Simulation of runoff and sediment yield for the calo watershed, Vinh Phuc province by using swat model

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Abstract. Smallest watershed is considered to be the ideal unit for management of the water resources in a water basin. Extraction of water-shed parameters using Remote Sensing and Geographical Information System (GIS) and use of mathematical models is the current trend for hydrologic evaluation of watersheds. The Soil and Water Assessment Tool (SWAT) having an interface with ArcView GIS software (AVSWAT2005) was selected for the estimation of runoff and sediment yield from an area of Vinh Phuc province, an intermediate watershed of Ca Lo River, located in Western Tam Dao mountain which cover nearly all region of the VinhPhuc province . Base on Hydo Response Unit HRU (as the basin parcel), the performance of the model was evaluated using statistical and graphical methods to assess the capability of the model in simulating the run-off and sediment yield from the study area. Result of the study are informations on quality and quatity of water in each sub basin and also for whole of the basin so it will supply valuable water information for integrated management of the Ca Lo Basin area and also for Vinh Phuc province.

Keywords: SWAT model, Calibration, Validation, Remote Sensing, GIS, Runoff, Hydo Response Unit HRU, basin parcel, Sediment Yield, SWAT model, Hydrological analysis.

1. Introduction

A watershed is a hydrologic unit which produces water as an end product by interaction of precipitation, slope and the land surface. Depending on size of watershed , a big wate shed (or basin) can be devided into various smaller watershed and it called sub-watershed. A smallest sub –watershed can be considered as a *basin parcel*.The quantity and quality of water produced by the watershed are an index of amount and intensity of precipitation and its impact to watershed characteristics. In some watersheds the aim may be to harvest maximum total quantity of water throughout the year for irrigation and living purpose. In other watersheds the objectives may be to reduce the peak rate of runoff for minimizing soil erosion and sediment yield or to increase ground water recharge. Hence, the modeling of runoff, soil erosion and sediment yield are essential for sustainable development. Further, the reliable

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estimates of the various hydrological parameters including runoff and sediment yield for remote and inaccessible areas are tedious and time consuming by conventional methods. So it is desirable that some suitable methods and techniques are used/ evolved for quantifying the hydrological parameters from all parts of the watersheds. So that it will be easy to take the practices accordingly.

2. Study Area

With area of 1.362 km^2, 115.700 peoples in population (statistical data, 2010), Vinhphuc province is located in northern Vietnam (fig.1), contiguous with the Ha Noi capital at north-west direction. Vinhphuc Province is surrounded by Tuyen Quang and Thai Nguyen provinces in the north, Hanoi in the east and in the south, and Phu Tho Province in the west. With picks elevation of 1590 mets,Tam Dao range longate along north west-southeast direction is natural provincial line between Thai Nguyen and VinhPhuc. From north east to south west direction, landform includes low mountain, low hill and plain with elevation about 6 to 8 mets obove sea level. Natual condition of vinh Phuc is various in soil condition, land use, forest cover, climate and water resource. There are four large rivers: Hong (Red), Lo, Pho Day, and Ca Lo. Among this, Ca Lo is a small river having all basin inside boundary of the Vinh Phuc Province. In general, climate of the Vinh Phuc Province is monsoonal with hot and wet summers and cool, cloudy and moist winters. Total annual rainfall ranges from 1100–3000 mm. Average temperature is 25^{0}C, with an average maximum of 39^{0}C (in August) and minimum of 5^{0C} (in January). Southwest monsoon occurs from May to October, bringing heavy rainfall and temperatures remain high. November to April is the dry season with a period of prolonged cloudiness, high humidity and light rain. The vinhphuc province has the red and yellow soil type and soil depth is near about 80 cm. the annual rain fall in this region is near about 1600 mm. Landcover contend difference type as: dense forest (in the Tam Dao range), spart forest, bare land, plantation, bush-grass land, fruit tree, shifting cultivated land, lowland agricultue with rice field, farm fields. This condition is the reason that this area faces a major problem which direct relate to the Ca Lo river basin such as soil erosion, landslide, flooding, water logging in rainy season and drought in drain season. With the concept of integrated management of river basin, there is meaning that good management of the Calo river basin is also good environmental management of the Vinh Phuc province. SWAT model was selected as a efficient tool for water basin management.

