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

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ABSTRACT Soil and Water Assessment Tool model, 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 Km^2-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

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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 Km^2 is one of the large sub catchments of 50,000 Km^2 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.

Figure 1 Dry land farming on the left and Gharehsoo River on the right in Gharehsoo watershed (photo by: A. Jafari, Nov. 2011)

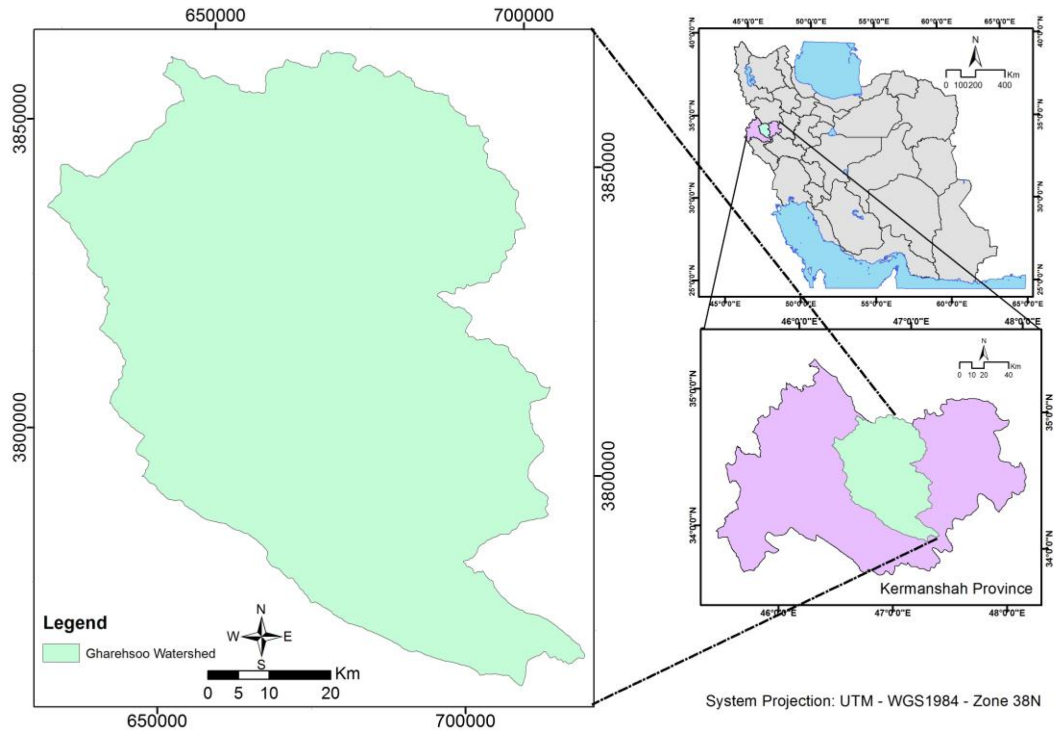


Figure 2 Location of Gharehsoo watershed in Kermanshah Province-Iran

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.

