Reliability of Land Capability Map in Watershed Hydrological Simulation using SWAT Model

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ABSTRACT Soil and Water Assessment Tool, SWAT, uses different layers of watershed data which out of soil layer is the important one. Soil layer data should be extracted from detailed soil maps. In most developing countries including Iran, these detailed maps are not available except for irrigation districts and rarely for dry land farming areas and also for some strategic places of development purposes. For larger plains, the available soil maps information are reduced to semi-detailed scale which adds uncertainty in data required for catchments and hydrologic modeling. This research studied the relations between land use (LU) maps, land suitability for agricultural activities (LS) and physiographic soil unit (PU) on one hand and detailed soil maps and their embedded data on the other hand. The research has focused on the replacement of data derived from the detailed soil maps (from large scale soil map information) with those of readily available LS, PU and LU maps. Using these two sets of data for modeling of hydrologic system with SWAT on a 5793 Km²-watershed in west of Iran showed no significant difference between the simulated discharges at the watershed outlet. So the available LS map for the whole country may be used for both plains and catchments in SWAT simulation.

Key words: FAO soil map, Hydrologic response unit, Land suitability, SWAT calibration

1 INTRODUCTION

LU change is among major challenges in environmental management all over the world which may have significant impacts on river runoff quality and quantity. Of the main objectives of developing distributed physically based models was to identify the role of LU change on rivers’ hydrologic balance. According to Abbott et al. (1986), physically based models are capable of overcoming the deficiencies of lumped models; however, they are found deficient for application in developing countries as data for their spatio-temporal parameters are not available. One of the very well known models is Soil and Water Assessment Tool, SWAT, which is developed for research on LU change impacts, watershed management and also analysis of interactions of hydrologic cycle components (Arnold et al., 1998). Besides LU change management options, the model is capable of finding hydrologic interactions of different components and their impacts on water quantity and quality (Ghafouri et al., 2012).

SWAT model uses a range of information and data where one of the main lists is a rather...
detailed data from soil maps. The model default soil data base is derived from a global soil map prepared by Food and Agriculture Organization, FAO, (FAO, 1995), which provides data for soil types comprising two depths (0–30 and 30–100 cm depths) at a very large spatial resolution of 10 km. Quality and availability of soil maps is related not only to their scales but also to the method of their development, type of information and quality of their outputs (Bossa et al., 2012). From a research in the USA it is resulted that soil data spatial resolution is very effective on hydrological responses (Sheshukov et al., 2012). In Iran, these kinds of maps at semi-detailed scale (1:250000) are only available for irrigation districts or on a rare occasion for dry land farming areas. However, there is a good connection between LU maps, LS and PU on one hand and detailed soil maps and their embedded data on the other. In addition to the simplicity and cost effectiveness of LU and LS studies they are available in 1:250000 scale for the whole country. If users can either define or derive precise relations between soil maps and both LU and LS, the data from the latter can be used in SWAT model as a surrogate to the soil map data. LS maps highly facilitate the application of the hydrologic models such as SWAT in Iran or similar countries in the region. SWAT model is a daily time-step, physically based semi-distributed continuous model which has been frequently used for LU change detection and its impact on water balance (Arnold et al., 1998, Neitsch et al., 2005). Although in original version of SWAT, (Arnold et al., 1998), runoff is estimated based on SCS method, saturation mechanism has been developed for runoff generation from variable source area where soil map plays an important role (Watson, 2006). SWAT has been used in Iran on Gharehsoo watershed for soil conservation scenarios and their impacts on erosion and sediment control where soil data has been found crucial in the study, however, the model which required soil data has not been clearly defined (Omani et al., 2007). Recent research in Iran using SWAT model showed that there is no clear relationship between land southern aspect and LU with the magnitude of evapotranspiration, however soil type was found to be effective on amount of evapotranspiration at the sub watershed scale. Appraisal of soil map in Taleghan watershed showed that the soil depth in southern slopes of the watershed is generally deeper than that of the northern slopes which causes evapotranspiration to be significantly higher over the southern slopes (Ghafouri et al., 2012 and Hosseini, 2010).