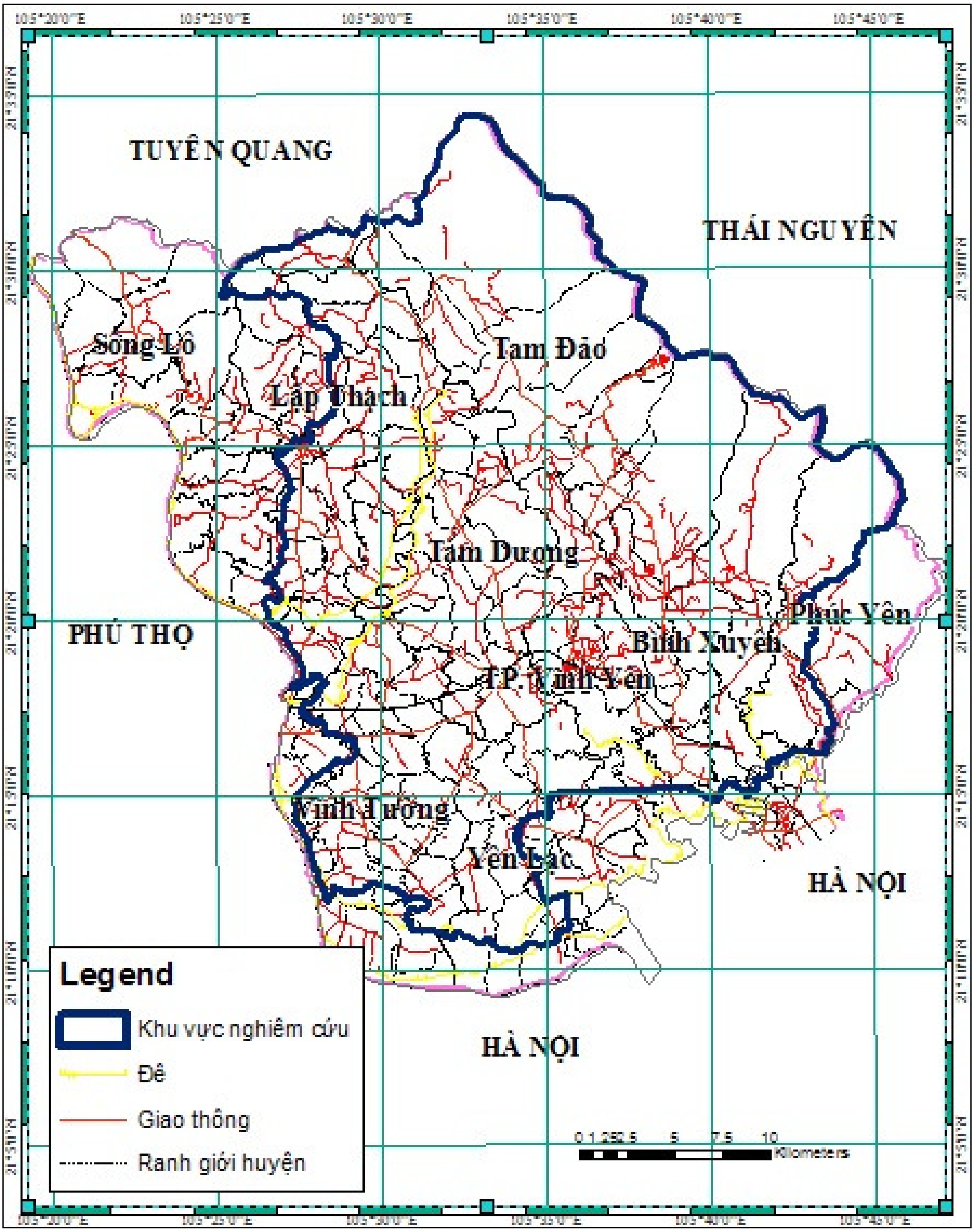

Fig. 1. Study area location.

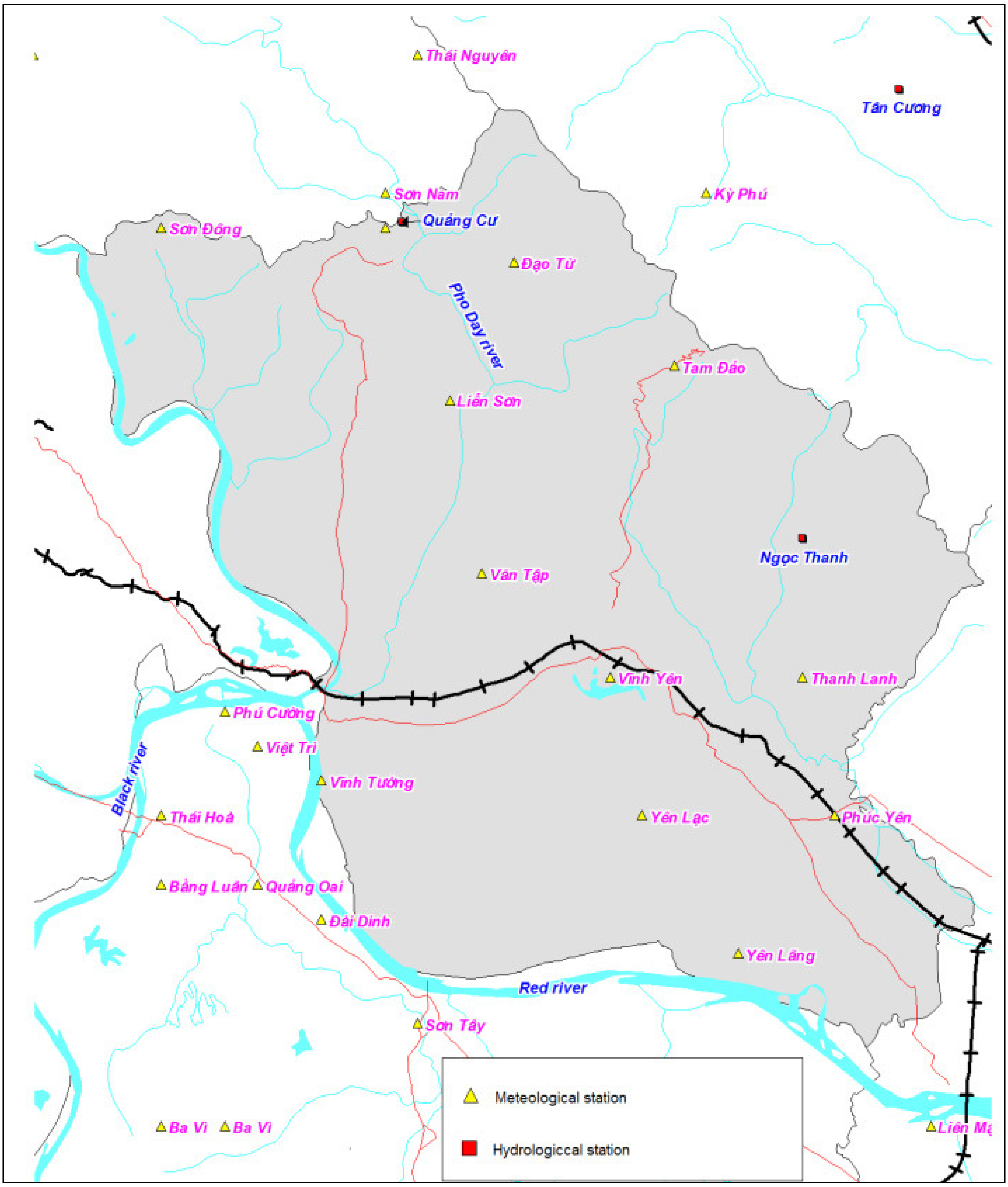

Fig. 2. Meterological and hydrological stations in the study area.

3. SWAT Model

The SWAT (Soil and Water Assessment Tool) is one of the most recent models developed jointly by the United States Department of Agriculture - Agricultural Research Services (USDA-ARS) and Agricultural Experiment Station in Temple, Texas [1]. SWAT is a comprehensive model that requires information provided by the user to simulate runoff and soil erosion. The first step in initializing a watershed simulation is to partition the watershed into sub basins. The physical processes associated with water flow, sediment transport, crop growth, nutrient cycling, etc. are directly modeled by SWAT [2, 3]. The land area in a small sub basin is divided into hydrologic response units (HRUs). A full model description and operation is presented in Neitsch *et al.* [4,5]. Hydrologic response units (HRUs) are portions of a sub basin and possess unique land use, slope range, and soil attributes [6].SWAT has different components. Hydrologic components of the model work on the water balance equation, which is based on surface runoff, precipitation, percolation, evapotranspiration, and return flow data; Weather is one of the model component that needs data on precipitation, air temperature, solar radiation, wind speed, and relative humidity data; Sedimentation is another component of the model that needs information on surface runoff, peak rate flow, soil erodability, crop management, erosion practices, slope length, and steepness; Soil temperature, crop growth, nutrient pesticides and agricultural management are also components of SWAT. Thus, the data required for the model are DEM, soil data, land use data, precipitation and other weather data. For calibrating the model and also for validation purposes, river discharge and sediment yield are required at the outlet of the watershed.

The water balance is the driving force for the simulation of hydrology. SWAT uses two steps for the simulation of hydrology, land phase and routing phase. The land phase is the phase in which the amount of water, sediment, nutrient and pesticides loading in main channel from each sub-basin are calculated.

$$SW_t = SW_0 + \sum_{t=1}^{t} (Pday) - Q_{surf} - AET - Q_{seep} - Q_{gw}$$

Where SW_t is the final water content in millimeters (mm), SW_0 is the initial soil water content on day I (mm), P_{day} is the precipitation on day i (mm), Q_{surf} is the surface runoff on day i(mm), AET is the actual evapo-transpiration on day I (mm), Q_{seep} is he water entering the unsaturated zone from soil profile on day i(mm), and Q_{gw} is the return flow from the shallow aquifer and lateral flow on day i(mm).

