects of urbanization on runoff. The results indicated that residential land increased 30.4% in the period 1987-2003 (16).

You and colleagues simulated non-point source nitrogen and phosphorus loads under different land uses in Sihu Basin, Hubei Province in China. They concluded NPS nitrogen and phosphorus load in residential areas is high and in grasslands is low (17). Esfandiyari and colleagues evaluated hydrological impact of land use change on annual runoff in Ghareso basin by L-THIA model. They concluded the amount of runoff is increased 1.8 mm in 25 years and forest area is increased and residential area is decreased (18). Vafakhah and colleagues evaluated land use chang effect on run off using L-THIA. They concluded that runoff volume increased in Chalus watershed (19). Pasandidehfar and colleagues modeled non-point source pollution by L-THIA model in Gorganrood basin. They concluded that land use change is best management practices (20). Galdavi and colleagues evaluated the impact of land use change on surface water by L-THIA model in Gorgan. They concluded that the volume and depth of runoff increased in the studied years (21). Yari evaluated the development effects on the quantity and quality of runoff in Kermanshah city using L-THIA model (22).

Aim of the Study: The aim of this study is modeling of non-point source pollution in Zayandehrood watershed by long-term hydrologic impact assessment in 2015. Since agriculture in the Zayandehrood catchment is one of the most important land uses, creation of non-point source pollution in the study area is quite natural and logical. So modeling of non-point source pollution at this location is necessary.

Materials & Methods

Study region

The study was carried out on the Zayandehrood watershed (latitude 31°12'N, longitude 50°02'E) in Iran County. Zayandehrood is one of the most important rivers of Iran. Total area of Zayandehrood watershed is 41500 km^2. The length of this river is about 350 km. This river is originated from The Zagros Mountains in the West of Isfahan province and ends in Gavkhuni wetland. Unfortunately Zayandehrood River faced with drought in recent years. Much of this watershed has an arid and semi-arid climate. This river is used for development of agriculture, water supply in industries and all economic activity. Zayandehrood basin with tributaries of river is shown in Figure 1.

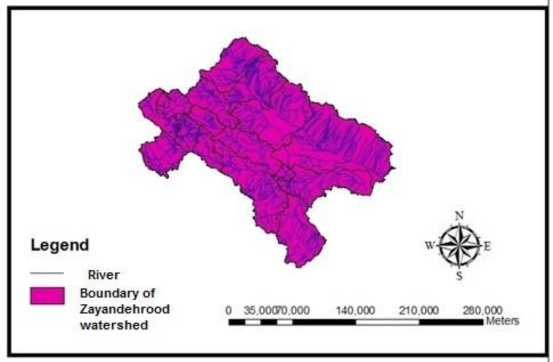

Figure 1) Zayandehrood basin with tributaries of river

Method

There are many models for evaluation of the effects of land use on runoff and hydrological condition and analysis of non-point source pollution. But most of these models are complex and need much data to run. Long-term hydrologic impact assessment (L-THIA) is a hydrology and non-point source pollutant loading model that can be calculate runoff depth and volume and amount of non-point source pollution in each grid cell of a study area (23). L-THIA GIS is integrated with ArcView GIS software.

Data Sets

The important data for L-THIA model are included hydrological and climate data, soil data, land use and text file rainfall in last thirty years and text file of CN-table.

L-THIA defines average annual runoff for a land use based on actual climate data for a long time, soils, and land-use data for an area (24). This model is working based on curve number (CN) for estimation of flow trend in a watershed.

Calculation of CN

L-THIA model estimates the runoff for different amounts of CN by daily rainfall data and then annual runoff calculate for watershed as output (15).

For various precipitation events, runoff volumes calculate by the Curve Number (CN) method (25). The CN method is a simple and practical approach for determining direct runoff volumes from a precipitation event (26,27). The

CN method computes the runoff volume (Q) in inches as

$$Q = \frac{(P-0.2S)^2}{P+0.8S}$$

$$For\ P \gg 0.2S \qquad \text{(Eq. 1)}$$

$$Q = 0\ for\ p < 0.2S$$

$$Where\ S = \frac{1000}{CN} - 10$$

In Equation (1), P is the depth of precipitation in inches, S is the potential maximum storage in inches, and CN is the curve number. The standard CN values range from 25 to 98, depending on land uses, hydrologic soil group, and antecedent moisture condition. For the implementation of this model, In addition to using 30 years of rainfall data, the Antecedent Moisture condition in an area is also considered. This model considers two statuses to Antecedent moisture conditions: Normal AMC and adjusted AMC. Antecedent Moisture condition is a type of moisture that effect on runoff volume. L-THIA model estimates the runoff volume and nonpoint source pollutant loadings within the ArcView L-THIA extension.