This paper compares the runoff simulation resulted from two different sources of soil data; namely field data, derived from soil profiles and laboratory analysis, and LS maps and soil experts’ intuitive judgments on soil parameters.

2 MATERIAL AND METHODS

Gharehsoo watershed with an area of 5793 Km² is one of the large sub catchments of 50,000 Km² grand Karkheh River Basin, KRB, located in Kermanshah province North West of Iran (Figures 1 and 2). Approximately 48% of the watershed area is mountainous and 52% consists of plains and hills. The maximum and minimum elevations of the watershed are 3351 and 1300 meters, respectively. The average elevation of the watershed is 1559 m and the mean slope is 15%. The length of the main river is 211 km. The mean annual rainfall is 400mm where January and February have the highest rain and June to August have the lowest.
A 13-year record, 1992-2005, of a discharge gauging station at the outlet of Gharehsoo watershed along with data from 52 rain gauges and 10 temperature monitoring stations located inside and outside of the watershed boundaries were used for meteorological investigation and modeling purposes. Gharehsoo river has the highest yield in KRB when the river usually starts rising on October, peaks on March and subsides on September with the lowest discharge. Figure 3 shows the channel network of this catchment.
2.1 SWAT model

There are many models with a number of advantages and limitations for watershed processes simulation; however, presently compatibility with GIS and association with the remotely sensed data are among the main criteria in choosing and using models (Merritt et al. 2003). SWAT is a semi-distributed hydrologic model which is used for water balance analysis, hydrologic components determination, water quality monitoring, soil erosion estimation, rangeland management and climate change impact assessment in more than 100 countries in the world including Iran. The smallest water balance calculation units in SWAT are called Hydrologic Response Units, HRUs, which are derived from overlaying slope, LU and soil maps (Neitsch et al., 2005; Arnold et al., 1990). While the main watershed can be subdivided to many subcatchments, each sub watershed contains a number of HRUs which depends on the details of the available soil map. SWAT is a continuous model which simulates water movement and evapotranspiration through soil during and between storm events for each HRU.
2.2 Soil map layer in SWAT
In this research, the primary data regarding soil studies, LU and LS of the Gharehsoo watershed were collected and entered in GIS platform for SWAT simulation. Soil sampling points were selected at each physiographic soil unit (a total of 41 points were chosen and 100 soil samples were taken based on number of layers in each profile) and sampling and interpretation were carried out on the dug soil profiles and trenches (Figure 4). Soil samples were analyzed in the lab to derive the required parameters based on SWAT manual as presented in Table 1. SWAT model was run twice with the field data on the first run and LS and LU maps data along with soil experts’ intuitive judgments for identifying ranges of the parameters on the second run. The simulated discharges at the watershed outlet for both runs were compared with the observed data and also with each other.

3 RESULTS AND DISCUSSION
The results of the SWAT model simulation for annual and monthly discharges were taken as the index for testing the compatibility of the soil input data from soil map and soil profile interpretation, referred to as field data hereafter, with those of LU and LS data along with soil experts’ judgments, referred to as LS hereafter. In Table 2 the comparison between observed and simulated discharges using both field data and LS map are presented.

Table 1 Soil parameters data entries required by SWAT model

<table>
<thead>
<tr>
<th>Row</th>
<th>Soil Parameters</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>NLAYERS</td>
<td>Number of Soil Layers</td>
</tr>
<tr>
<td>2</td>
<td>HYDGRP</td>
<td>Soil Hydrologic Group</td>
</tr>
<tr>
<td>3</td>
<td>Sol_ZMX</td>
<td>Soil Depth</td>
</tr>
<tr>
<td>4</td>
<td>Sol_BD</td>
<td>Bulk Density</td>
</tr>
<tr>
<td>5</td>
<td>Sol_CBN</td>
<td>Organic Matter</td>
</tr>
<tr>
<td>6</td>
<td>Sol_K</td>
<td>Hydraulic Conductivity</td>
</tr>
<tr>
<td>7</td>
<td>Sol_AWC</td>
<td>Available Water Capacity</td>
</tr>
<tr>
<td>8</td>
<td>Sol_ALB</td>
<td>Albedo Rate</td>
</tr>
</tbody>
</table>