Daily rainfall, run-off and sediment yield data of 31 years (1973-2003) were used for the study. Apart from hydro-meteorological data, topographical map, soil map, land resource map and satellite imageries for the study area were also used.

A full model description and operation is presented in Neitsch *et al.* [4,5]. The review indicated that SWAT is capable of simulating hydrological processes with reasonable accuracy and can be applied to large ungauged basin[7]. Therefore, to test the capability of model in determining the effect of spatial variability of the watershed on runoff, AVSWAT 2005 with ArcGIS interface was selected for the present study.

4. Methodology

4.1. Creation of GIS database in SWAT

Digital elevation model is the main input in the SWAT analysis. DEM is used in this study is SRTM DEM (fig 2).The area has the elevation ranges up to 1590 meter. In SWAT the grid format of the DEM is used. It is mainly it used to delineate the watershed automatically (fig 3).

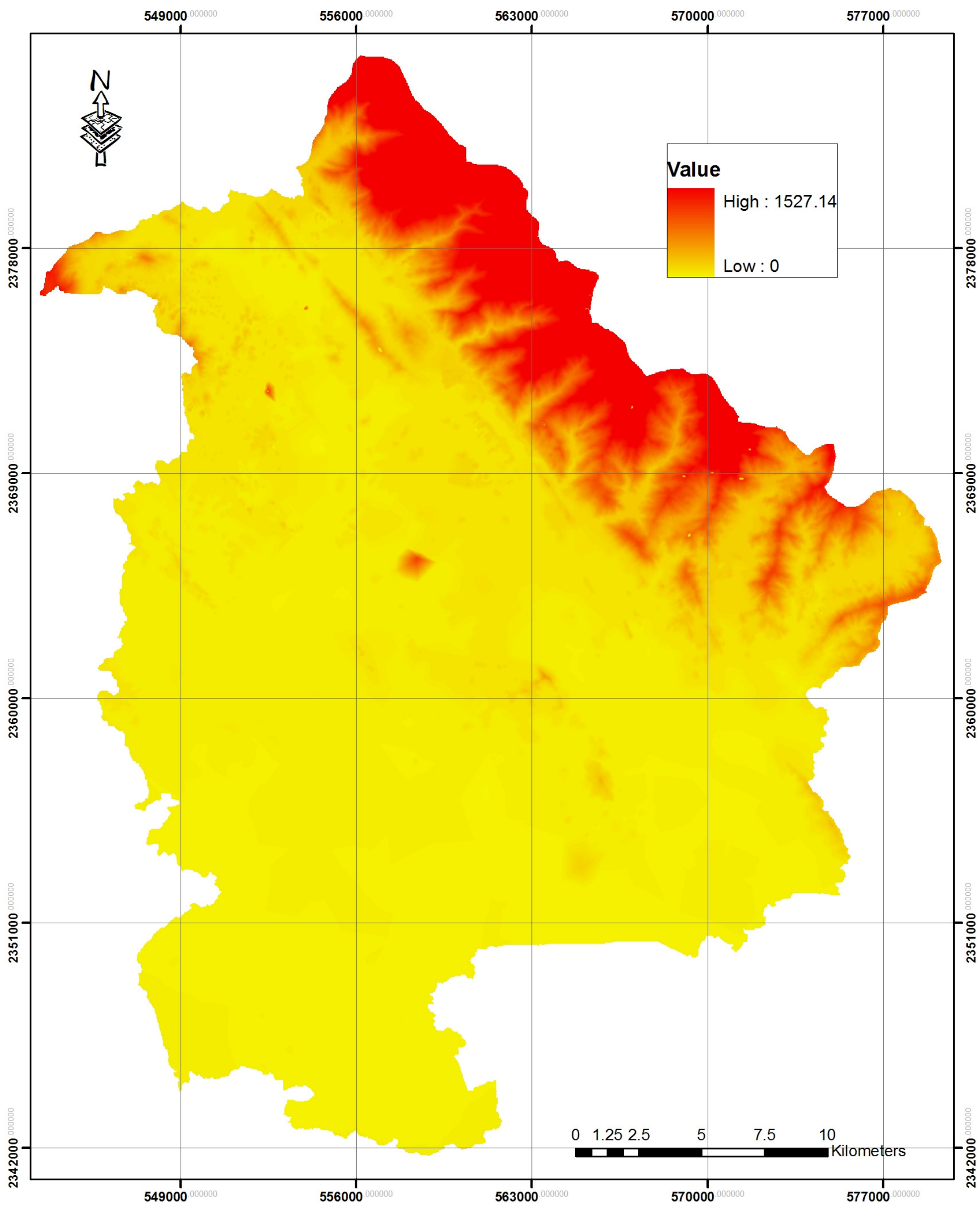

Fig. 3. Digital elevation map (DEM).