Preparation of the hydrological soil groups

In this model, Soils are generally divided into four groups (hydrological soil groups: A, B, C, and D) as shown in Table 1 based on soil texture (25).

Table 1) Hydrologic Soil Groups

Soil Group	Description	USDA Soil Texture
A	Deep soils with high permeability rate	Sand, loamy sand, or sandy loam
B	Relatively fine to relatively coarse-textured soils with moderate permeability	Silt loam or loam
C	Fine textured soils with low permeability rate	Sandy clay loam
D	Soils with very low transfer and permeability rates	Clay loam, silt clay loam, sandy clay, silt clay, or clay

The hydrologic soil groups (HSG) were derived from type of soil textures (figure 2).

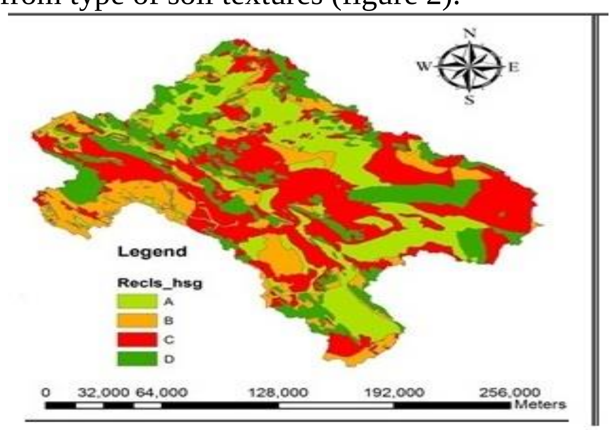

Figure 2) The hydrologic soil groups in Zayanderood watershed

Preparation of land use map

In L-THIA model, land uses classified into 8 categories including: Commercial, Industrial, High Density Residential, Low Density Residential, water, Grass/ pasture, Agricultural and Forest. The map of land use that used in this research is shown figure 3. In this research, land use map obtained from the classification of satellite images. The primary data sources for the land cover classification was Landsat Enhanced Thematic Mapper Plus (ETM^+) for the 2015 period. After providing satellite data, to prepare the data for processing and extracting useful information, the geometric correspondence operations and image coordinates were performed using roads vector map and area aerial photograph. Resampling procedure was performed using nearest-neighbor interpolation. Correction of spectral imagery was done to create a high quality images and to eliminate adverse effects of light and atmosphere. Then, the correlation between bands 4, 3, 2 for 2015 was carried out and then supervised classification of land use was performed by maximum likelihood method. To evaluate the precision of image classification, using training samples, the accuracy was calculated based on the error matrix and statistical parameters of overall accuracy, kappa coefficient, producer precision and user precision.

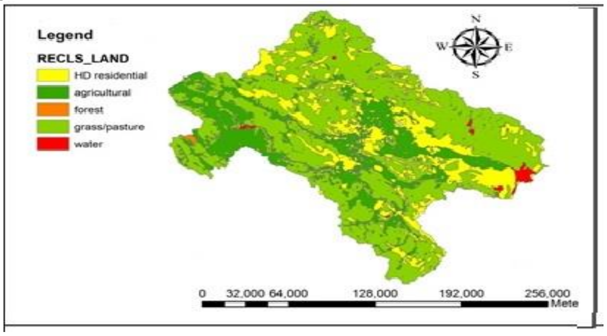

Figure 3) Land use map

Results

Satellite Data Classification Accuracy

The results of satellite data classification accuracy are given in Table 2. Kappa coefficient of 0.94 in 2015 image showed that the classification had the high accuracy and was acceptable. Then Mode filter for obtaining consistent image and deleting the sparse-pixel on classified image was applied.