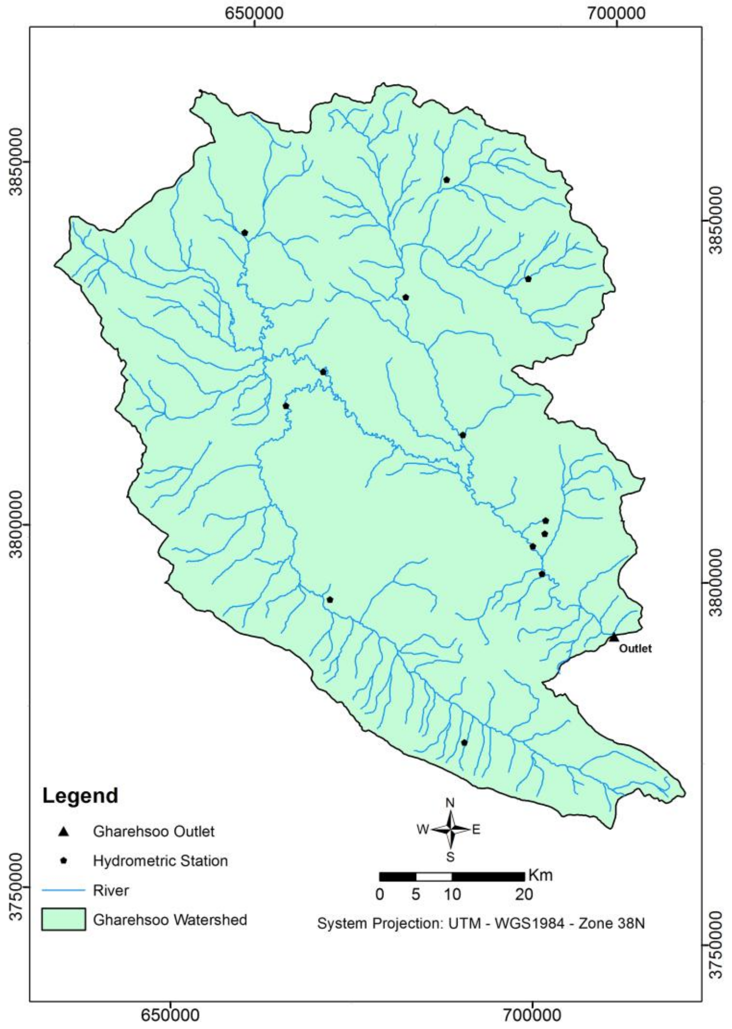


Figure 3 Gharehsoo watershed channel network

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

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

Table 2 Observed and simulated annual flows-Gharehsoo River