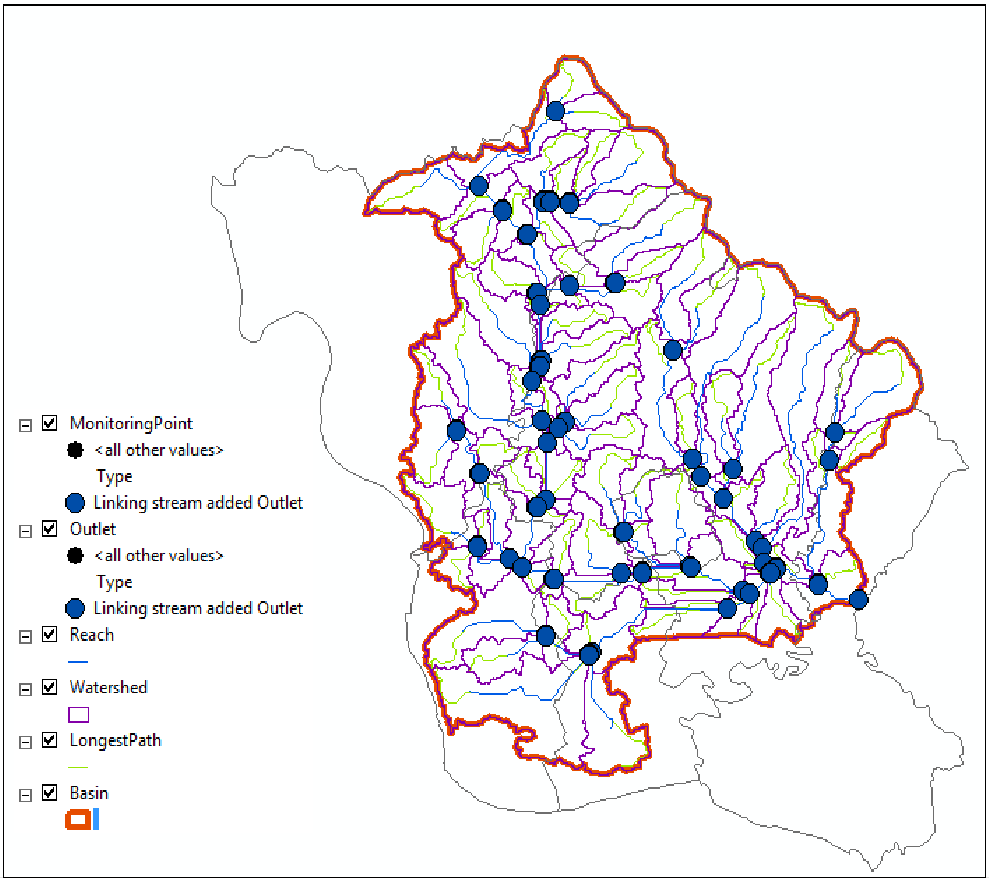

Fig 4. Sub water shed delineated from DEM.

Land use map is a critical input for SWAT model. Land use/land cover map was prepared using remote sensing data of SPOT-3 image(fig 5).The intent of the classification process is to categorize all pixels in a digital image into one of several land cover classes, or "*themes*". This categorized data may then be used to produce thematic maps of the land cover present in an image. Soil plays an important role in modeling various hydrological processes. In the SWAT model, various soil properties like soil texture, hydraulic conductivity, organic carbon content, bulk density, available soil water content are required to be analyzed to make an input in the model for simulation purpose . Based on the analysis of collected 17 soil samples, it was observed that the soils in the study area were mostly clayey soils and alluvial soil and falls in the hydrologic soil group C & D (fig 6). With the rain fall data were taken from the metrological station TAMDAO, the processing of meteorological data was done statistically [8,9]. The simulated daily weather data on maxi-mum and minimum temperature, rainfall, wind speed and relative humidity at all the grid locations for 31 years representing the series approximating 1973 to 2003 time period were processed.

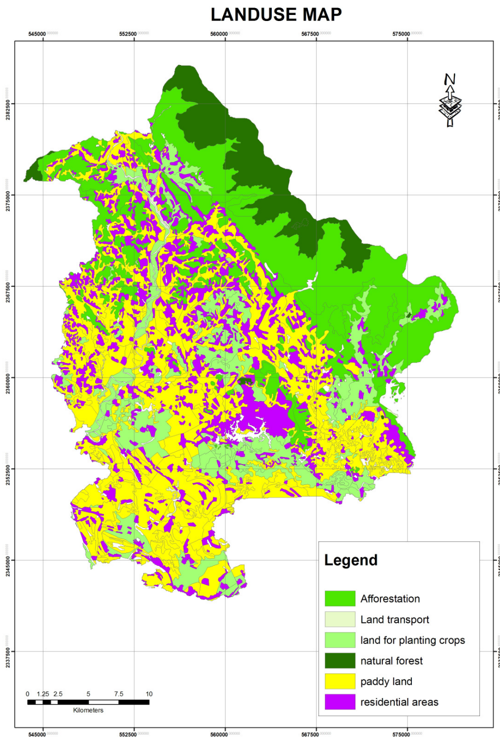

Fig. 5. Landuse map interpreted from SPOT image.

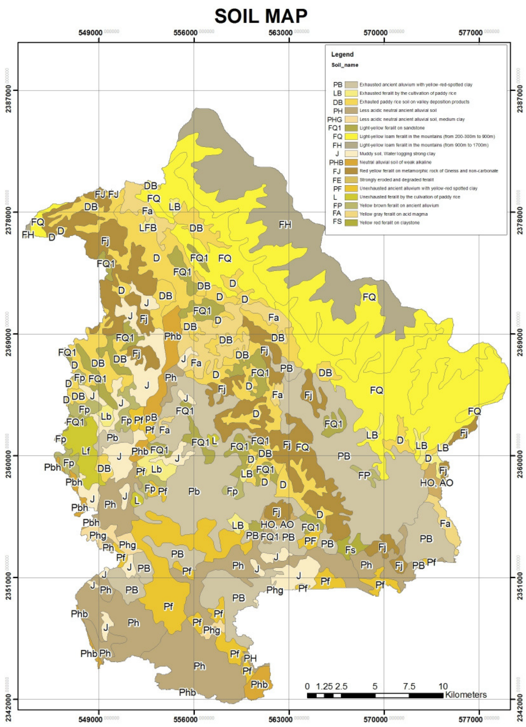

Fig 6. Soil Map.

3.2. Model set up

SWAT automatically delineates a watershed into sub-watersheds based on DEM and drainage pattern (fig3). The land use and soil map in Arc shape format were imported in the SWAT model. Both the maps were made to overlay to subdivide the study watershed into hydrologic response units (HRU) based on the land use , soil types and slope (table1).

Table 1. Example of paremeters for each sub basin extracted from SWAT processing

		Area [ha]	Area[acres]	%Wat.Area	%Sub.Area
SUBBASIN #	1	685.4991	1693.9026	0.80	
LANDUSE:					
	Forest-Mixed --> FRST	653.7093	1615.3484	0.76	95.36
SOILS:					
	LIGHT YELLOW STAND STONE	653.7093	1615.3484	0.76	95.36
SLOPE:					
	3-9999	653.7093	1615.3484	0.76	95.36
HRUs					
1 Forest-Mixed --> FRST/LIGHT YELLOW STAND STONE/3-9999		653.7093	1615.3484	0.76	95.36

Climate data input consists of precipitation, maximum and minimum temperature, wind speed, relative humidity and the weather were generator into .dbf file and then imported in the SWAT model.

4. Result and Analysis

A number of output files generated in every SWAT simulation. Subdividing the areas into hydrologic response units (HRU) enables the model to reflect the evapotranspiration and other hydrologic conditions for different land cover/crops and soils (table 2).There are difference files can be exrtracted from data base : the summary input file (input.std), the summary output file (output.std), the HRU output file (output.hru), the sub basin output file (output.sub) and the main channel or reach out put file (reach. output).

In addition to model results, VIZSWAT is a analyze and visualize SWAT model results with number of powerful and convenient functions are available for data analysis in VIZSWAT. Analysis functions include time series aggregation, basic statistics, and correlation, frequency, baseflow and flow duration analyses. Time series data can be extracted from model results and plotted separately. Animations of model data can be produced using graphic layers that can be easily controlled through the hierarchic layer controller. VIZSWAT provides a few types of sub-maps, which can be used for multiple map views, time series and X-Y plots.VIZSWAT also provides the capability for recording movies in various formats and publishing high-resolution maps [10]. Belowing are the results in three way of SWAT and VIZSWAT processing.