Table2) Precision of images classification in 2015

classes	2015 image	
	Producer Precision	User Precision
High density residential	95.71	99.52
agriculture	87.56	92.94
forest	98.33	96.68
Grass/pasture	94.74	94.52
water	98.68	95.18
Overall Accuracy	95.004	
Kappa Coefficient	94.66	

GIS is a good tool in hydrologic modeling, because it can handle various spatial data and can store the results for next researches and analysis. L-THIA model is implemented fully in a GIS environment. In this model, the first hydrologic soil groups and land use maps are converted to raster (figure 4 and 5).

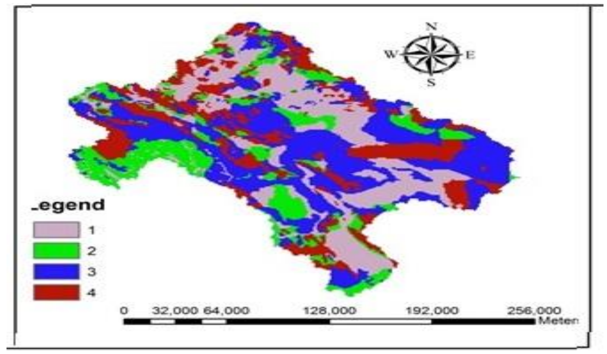

Figure 4) Soil grid

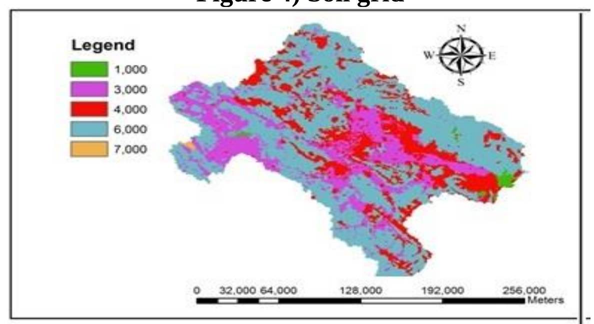

Figure 5) land use grid

Then, a CN (curve number) map is calculated (figure 6). The CN can be used for determination of amount of rainfall event converted to surface runoff based formula (formula 1). Non-linearity of relationship between rainfall, runoff and CN value cause that small changes in land use or rainfall could produce large changes in runoff.

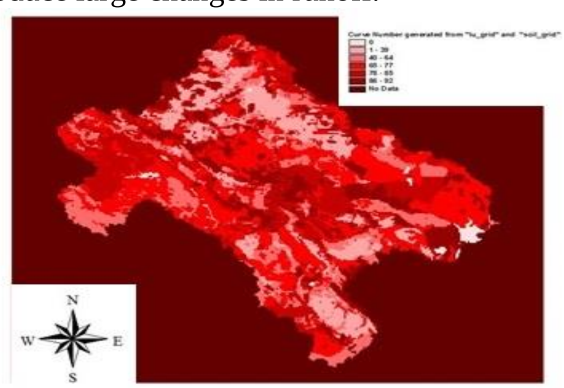

Figure 6) Map of curve number

CN value was calculated based on land use data and soil data. As showed in Figure 6, the maximum CN value is in HD residential and the CN value of woodlands and pastures is the minimum.

In next step, after the introduction of the required data, model is run. This model are calculated runoff-depth (figure 7) and then runoff-volume (figure 8) respectively.