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

*Qobs: Surface runoff observation

**Qsim: Surface runoff simulation

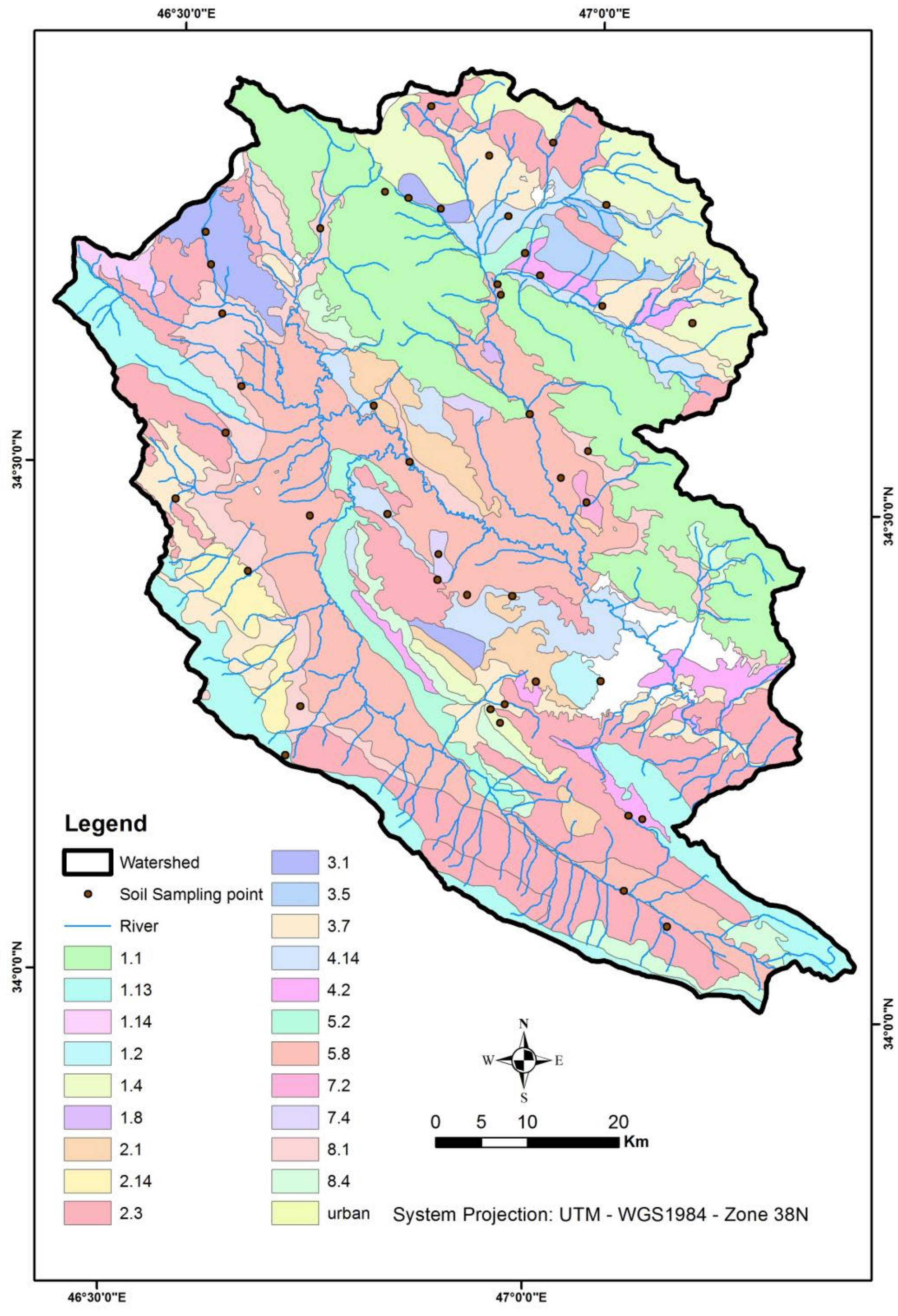
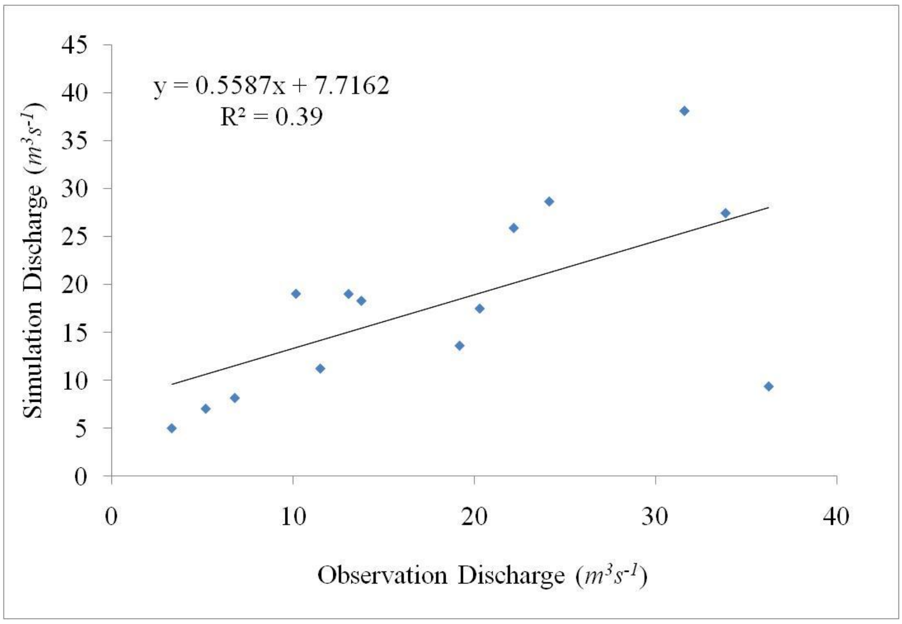
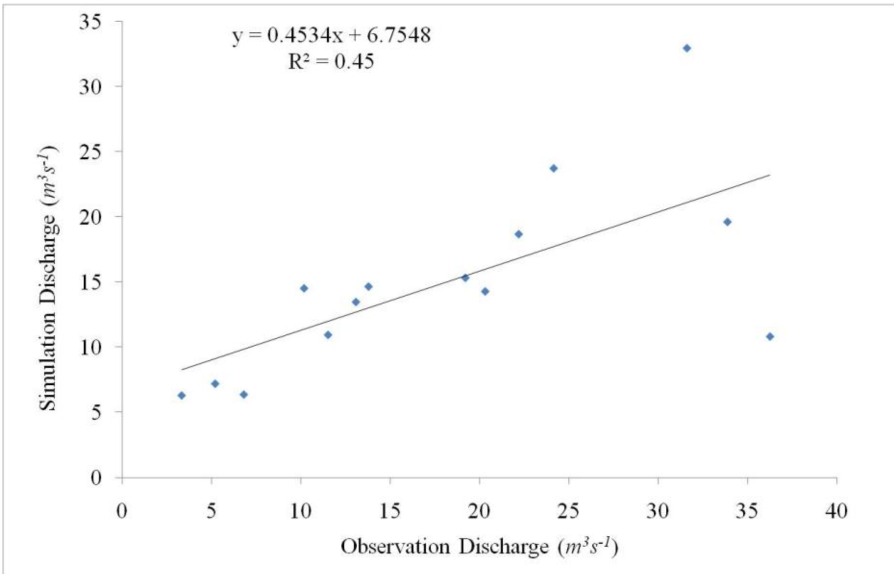