Table 2. HUR Paremeters extracted from SWAT processing

OBJECTID *	Shape *	GRIDCODE	Shape_Length	Shape_Area	SUBBASI	LU_NUM	LU_CODE	SOIL_NUM	SOIL_CODE	SLOPE_NUM	SLOPE_COD	MEAN_SLOPE	AREA	UNIQUECOMB
1	Polygon	1	18328	5049364	1	0	FRST	0	LIGHT YELLOW STAND S	999	3-9999	58.128071	504.9364	1_FRST_LIGHT YELLOW STAND STON
2	Polygon	2	6380	1173195	1	0	FRST	1	YELLOW GRAY ONACID	999	3-9999	46.590611	117.3195	1_FRST_YELLOW GRAY ONACID MAG
3	Polygon	3	2726	111853	3	0	FRST	0	LIGHT YELLOW STAND S	999	3-9999	53.335949	11.1853	3_FRST_LIGHT YELLOW STAND STON
4	Polygon	4	10962	138765	1	10	AGRC	0	LIGHT YELLOW STAND S	999	3-9999	50.684135	13.8765	1_AGRC_LIGHT YELLOW STAND STON
5	Polygon	5	5916	69803	1	5	SWRN	0	LIGHT YELLOW STAND S	999	3-9999	59.547447	6.9803	1_SWRN_LIGHT YELLOW STAND STON
6	Polygon	6	7250	70644	1	6	WETL	0	LIGHT YELLOW STAND S	999	3-9999	55.954624	7.0644	1_WETL_LIGHT YELLOW STAND STON
7	Polygon	7	812	5887	1	14	URML	0	LIGHT YELLOW STAND S	999	3-9999	53.911625	0.5887	1_URML_LIGHT YELLOW STAND STON
8	Polygon	8	100224	1436428	2	10	AGRC	0	LIGHT YELLOW STAND S	999	3-9999	69.787926	143.6428	2_AGRC_LIGHT YELLOW STAND STON
9	Polygon	9	67106	3248783	2	0	FRST	0	LIGHT YELLOW STAND S	999	3-9999	61.700516	324.8783	2_FRST_LIGHT YELLOW STAND STON
10	Polygon	10	49938	539922	2	6	WETL	0	LIGHT YELLOW STAND S	999	3-9999	72.255814	53.9922	2_WETL_LIGHT YELLOW STAND STON
11	Polygon	11	37874	577767	2	5	SWRN	0	LIGHT YELLOW STAND S	999	3-9999	71.384659	57.7767	2_SWRN_LIGHT YELLOW STAND STON
12	Polygon	12	84854	1887204	3	0	FRST	1	YELLOW GRAY ONACID	999	3-9999	30.935247	188.7204	3_FRST_YELLOW GRAY ONACID MAG
13	Polygon	13	9454	74008	2	14	URML	0	LIGHT YELLOW STAND S	999	3-9999	72.770844	7.4008	2_URML_LIGHT YELLOW STAND STON
14	Polygon	14	232	1682	2	4	WATR	0	LIGHT YELLOW STAND S	999	3-9999	71.023636	0.1682	2_WATR_LIGHT YELLOW STAND STON
15	Polygon	15	8004	222865	2	0	FRST	1	YELLOW GRAY ONACID	999	3-9999	57.950771	22.2865	2_FRST_YELLOW GRAY ONACID MAG
16	Polygon	16	28768	670277	2	10	AGRC	1	YELLOW GRAY ONACID	999	3-9999	48.242512	67.0277	2_AGRC_YELLOW GRAY ONACID MAG
17	Polygon	17	25520	298555	2	6	WETL	1	YELLOW GRAY ONACID	999	3-9999	46.939903	29.8555	2_WETL_YELLOW GRAY ONACID MAG
18	Polygon	18	15776	242208	2	5	SWRN	1	YELLOW GRAY ONACID	999	3-9999	47.182392	24.2208	2_SWRN_YELLOW GRAY ONACID MAG
19	Polygon	19	2610	21866	2	14	URML	1	YELLOW GRAY ONACID	999	3-9999	42.602501	2.1866	2_URML_YELLOW GRAY ONACID MAG
20	Polygon	20	145696	2470858	3	10	AGRC	1	YELLOW GRAY ONACID	999	3-9999	24.442194	247.0858	3_AGRC_YELLOW GRAY ONACID MAG
21	Polygon	21	78416	869594	3	6	WETL	1	YELLOW GRAY ONACID	999	3-9999	26.296431	86.9594	3_WETL_YELLOW GRAY ONACID MAG
22	Polygon	22	4872	38686	3	14	URML	1	YELLOW GRAY ONACID	999	3-9999	28.162865	3.8686	3_URML_YELLOW GRAY ONACID MAG
23	Polygon	23	40774	500395	3	5	SWRN	1	YELLOW GRAY ONACID	999	3-9999	30.133423	50.0395	3_SWRN_YELLOW GRAY ONACID MAG

4.1. Precipitation analysis

The precipitation value of each sub basin during the complete time period will be analyzed here (table 3). We will see that there is some sub basin having very high precipitation that's why their soil water content as well as runoff will be high.

Table 3. Example of precipitation for sub basins extracted from SWAT processing

A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S
sub basin no/year(	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990
1	159.341	276.279	596.807	359.37	171.237	586.529	513.77	478.164	285.894	436.458	333.813	792.512	249.097	449.792	279.366	641.644	416.68	735.693
2	185.864	318.233	656.517	387.692	188.146	621.628	563.648	537.41	319.475	478.693	367.25	847.613	285.271	506.372	308.06	716.576	466.086	811.553
3	289.403	365.646	705.571	430.835	239.07	682.218	638.525	603.286	356.136	524.274	418.108	898.057	340.063	556.576	373.125	793	525.141	889.567
4	295.641	458.574	824.808	497.095	285.719	775.255	724.437	693.181	446.332	636.454	489.588	1019.992	399.182	627.854	421.434	865.036	602.771	1002.827
5	288.503	403.551	752.81	463.24	266.937	726.807	682.795	642.482	399.409	570.682	450.542	949.3	365.016	586.191	398.359	822.784	553.122	930.213
6	396.351	523.727	885.922	575.391	357.241	853.591	822.114	784.598	519.096	706.182	572.138	1092.367	470.609	697.508	495.796	954.463	666.914	1092.257
7	235.473	365.058	704.474	429.828	228.327	678.675	621.371	585.17	365.391	528.89	408.996	905.731	326.738	543.221	350.294	773.138	508.757	870.36
8	522.952	693.982	1077.594	741.097	488.78	1034.293	1013.665	976.011	701.756	903.635	746.898	1288.55	618.22	842.13	628.127	1102.325	816.889	1295.966
9	227.781	358.876	696.265	422.826	222.397	669.741	614.077	580.997	361.664	522.845	406.524	901.559	319.769	539.304	342.765	765.254	501.8	865.538
10	456.97	612.15	977.998	650.899	419.835	941.618	909.572	871.609	616.389	803.288	655.61	1195.073	542.984	756.981	552.44	1014.428	738.711	1192.759
11	391.671	552.901	916.102	590.375	365.092	874.592	839.941	803.201	549.633	736.865	588.773	1130.541	484.846	710.694	500.954	966.304	685.629	1123.462
12	234.088	348.265	697.59	411.425	213.949	668.109	613.906	578.64	326.629	512.87	387.561	885.256	310.813	550.581	357.084	802.435	511.516	873.327
13	477.628	632.4	997.478	671.724	437.62	964.596	931.33	894.009	638.413	826.638	677.291	1218.039	562.204	772.826	568.373	1031.924	756.898	1216.319
14	416.41	556.548	917.712	604.029	387.132	890.256	862.456	818.759	560.417	740.616	603.816	1131.917	500.307	714.677	520.559	965.492	692.684	1121.031
15	222.531	325.861	659.091	395.732	201.482	638.293	578.319	545.293	321.995	484.335	374.893	856.087	297.008	512.905	325.635	737.735	476.372	824.249