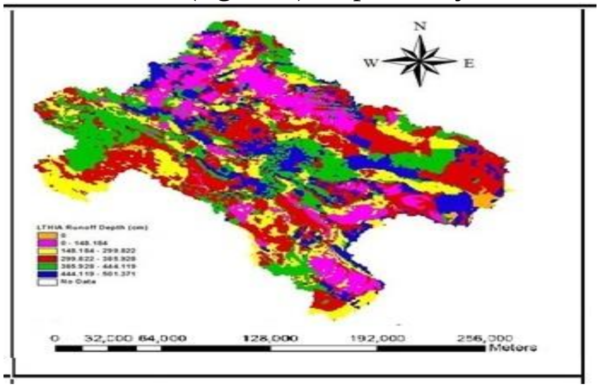

Figure 7) Map of runoff-depth

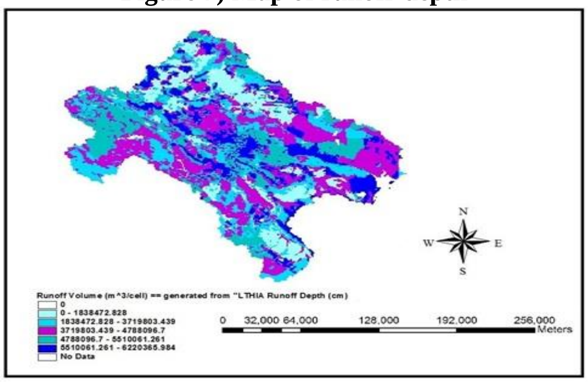

Figure 8) Map of runoff-volume

Ultimately, non-point source pollution map is created (figure 9). In this figure, it identifies that urban areas produce high amounts of NPS pollution because their im¬pervious surfaces inhibit the absorption of rainfall (28,29). Also, the higher fertilizer application rate for cropland and land use change in region increase the amount of nonpoint source pollution.

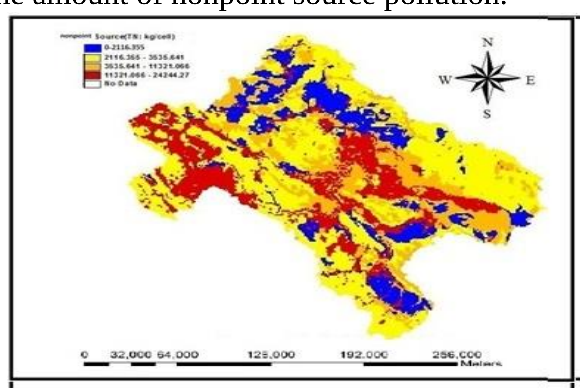

Figure 9) Map of non-point source pollution

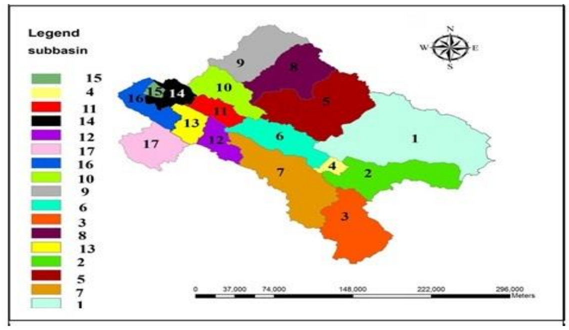

Figure 10) sub basins of zayandehrood watershed

According to the figure 10, sub basins with numbers 1,2,5,6,12,13,15 and 16 have critical condition considering non-point pollution and sub basins 3,8,9 and 10 have good condition and amount of non-point source in these sub basins is low.

Nitrogen (N) and phosphorus (P) are the the most important element in agricultural fertilizers (30). Therefore, N and P are important parameters of water quality (31). The spatial distribution of dissolved phosphor, total phosphorus and total nitrogen pollutant loads are shown in Figs. 11 through 13 respectively.

