Modeling of non-point source pollution by long-term hydrologic impact assessment (L-THIA) (Case study: Zayandehrood watershed)

Mojgan mirzaei¹, Eisa solgi², Abdolrassoul Salman Mahiny³

1. PHD student in environmental science, Malayer University
2. Asistant Profesor, Department of Environment, Faculty of Natural Resources and Environment, Malayer University
3. Associate Professor, Gorgan University of Agriculture Sciences and Natural Resources.

Abstract: Many water quality models have been extensively used to evaluate non-point source pollution. Hydrologic and water quality modeling require the characterization of runoff generating processes within watersheds. In this research long-term hydrologic impact assessment model is selected. The L-THIA model can be used to simulate runoff and NPS pollution in watershed scales. Zayandehrood watershed is the most important watershed in Iran. This basin is located in Esfahan province and Zayandehrood River passed through it. The annual average runoff volume, depth and the non-point source nitrogen and phosphorus load and the spatial distribution were estimated by L-THIA model. According to the study, we concluded the NPS nitrogen and phosphorus load in agricultural and residential areas are more serious and the NPS nitrogen load was larger than NPS phosphorus load in Zayandehrood basin. 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 in the vulnerable sections.

Key words: Esfahan, Hydrology, nitrogen, phosphorus, water quality.

Introduction
Non-point pollution is defined as surface and subsurface soil, air, surface and underground water contaminants in nature that cannot be traced its central location (Loague and Corwin, 2005). In other words, the source of this type of pollution is widespread and often created from agricultural land. Non-point source pollution is caused when rain, snowmelt or wind carry pollutants off the land and into water bodies (Mol et al., 2010). Typically, agriculture urbanization leads to increases in impervious surface and results in increased runoff and nonpoint source (NPS) pollutant loads (Jang et al., 2013). Today, non-point source pollution is increasing in the world. Therefore, modeling approaches that can simulate runoff and NPS pollutant loads at regional/watershed-scales are required (Rewerts and Engel, 1991). In many cases non-point pollution associated with agricultural land (Luo et al., 2006).

Bhaduri pointed that the L-THIA model was a very important tool to analyze sensitivity to NPS pollution of the areas (Bhaduri, 2000).

Tang and colleagues is evaluated changes in land use and environmental impacts in the watershed scale, in the Muskegon River watershed using L-THIA model. Results showed that watershed is exposed to the effects of urban development and some of the nonpoint source pollutants (Tang et al., 2005). Jinheng used L-THIA model to analyze the spatial distribution of NPS pollution in Qingdao, and found that the impact of agricultural land on NPS pollution load was the greatest, followed by residential areas (Jinheng et al., 2011). Wilson and Weng used L-THIA model to simulate the surface water quality and its relation with urban land cover changes in the Lake Calumet area, Greater Chicago.

You and colleagues simulated non-point source nitrogen and phosphorus loads under different land uses in Sihu Basin, Hubei Province in China. They concluded effects of dry lands on NPS nitrogen and phosphorus load were both the largest, residential areas and paddy fields were the medium, grasslands and woodlands were the minimum (You et al., 2012). Esfandiyari and colleagues evaluated hydrological impact of land use change on annual run off in Ghareso basin by L-THIA model. They concluded amount of run off is increased 1.8 mm in 25 years and forest area is increased and residential area is decreased (Esfandiyari et al., 2014). The aim of this study is modeling of non-point source pollution in Zayandehrood watershed.

Materials and methods
Study region
The study was carried out on the Zayandehrood watershed (latitude 31°12’N, longitude 50°02’E) in Iran County. Zayandehrood watershed extends over a total area of 41500 km².

Method
L-THIA is a hydrology and NPS pollutant loading model that calculates direct runoff and NPS pollutant loads in each tessellated grid cell of a study area (Choi, 2007). L-THIA gives long-term average annual runoff for a land use based on actual long-term climate data, soils, and land-use data for an area (Pandey et al., 2000). This model is worked based on curve number (CN) which is widely used for estimating the flow behavior in a watershed. L-THIA model are estimates the daily runoff for different amounts of CN by using daily rainfall data and the amount of CN afterward total values of daily data were sum and the model estimated the annual runoff which shall be considered as the model output (Mahiny et al., 2012).