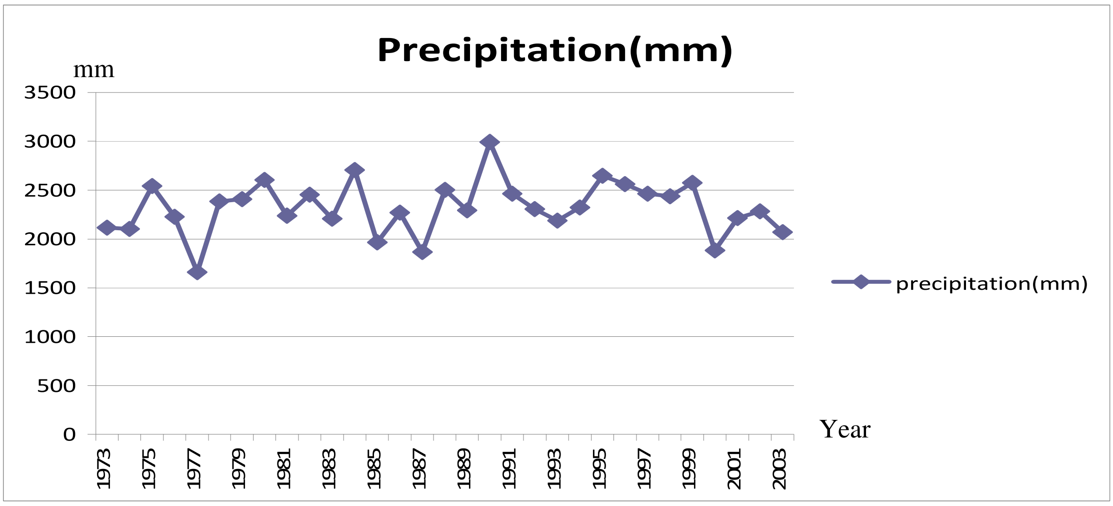

Fig. 7. Precipitation for sub basins extracted from SWAT processing.

By the graph, we can analyze the changing of precipitation in the main basin during a long period from 1973 to 2003.

4.2. Soil Water Content

The graph show about the water in the soil profile at the outlet of each sub basin at the end of the time period in mm (fig 8). By usingVIZSWAT, map was created which show soil water content level for each sub basin (fig9). In the above graph and the map , maximum soil water content were found in basins N^0 72-76.

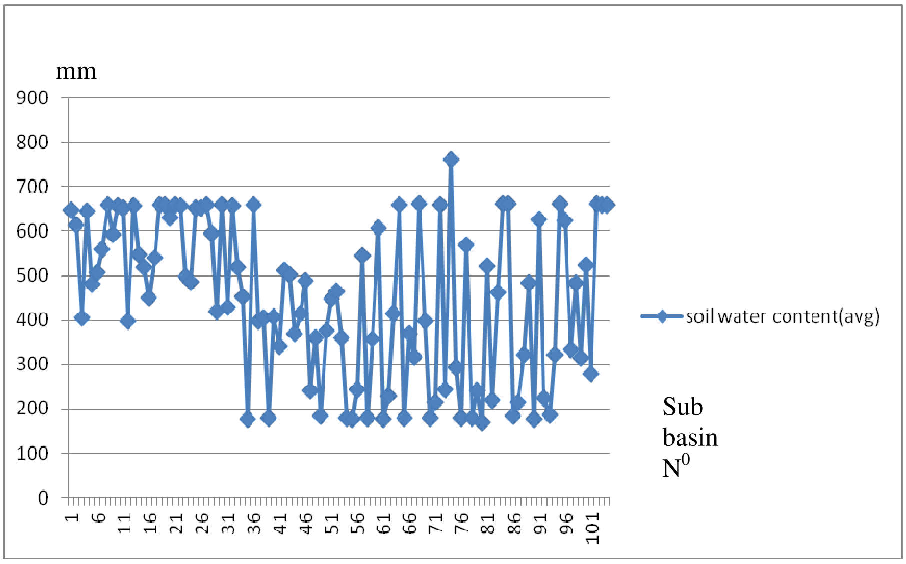

Fig 8. Soil water content for sub basins extracted from SWAT processing.

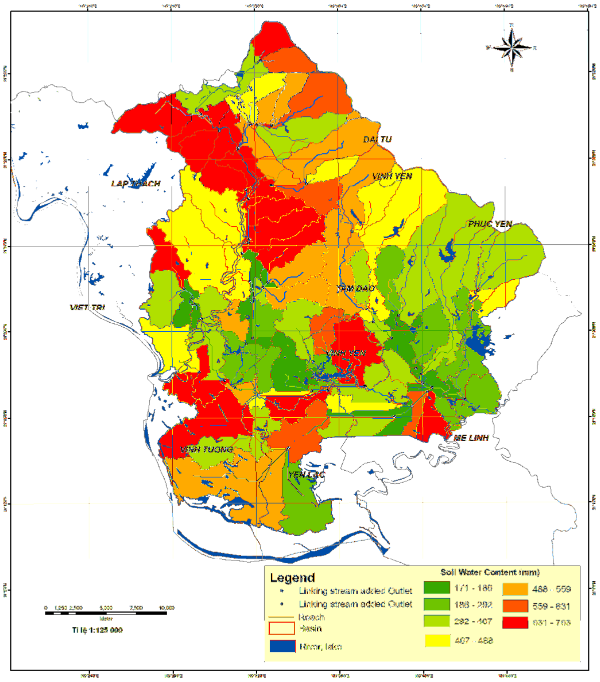

Fig 9. Map of soil water content for sub basins extracted from VIZSWAT.

4.3. Surface Runoff Contribution

This is the result generated by the SWAT. It tells about that how much water is yielded from each of the sub basin to the main reach. fig 11 is map of soil water content , in which, level for each sub basin can be determined. High values of surface runoff are found in sub basins N^0 11,21,26,31,36,71,76,81,86,101, which are having more than 350mm of surface runoff.