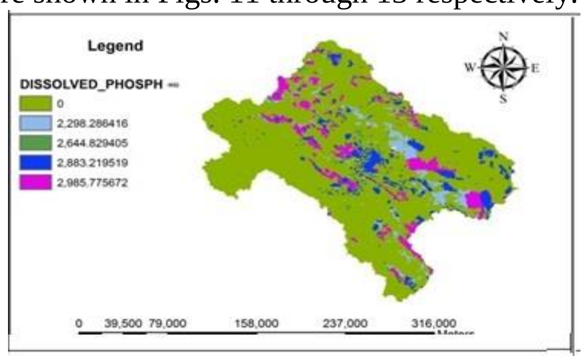

Figure 11) The spatial distribution of dissolved phosphor pollutant loads

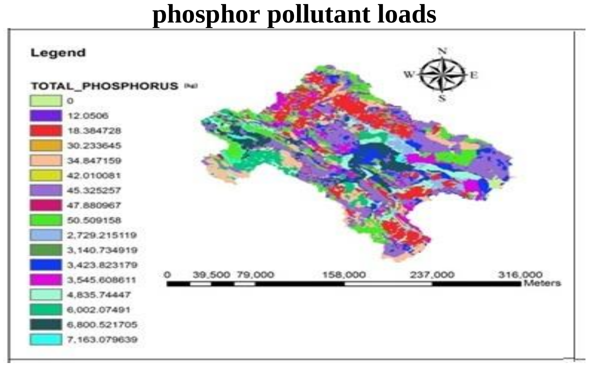

Figure 12) The spatial distribution of total phosphorus pollutant loads

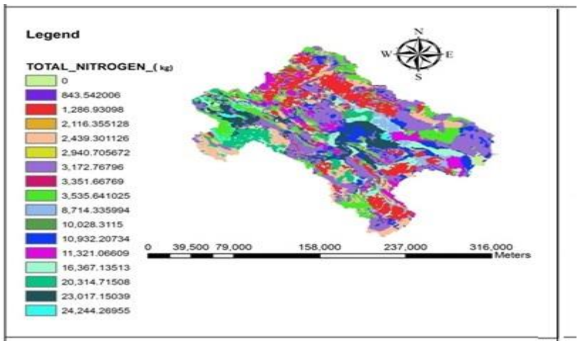

Figure 13) The spatial distribution of total nitrogen pollutant loads

Discussion

Life of Isfahan province is dependent on Zayandehrood River. Therefore, conservation of the quality and quantity of water of this river is very important. Discharge of domestic, agricultural and industrial wastewater into the rivers increase chemical substances such as nitrate and phosphate. In the most countries, nutrients from agricultural fertilizers are caused water quality problems. Evaluation of non-point source pollution has performed with different models due to increasing concern about the problems caused by agricultural and urban areas. Among different models, L-THIA model as an integrated model is selected for this study. L-THIA is a simple and associated with GIS that estimates direct, depth and volume runoff from the input data. Because this model doesnt need much data in comparison other models and is easier. This model is applicable in different countries with different weather patterns and topography. The advantage of the L-THIA model is the reduction of differences in opinions and a more accurate in the determination of the coefficients CN using GIS software. Controling and management of events before incidence is one of advantage of the model. Also L-THIA model can be showed land use change impact on volume and depth of runoff and therefore is a suitable tool to provide important information to land use and environmental protection planning that this issue is compatible with results of Mahiny et al.,(15), Choi (23), Zhang et al., (32) and Lim et al., (33).

According to the classification results of the Zayandehrood basin soil, there is C class in most parts of this basin. Since the C class has soils with the low permeability rate, the possibility of runoff flow increases. The results revealed the amount of non-point source pollution is high in the agricultural and residential area and in forest and pasture areas is low. In Zayandehrood basin, the NPS nitrogen and phosphorus load in agricultural and residential areas are more serious. Also, runoff volume and depth are higher in residential areas. These results are similar to previous reports that implemented by Wilson and Weng (14), Mahiny (15), Perry and Nawaz (34), Galdavi (35), Cowden (36), Engel (37), Saadati et al., (38), Shi et al., (39) and Ghafari et al., (40) that showed rapid urbanization and industrial developments and increases of impervious areas have led to the high levels of nonpoint source pollution. Due to urbanization, impervious surfaces increase and finally it cause increasing in surface runoff volume and downstream flooding (41).

Thus, according to the results of the model, the correct program to control land use change in order to maintain the ecological balance of the area determined. According to the study, we concluded that the NPS nitrogen load was larger than NPS phosphorus load in Zayandehrood basin. The population growth over 2.5 million people showed dependence on limited water resources is the Zayandehrood river basin. Increasing population and the subsequent increase in food consumption have prompted farmers to increase their yields which subsequently have been increased toxins and pesticides.

In addition, industrial development has been increased pollution. On the other hand, the lack of adequate facilities for treatment of pollution and the high cost of treatment processes has caused depletion of pollution in the river bed. Nowadays, convrsion of non-urban to impervious urban uses is principle factor in increasing runoff and all NPS pollutants.