The NRCS-Curve Number (CN) method (USDA-SCS, 1972) was selected to calculate the runoff volumes of various precipitation events for both the potential contributing area and traditional catchment area for comparison with the measured runoff volumes. The CN method was used because it is a simple and widely applied approach for determining direct runoff volumes from a precipitation event (Ponce and Hawkins, 1996; Garen and Moore, 2005). The CN method computes runoff volume (Q) in inches as

\[
Q = \frac{(P-0.2S)^2}{P+0.8S} \quad \text{for } P \geq 0.2S
\]

\[
Q = 0 \quad \text{for } P < 0.2S
\]

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. Input data required for this model are: land use maps, soil maps (soil hydrological groups), text file rainfall last thirty years and text file of CN-table. 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 area is also considered. This model considers two statuses to Antecedent moisture conditions: Normal AMC and adjusted AMC. Antecedent Moisture condition is the preceding relative moisture of the pervious surfaces prior to the rainfall event. This is also referred to as Antecedent Runoff. L-THIA model estimates the runoff volume and nonpoint source pollutant loadings within the ArcView L-THIA extension. Runoff volume is computed by runoff depth multiplied by cell area.

In this model, Soils are generally classified into four HSG's (hydrological soil groups: A, B, C, and D) as shown in Table 1 based on soil texture (USDA, 2007).

### Table 1. Hydrologic Soil Groups

<table>
<thead>
<tr>
<th>Soil Group</th>
<th>Description</th>
<th>USDA Soil Texture</th>
</tr>
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<tbody>
<tr>
<td>A</td>
<td>Well drained (high infiltration)</td>
<td>Sand, loamy sand, or sandy loam</td>
</tr>
<tr>
<td>B</td>
<td>Moderate to well drained (moderate infiltration)</td>
<td>Silt loam or loam</td>
</tr>
<tr>
<td>C</td>
<td>Poor to moderately well drained (low infiltration)</td>
<td>Sandy clay loam</td>
</tr>
<tr>
<td>D</td>
<td>Poorly drained (very low infiltration)</td>
<td>Clay loam, silt clay loam, sandy clay, silt clay, or clay</td>
</tr>
</tbody>
</table>

The hydrologic soil groups (HSG) were derived from the Land Type data by reclassifying the soil textures (figure 1).

![Figure 1. The hydrologic soil groups in Zayanderood watershed](image)
In L-THIA model, land uses classified to 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 2.

![Figure 2. Land use map](image)

**Results**

The first, L-THIA Model converted hydrologic soil groups and land use maps to raster (figure 3 and 4).

![Figure 3. Soil grid](image)
Then, a CN (curve number) map is calculated (figure 5).

In next step, after the introduction of the required data, model is run. This model are calculated run off-depth (figure 6) and then run off-volume (figure 7) respectively.
Figure 6. Map of run off-depth

Figure 7. Map of run off-volume

Ultimately, non-point source pollution map is created (figure 8).
Figure 8. Map of non-point source pollution

Figure 9. Sub basins of Zayandehrood watershed
According to the figure 9, 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 main nutrients in agricultural fertilizers (Carpenter et al. 1998). Therefore, N and P are important parameters of water quality (Mattikalli and Richards 1996). The spatial distribution of dissolved phosphor, total phosphorus and total nitrogen pollutant loads are shown in Figs. 10 through 12 respectively.

Figure 10. The spatial distribution of dissolved phosphor pollutant loads

Figure 11. The spatial distribution of total phosphorus pollutant loads
Discussion and conclusion

Historical development of Isfahan city is due to presence of Zayandeh Rood. Zayandehrood is one of these rivers which is the main reason for creation of a sustainable city called Esfahan. This river has caused beauty, elegance and urban design. Therefore, conservation of this river and its watershed is very important. Nutrients from agricultural fertilizers are major causes of water quality problems in the most countries. Increasing concern about the problems caused by agricultural and urban areas led to evaluation of non-point source pollution with different models. Among different models, L-THIA model as integrated model is selected for this study. Because this model need lower data in comparison another models and is easier. The results revealed amount of non-point source pollution is high in 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. According to the study, we accessed the conclusions that the NPS nitrogen load was larger than NPS phosphorus load in Zayandehrood basin. 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 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.

In a hydrological perspective, this article reveals the effect of different urban land-use types on runoff and NPS pollutant loads. In a regional planning perspective, it is suggested that careful planning of development types and locations can help minimize negative environmental impacts.

References