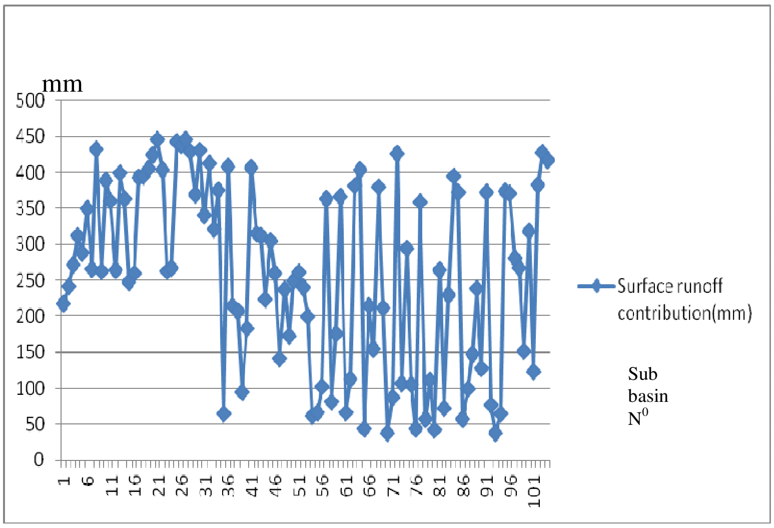

Fig 10. Surface runoff contribution established by VIZSWAT.

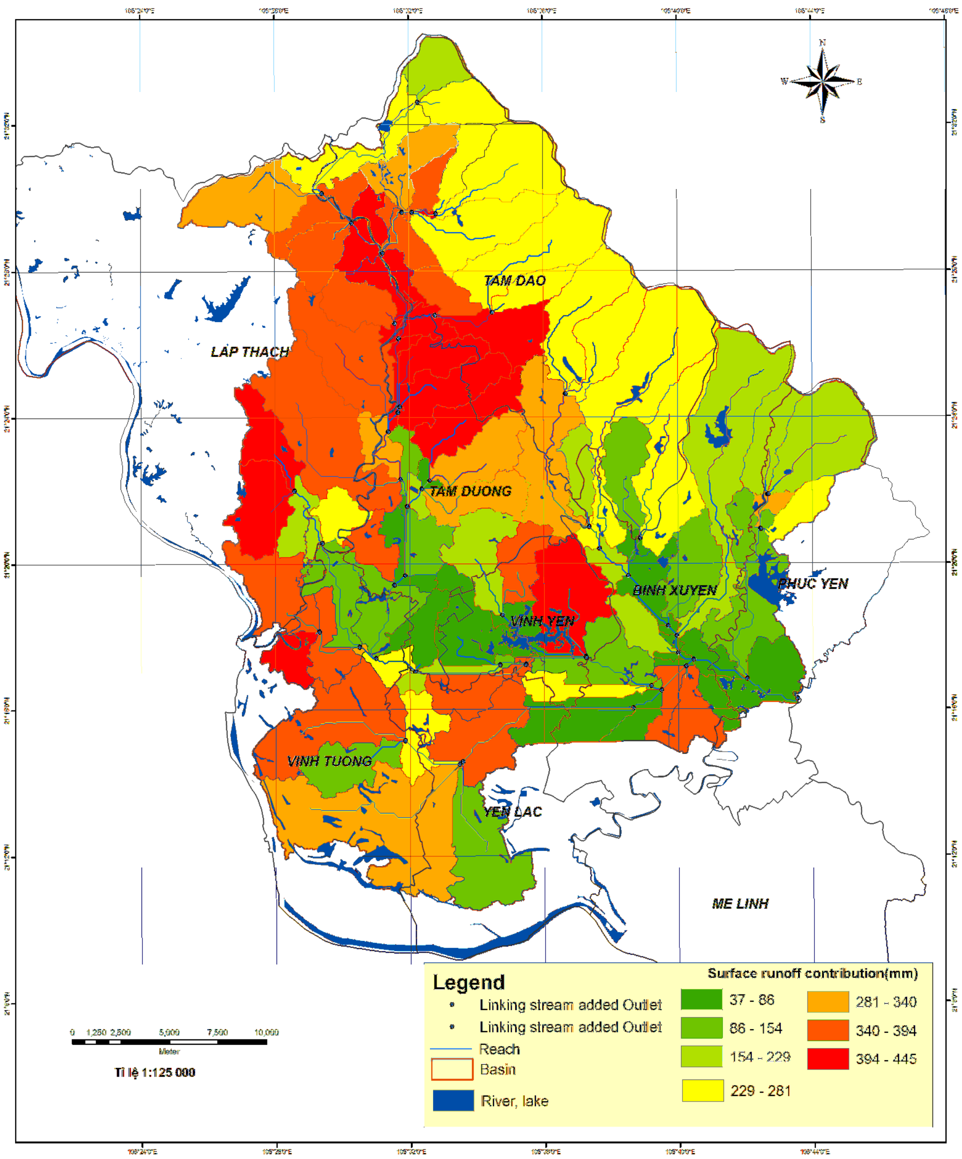

Fig. 11. Maximum of surface runoff of sub –basin system established by VIZSWAT.

4.4. Sediment yield

Sediment yields is a parameter tells about total of sediment (tons per hecta.) from each sub basin that is transported into the reach during the time steps._It is the main important parameter which is needed to take any management action at sub basin level. Beside of the graph, map for maximum sediment yield of sub –basin system was established by VIZSWAT . In these , we can observe that sediment is yielded during time step is maximum for the sub basin no 11, 21, 23, 24, 46, 47, and 48. There are total 14 sub basins which are having more than 100 tons per hecta during the time period. (Fig. 12,13).

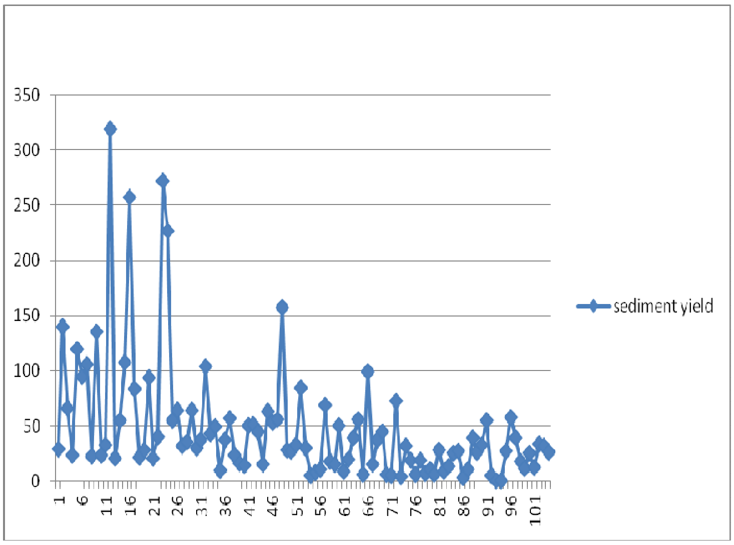

Fig.12. Maximum sediment yield of sub –basin system established by VIZSWAT.