Conclusion

Many diffuse sources are cause of NPS pollution. As a result runoff moves by rainfall or snowmelt over and through the ground. Then runoff pick up and carry away natural and human-made pollutants, finally depositing them into lakes, rivers, wetlands, coastal waters, and even our underground water for drinking. In many cases, discharged pollution in the river bed leads to irreversible harm to the environment of streams. Although it is not possible to eliminate of NPS pollution sources completely, monitoring and controlling strategies can be obtained by gaining increased understanding of NPS pollution sources and transport processes. Fortunately, remote sensing technologies, computer models, and geographic information systems (GIS) are good tools to achieve that understanding. The proper management of watersheds is one of the most effective measures for optimal use of water resources and soil. Simulation of hydrological phenomena in the watershed can be used for management planning. The use of models provides opportunities for managers and planners that before events can control and manage them. Since different land uses generate different amount of runoff, so relocating land uses based on the hydrologic soil type can be reduce the long-term impact of the development.

Application of L-THIA is easy and results of this model can be used to enhance of community and urban manager awareness of potential long-term problems due to urban sprawl. They can also be used to minimizing disturbance of critical areas in cities. This model is very beneficial to assessment of land use change impacts on the hydrology of a region and selection of the best place of a specific land use to have minimum impact on the natural environment of the area by Urban and regional planners and land-use decision-makers. So due to different impacts of each land use, careful physical planning can minimize these impacts.

Integration of L-THIA model and other hydrologic models can be increased accuracy and precision of results. Also, sub-basins can be prioritized for watershed management in the vulnerable sections. Since the Zayandehrood River have been faced with numerous droughts in recent years, it is necessary to take serious measures to reduce pollution in the river basin and river restoration.

This article determines the effect of different land-use on runoff and NPS pollutant loads. In a regional planning aspect, careful planning of development and location of different land use can help minimize negative environmental impacts. Accurate Physical design in land use can be reduced the effects of land use change, including its hydrological effects.

Many direct discharges of industrial wastewater, agricultural and municipal wastewater spill into Zayandehrood river, so the water and habitat quality of Zayandehrood river has been degraded. The results of this study will be useful for management of watershed condition. Mathematical models play an important role in the assessment of pollution and the evaluation of intended measures.

Good management practices can prevent from entering several non-point source pollutants to water bodies. Also proper disposal of waste and reducing the use of fertilizers and pesticides in agricultural area can remarkably reduce the nitrates and phosphates in urban runoff.

Some Strategies can be performed to minimize long-term impacts on a watershed that is affected by urbanization. These strategies are including:

- Selection of a site considering the long-term impacts
- Reduce urban sprawl by using careful urban planning
- Protect natural resource especially in a regional watershed scale

- Minimize impervious areas by Limiting road widths and increasing green space in cities
- Protect critical areas, such as places that are near to streams and water bodies
- Reduce pollutant sources on all surfaces

Footnotes

Conflict of Interest:

The authors declared no conflict of interest.