Table 2 Observed and simulated annual flows-Gharehsoo River

<table>
<thead>
<tr>
<th>Year</th>
<th>Qobs$^*$ ($m^3s^{-1}$)</th>
<th>Qsim$^{**}$ ($m^3s^{-1}$) (Field data)</th>
<th>Qsim ($m^3s^{-1}$) (LS)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1992</td>
<td>36.26</td>
<td>9.38</td>
<td>10.80</td>
</tr>
<tr>
<td>1993</td>
<td>19.20</td>
<td>13.63</td>
<td>15.30</td>
</tr>
<tr>
<td>1994</td>
<td>31.61</td>
<td>38.11</td>
<td>32.93</td>
</tr>
<tr>
<td>1995</td>
<td>22.19</td>
<td>25.90</td>
<td>18.66</td>
</tr>
<tr>
<td>1996</td>
<td>24.15</td>
<td>28.66</td>
<td>23.71</td>
</tr>
<tr>
<td>1997</td>
<td>11.52</td>
<td>11.25</td>
<td>10.93</td>
</tr>
<tr>
<td>1998</td>
<td>33.88</td>
<td>27.45</td>
<td>19.60</td>
</tr>
<tr>
<td>1999</td>
<td>6.80</td>
<td>8.18</td>
<td>6.35</td>
</tr>
<tr>
<td>2000</td>
<td>3.32</td>
<td>5.02</td>
<td>6.30</td>
</tr>
<tr>
<td>2001</td>
<td>5.20</td>
<td>7.06</td>
<td>7.18</td>
</tr>
<tr>
<td>2002</td>
<td>10.17</td>
<td>19.05</td>
<td>14.50</td>
</tr>
<tr>
<td>2003</td>
<td>13.08</td>
<td>19.02</td>
<td>13.45</td>
</tr>
<tr>
<td>2004</td>
<td>13.78</td>
<td>18.31</td>
<td>14.64</td>
</tr>
<tr>
<td>2005</td>
<td>20.31</td>
<td>17.50</td>
<td>14.28</td>
</tr>
</tbody>
</table>

$^*$Qobs: Surface runoff observation
$^{**}$Qsim: Surface runoff simulation
Figure 4 Distribution of sampling points in Gharehsoo watershed on Soil Physiographic Units map
Although, the simulation results from LS map are closer to the observed than those of the field data (Figure 5), the statistical t-test revealed no significant (p-value < 5%) difference between using these two different sets of data. In Figure 6, monthly discharges for years 1992 to 2005 are depicted for both data series. Coefficient of determination ($R^2$) of 0.92 showed strong relations between the discharges resulted from the two sets of soil data. Figure 7 showed the relationship of two average annual data with $R^2$ above 0.9.

![Diagram](image)

Figure 5 SWAT simulation annual flow results with two sets of soil data
Figure 6 Equality of the monthly flow simulation results with two sets of soil data series

\[ y = 0.7892x + 0.8892 \]
\[ R^2 = 0.92 \]

Figure 7 Equality of the annual flow simulation results with two sets of soil data

\[ y = 0.7278x + 1.9788 \]
\[ R^2 = 0.93 \]
Using independent T-test for monthly and annual discharges for both series showed P-value of 0.18 and 0.38 for degree of freedom of 334 and 24 which shows no significant difference (p-value < 5%) between the two sets of results. (Tables 3 and 4).

<table>
<thead>
<tr>
<th>Table 3</th>
<th>Two sample- t- test for monthly results of Simulation (Field data) versus Simulation (Land Suitability)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N</td>
</tr>
<tr>
<td>Sim S</td>
<td>168</td>
</tr>
<tr>
<td>Sim C</td>
<td>168</td>
</tr>
</tbody>
</table>

95% CI and DF=334 Both use Pooled SD= 19.8, \( P=0.19 \)

<table>
<thead>
<tr>
<th>Table 4</th>
<th>Two sample-t-test for annual results of Simulation (Field data) versus Simulation (Land Suitability)</th>
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<tr>
<td></td>
<td>N</td>
</tr>
<tr>
<td>Sim SY</td>
<td>14</td>
</tr>
<tr>
<td>Sim CY</td>
<td>14</td>
</tr>
</tbody>
</table>

95% CI and DF=24, \( P=0.38 \)

The insignificant difference between the results of using two different maps indicates that in a large watershed like Gharehsoo with a considerable variety of physiographical units we may use LS and LU maps without the need to the detailed soil maps. However, it should be mentioned that uncertainty is associated with the scale of soil maps and map preparation methods which should be included in the planning for data provision in modeling (Bossa et al., 2012).