Figure 4 Distribution of sampling points in Gharehsoo watershed on Soil Physiographic Units map

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.



(a): Field data



(b): Land suitabilty

Figure 5 SWAT simulation annual flow results with two sets of soil data

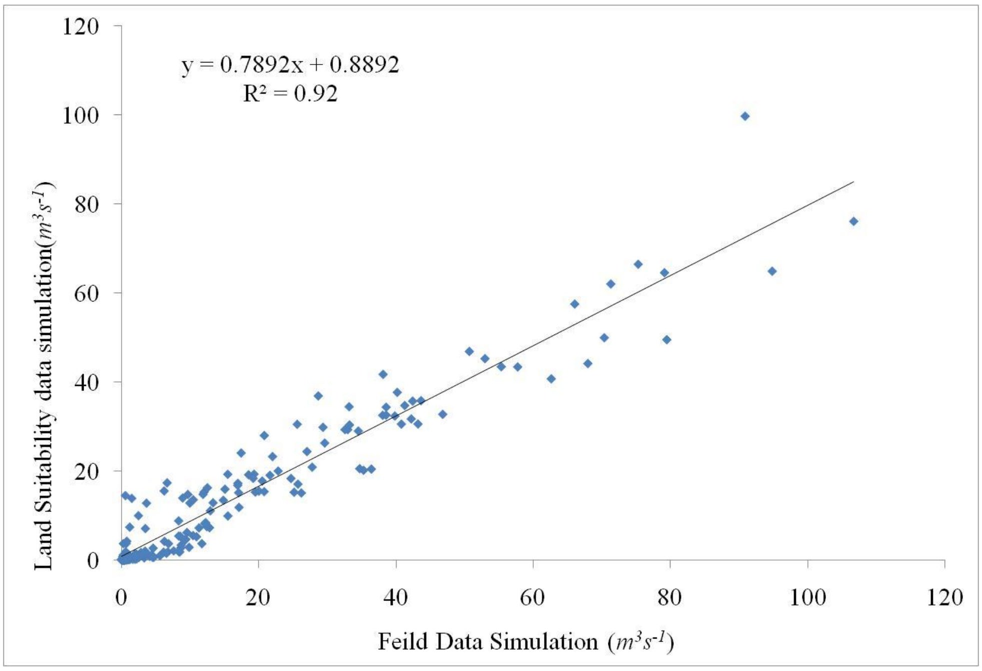


Figure 6 Equality of the monthly flow simulation results with two sets of soil data series