References

1. Khorramabadi Shams GH, Yusefzadeh A, Godini H, Hoseinzadeh E, Khoshgoftar M, Yusefzadeh A. Evaluation of River Water Quality using NSFWQI and GIS: A case study of Khorramrood River in Khorramabad, Iran. Arch Hyg Sci 2014;3(3):101-111.
2. Loague K, Corwin DL. Point and nonpoint source pollution. Encyclopedia of Hydrological Sciences 2005;3:1427-1439.
3. Mol N, Thompson K, Rediske R. Baseline study on Fremont Lake and its connecting waterways. Annis water resources institute of Grand Valley State University; 2010. P. 165.
4. Jang C, Kum D, Jung Y, Kim K, Shin DS, Engel B, et al. Development of a Web-Based L-THIA 2012 Direct Runoff and Pollutant Auto-Calibration Module Using a Genetic Algorithm. Water 2013;5(4):1952-1966.
5. Ardani R, Yari AR, Fahiminia M, Hashemi S, Fahiminia V, Saberi Bidgoli M, et al. Assessment of Influence of Landfill Leachate on Groundwater Quality: A Case Study Albourz Landfill (Qom, Iran). Arch Hyg Sci 2015;4(1):13-21.
6. Mahvi AH, Vosoughi M, Mohammadi MJ, Asadi A, Hashemzadeh B, Zahedi A, et al. Sodium Dodecyl Sulfate Modified-Zeolite as a Promising Adsorbent for the Removal of Natural Organic Matter From Aqueous Environments. Health Scope 2016;5(1):e29966.
7. Alavi N, Zaree E, Hassani M, Babaei AA, Goudarzi G, Yari AR, Mohammadi MJ. Water quality assessment and zoning analysis of Dez eastern aquifer by Schuler and Wilcox diagrams and GIS. Desalination and Water Treat 2016;57(50):1-2.
8. Lin YP, Hong NM, Wu CF, Verburg PH. Impacts of land use change scenarios on hydrology and land use patterns in the Wu-Tu watershed in northern Taiwan. Landscape Urban plann J 2007;80(1-2):111-126.
9. Rewerts CC, Engel BA. ANSWERS on GRASS: Integrating a watershed simulation with a GIS. American Society of Agricultural Engineers; 1991.91. p. 1–9.
10. Bhaduri B, Harbor J, Bernie E, Grove M. Assessing Watershed-Scale, Long-Term Hydrologic Impacts of Land-Use Change Using a GIS-NPS Model. Environ Manage 2000;26(6):643–58.
11. Karimi S, Salman mahini A, Khorasani N, Feghhi J. Application of L-THIA model to estimate the amount of runoff and non-point source pollution in Gorgan and Aliabad watersheds in Golestan province. Fifth National Conference on World Environment Day. Tehran; 2010. (Persian)
12. Tang Z, Engel BA, Pijanowski BC, Lim KJ. Forecasting land use change and its environmental impact at a watershed scale. J Environ Manage 2005;76(1):35–45.
13. Zhang J, Shen T, Liu MH, Wan Y, Li J. Research on Non-point Source Pollution Spatial distribution of Qingdao Based on L-THIA Model (in Chinese). Math Comput Model J 2011;54(3-4):11-19.
14. Wilson C, Weng Q. Assessing Surface Water Quality and Its Relation with Urban Land Cover Changes in the Lake Calumet Area, Greater Chicago. Environ Manage 2010;45(5):96–111.
15. Salman Mahiny A, Hosseinnia A, Ghasempoori SM, Tavasoli A. Long Term Hydrological Impact Assessment of Land use Change on Surface Annual Runoff at the Catchment Scale. Geography Dev 2012;10(26):33-36.
16. Yang L, Ma K, Guo Q, Bai X. Evaluating long-term hydrological impacts of regional urbanization in Hanyang, China, using a GIS model and remote sensing. Int J Sustainable Dev World Ecol 2008;15(4):350-356.
17. You YY, Jin WB, Xiong QX, Xue L, Ai TC, Li BL. Simulation and Validation of Non-point Source Nitrogen and Phosphorus Loads under Different Land Uses in Sihu Basin, Hubei Province, China. Procedia Environ Sci J 2011;13:1781–1797.
18. Esfandiyari F, Beheshti Javid E, Fathi MH. Evaluation of hydrologic impacts of land use on runoff in Ghareso basin using L-THIA model. Hydrogeomorphology 2015;1(1):59-73. (Full Text in Persian)
19. Vafakhah M, Javadi MR, Najafi J. Effect of Land Use Changes on Runoff Depth in Chalousrud Watershed. Iran J Ecohydrol 2015;2(2):211-220. (Full Text in Persian)
20. Pasandidehfar Z, Salman Mahiny A, Mirkarimi H, Akbari M, Gholamalifard M. Non-point Source Pollution Modeling Using Geographic Information System (GIS) for Representing Best Management Practices (BMP) in the Gorganrood Watershed. Iran J Appl Ecol 2014;8(3):43-53. (Full Text in Persian)
21. Galdavi S, Mohammadzadeh M, Salman mahiny A, Najafi Nejad A. Assessment of impact of land use change on surface water by L-THIA model in Gorgan. Environ Res 2015;6(11):131-140. (Full Text in Persian)
22. Yari T. Assessment of development effects on quantity and quality of runoff in Kermanshah city using

L-THIA model. [MSc Thesis]. Iran: Sari University of Agricultural Sciences and Natural Resources, Department of Natural Resources; 2014. (Persian)

23. Choi W. 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 Spatial Hydrol 2007;7(1):47-65.

24. Pandey S, Gunn R, Lim KJ, Engel B, Harbor J. Developing a Web-enabled Tool to Assess Long-term Hydrologic Impacts of Land-use Change: Information Technology Issues and a Case Study. J Am Water Resour Assoc 2000;12(4):5-17.