At present, there are two options regarding SWAT soil maps; the first one demands at least semi-detailed soil map which is costly and generally unavailable and the second one which considers SWAT model insensitive to soil data so uses a FAO embedded global soil data base with a resolution of 10 Km (FAO, 1995).

Despite the indifferent results in the current study using either field data (say semi-detailed soil map data) or LS maps, some effective environmental conditions can question this simple vision and challenge the sensitivity of the model to soil map. Very recent research emphasize on spatial resolution, sampling point density and also sensitivity of the model to various methods of soil data acquisition and demand for more research on calibration of the model regarding soil data (Sheshukov et al., 2011, Boluwade and Madramootoo, 2013 and Bossa et al., 2012). Using SWAT model, the magnitude of actual evapotranspiration on southern aspects of an Iranian watershed were found to be significantly higher than those of the northern aspects which was attributed to the deeper soil in the southern aspects which shows the importance of the soil map resolution and data in reaching better understanding of hydrologic processes in catchments (Ghafouri et al., 2012).

4 CONCLUSION

Land suitability maps for agricultural activities with scale of 1:250000 have greater details and can improve the output of the model when compared with the Iranian country wide available soil maps with scale of 1:1000000 which is the base for the FAO soil map embedded in SWAT model as the global default soil data map. Detailed soil maps in Iran are only available for irrigation districts, while the land suitability maps for agricultural activities covers whole catchments of the country which can help in building a customized cost effective
soil data base and help modelers and decision makers to perform better in watershed simulation and planning management practices.

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6 REFERENCES


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بررسی امکان استفاده از داده‌های نقشه‌های قابلیت اراضی در شبیه‌سازی هیدرولوژیکی SWAT

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چکیده: کیفیت به‌طورکلی مدل SWAT از اطلاعات مختلفی استفاده می‌کند که یکی از اصلی‌ترین آن‌ها اطلاعات تفصیلی از نقشه‌های خاک‌شناسی است. در ایران اغلب دشت‌ها و مناطق ناحیه‌ای این‌گونه مطالعات هستند. خصوصاً این مطالعات بیشتر در مقیاس‌های نیمه‌تفصیلی بوده که مدل را گاهی با کمک اطلاعات منابع مسازد. تحقیق حاضر با توجه به این موضوع که به‌طور اختصاصی یکی از داده‌های نقشه‌های کاربری اراضی، قابلیت اراضی و واحدهای فیزیوگرافی خاک و نطقه‌های خاک‌شناسی و داده‌های مورد استفاده در آن جوی و دارد، بررسی و پژوهشی را به‌منظور قرار داد تا بر امکان یا نبودن امکانات لازم برای شبیه‌سازی اطلاعات نقشه‌های قابلیت اراضی و واحدهای فیزیوگرافی و همچنین کاربری اراضی با داده‌های مستخرج از نقشه‌های تفصیلی خاک‌شناسی به انجام رسد. استفاده از سامانه اطلاعات جغرافیایی در مسیر تحقیق حاضر و همچنین از روش‌های مقایسه صحت نهایی بیشتر با تحقیق طرح را شامل شده است. نتایج این تحقیق در یک عرض ۵۷۸۰ کیلومتری در زیست‌زدایی آبیاری قربان در استان کرمانشاه نشان داد که جایگزینی اطلاعات نقشه‌های قابلیت اراضی با نقشه‌های واحدهای کاربری اراضی امکان‌پذیر نیست که این امکانات مورد نیاز ویژه در مدل آب‌ا伫 و حوزه‌های آبیاری باید بوده نسبت به امکانات موجودی در مدل سطح شکاف‌ها و حوزه‌های آبیاری در مدل مورد مطالعه‌ای از این‌جا آمده است.

کلمات کلیدی: تناسب اراضی، نقشه خاک، SWAT

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