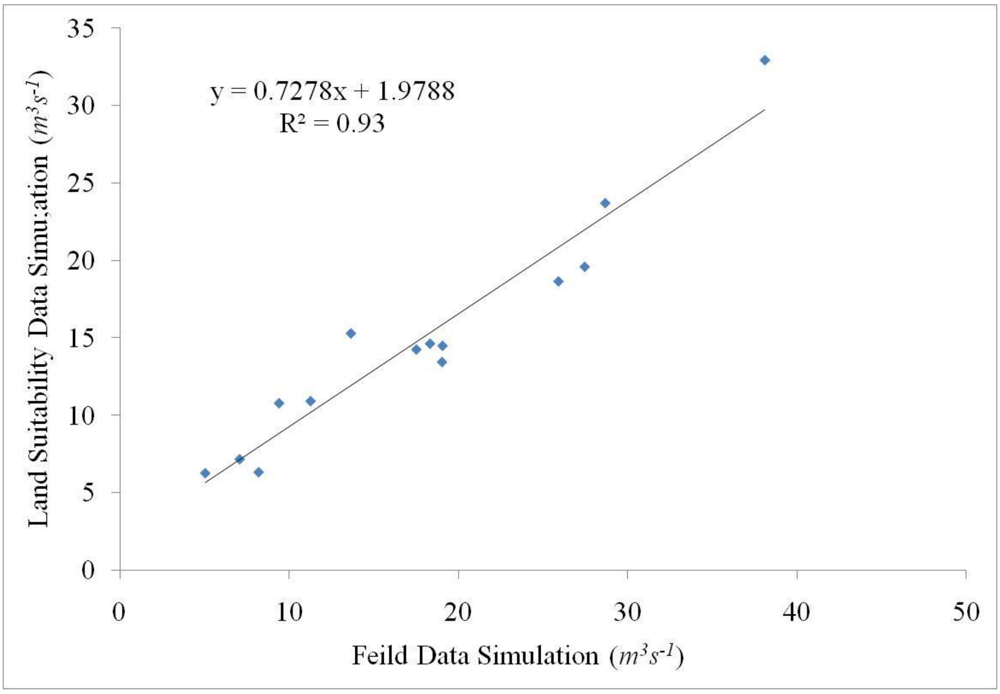


Figure 7 Equality of the annual flow simulation results with two sets of soil data

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 3 Two sample- t- test for monthly results of Simulation (Field data) versus Simulation (Land Suitability)

	N	Mean	STD	SE Mean
Sim S	168	17.8	21.6	1.7
Sim C	168	14.9	17.8	1.4
95% CI and DF=334 Both use Pooled SD= 19.8, **P=0.19**				

Table 4 Two sample-t-test for annual results of Simulation (Field data) versus Simulation (Land Suitability)

	N	Mean	STD	SE Mean
Sim SY	14	17.75	9.59	2.6
Sim CY	14	14.90	7.24	1.9
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.

5 ACKNOWLEDGEMENTS

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بررسی امکان استفاده از داده‌های نقشه‌های قابلیت اراضی در شبیه سازی هیدرولوژیکی حوزه آبخیز قره‌سو در مدل 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 خاصی دارای این‌گونه مطالعات هستند. خصوصاً این مطالعات بیش‌تر در مقیاس‌های نیمه تفصیلی بوده که مدل را گاهی با کمبود اطلاعات مواجه می‌سازد. تحقیق حاضر با توجه به نوع ارتباطی که بین داده‌های نقشه‌های کاربری اراضی، قابلیت اراضی و واحدهای فیزیوگرافی خاک و نقشه-های خاک‌شناسی و داده‌های مورد استفاده در آن وجود دارد، بررسی و پژوهشی را مد نظر قرار داد تا بر امکان جایگزینی 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 آزمون و مقایسه صحت نهایی نتایج به‌وسیله مقایسه اطلاعات نهایی مدل اجرا شده SWAT، روش تحقیق طرح را شامل شده است. نتایج تحقیق در یک عرصه ۵۷۹۳ کیلومتر مربعی در زیرحوزه آبخیز قره‌سو در استان کرمانشاه نشان داد که جایگزینی اطلاعات نقشه‌های قابلیت اراضی با نقشه‌ها و مطالعات کامل خاک‌شناسی امکان‌پذیر بوده، نتایج نهایی دارای تغییرات معنی‌داری نیستند، لذا استفاده از نقشه‌های قابلیت اراضی برای اجرای مدل SWAT در سطح دشت‌ها و حوزه-های آبخیز برای بحث مدل‌سازی با مدل مذکور امکان‌پذیر است.

کلمات کلیدی: تناسب اراضی، نقشه خاک FAO، واحد پاسخ هیدرولوژیک، واسنجی SWAT