25. US Department of Agriculture, Natural Resource Conservation Service, 2007. National Soil Survey Handbook, title 430-VI. Available from: http://soils.usda.gov/technical/handbook/.

26. Ponce VM, Hawkins RH. Runoff Curve Number: Has It Reached Maturity? Hydrologic Engineering Journal 1996;1(1):11-19.

27. Garen DC, Moore DS. Curve Number Hydrology in Water Quality Modeling: Uses, Abuses, and Future Directions. J Am Water Resour Assoc 2005;41(2):377-388.

28. Basnyat P, Teeter LD, Lockaby BG, Flynn KN. The Use of Re¬mote Sensing and GIS in Watershed Level Analyses of Non-point Source Pollution Problems. Forest Ecol Manag 2000;128(1-2):65-73.

29. Esen E, Uslu O. Assessment of the Effects of Agricultural Practices on Non-point Source Pollution for a Coastal Watershed: A Case Study Nif Watershed, Turkey. Ocean Coastal Manag 2008;51(8-9):601-611.

30. Carpenter SR, Caraco NF, Correll DL, Howarth RW, Sharpley AN, Smith VH. Nonpoint Pollution of Surface Waters with Phosphorus and Nitrogen. Journal of Ecological Applications 1998;8:559-568.

31. Mattikalli NM, Richards KS. Estimation of Surface Water Quality Changes in Response to Land Use Change: Application of the Export Coefficient Model Using Remote Sensing and Geographical Information System. J Environ Manage 1996;48(3):268-282.

32. Lim KJ, Engel BA, Tang Z, Muthkrishnan S, Choi J, Kim K. Effects of calibration on LTHIA GIS runoff and pollutant estimation. J Environ Manage 2006;78(1):35-43.

33. Lim KJ, Engel BA, Tang Z, Muthkrishnan S, Choi J, Kim K. Effects of calibration on LTHIA GIS runoff and pollutant estimation. J Environ Manage 2006;78(1):35-43.

34. Perry T, Nawaz R. An investigation into the extent and impacts of hard surfacing of domestic gardens in an area of Leeds, United kingdom. Landscape Urban Plann 2008;86(1):1-13.

35. Galdavi S. Comparison of geomod and logestic regression method to modelling of land use changes and vegetation and investigation of changes effect on surface water (case study: Gorgan). [MSc Thesis]. Gorgan University of Agriculture and Natural Resources, Department of Fisheries and Environment; 2011. (Persian)

36. Cowden JR, Watkins D, Croley TE. Investigating Urban Land Use Effects on Runoff by using theDistributed Large Basin Runoff Model. The World Environmental and Water Resource Congress 2006; Examining the Confluence of Environmental Water Concerns Environmental and Water Resource Institute American Society of Civil Engineers, May 21-25. Omaha, Nebraska; 2006.

37. Engel BA, Choi JY, Harbor J, Pandey SH. Web-based DSS for Hydrologic Impact Evaluation of small Watershed land use changes. Comput Electron Agr 2003;39(3):241-249.

38. Saadati H, Gholami SH, Sharifi F, Ayubzadeh A. Evaluation of land use change in surface runoff simulation using SWAT model. Iran J Natural Resour 2006;59(2):1-12. (Full Text in Persian)

39. Shi PJ, Yuan Y, Zheng J, Wang JA. The effect of land use/cover change on surface runoff in Shenzen region, China. Catend 2007;69(1):31-35.

40. Ghafari G, Ghodoosi J, Ahmadi H. Investigating the hydrological effects of land use change in catchment (Case study: Zanjanrood Basin). J Water Soil Conserv 2009;16(1):163-180. (Full Text in Persian)

41. Kim Y, Engel B, Lim KJ, LarsonV, Duncan B. Runoff Impacts of Land Use Change in the Indian River Lagoon Watershed. J Hydrol Eng 2002;7(3):245-251.