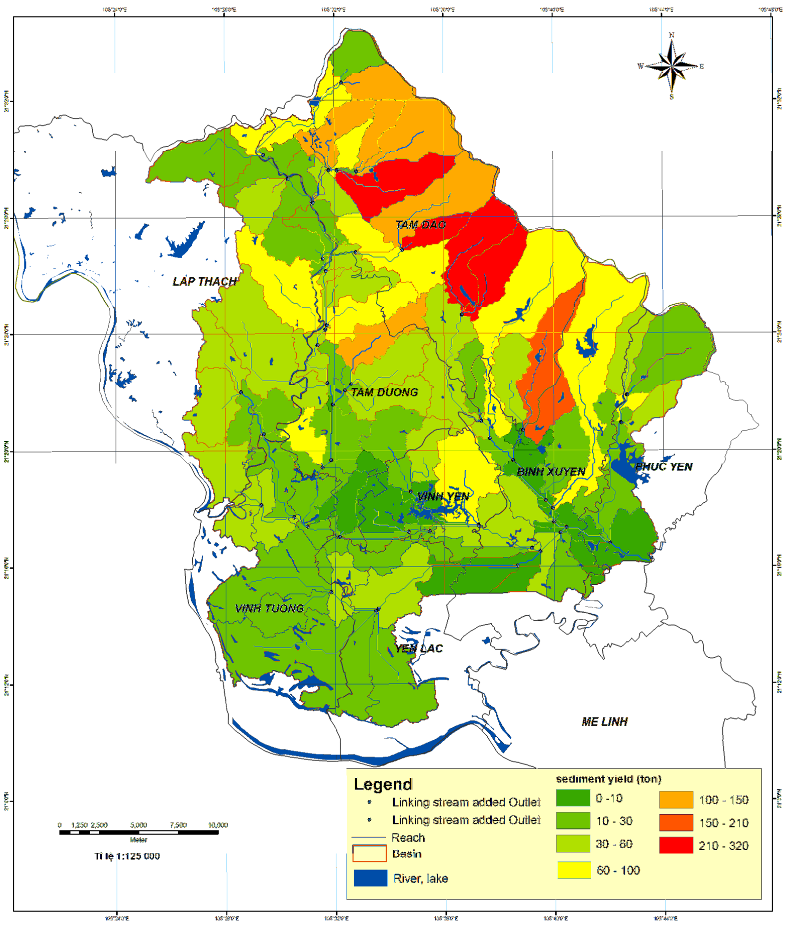

Fig. 13. Maximum sediment yield of sub –basin system established by VIZSWAT.

4.5. Accuracy acessement

Comparing with the statistic surface runoff data of the Tamdao station (outlet of the basin N^0 12), the correlation can be presented as the graph and statistic values below (fig 14)

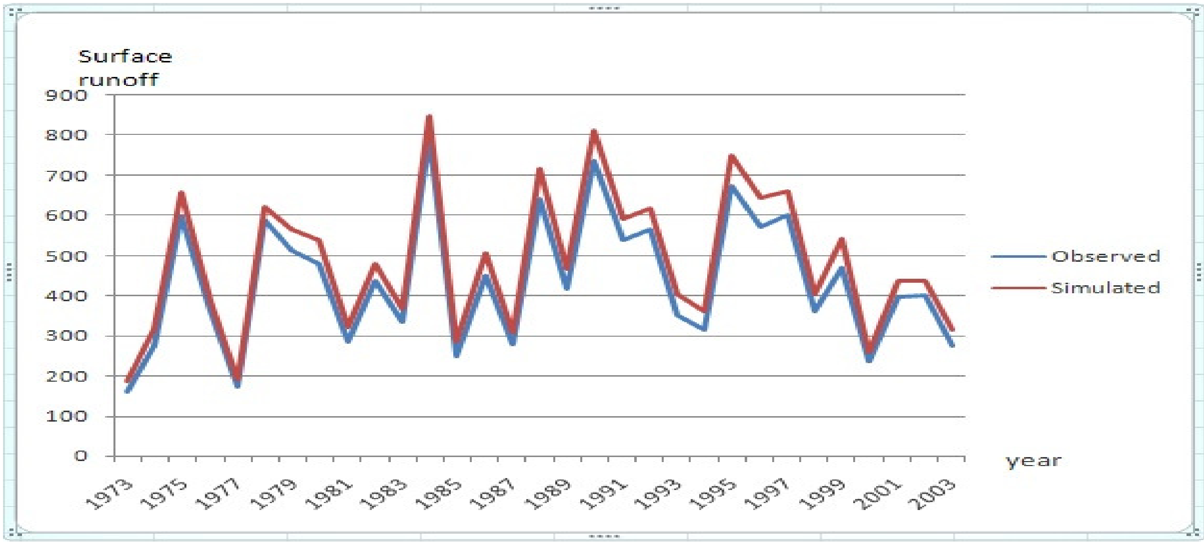

Fig. 14. Comparision beetween observated and simulated data of surface runoff (sub-watershed $N^0$12).

With R = 0.9081, this statistic value presente for good relationship and the simulated data can be confidenced. Correlation function is Y = 1.057039*X + 0.3309 and by this, prediction can be calculated for each HRU.

4.6. Discusion

With long time period of climate and surface runoff data and land cover change, difference type of ouput parameter can be extracted from the SWAT processing. Base on this parameters many aspect can be discused as: role of difference type of lancover or soil to surface runoff, soil water content, topographic characteristic to sediment yield or soil errosion, water polution etc.

Attributes of ClipSDD_SUB

NAME_LANDU	Surface runoff
paddy land	406.556693
paddy land	172.305532
paddy land	406.556693
paddy land	172.305532
residential areas	340.021323
residential areas	375.052887
residential areas	340.021323
residential areas	375.052887
residential areas	375.052887
paddy land	375.052887
residential areas	340.021323
residential areas	94.667435
Afforestation	438.053823
residential areas	412.300097
residential areas	321.325161
residential areas	321.325161
residential areas	314.916742
residential areas	321.325161
residential areas	314.916742
residential areas	314.916742
residential areas	312.270371
residential areas	314.916742
residential areas	321.325161
residential areas	321.325161
residential areas	314.916742
residential areas	312.270371
land for planting crops	380.332952
land for planting crops	154.161468
paddy land	154.161468
paddy land	340.021323
paddy land	94.667435
land for planting crops	412.300097

Record: 274 Show: All Selected ords

Fig 15. Table show the role of lancover type to simulated surface runoff by SWAT.

In the fig.15, good relationship between forest cover to high value of surface runoff is cleared..If compare between results in fig.8 and 9, 10 and 11,12 and 13 , the result presente that where having hight soil water content is the low surface runtoff and low value of sedimentation. It meaning that good forest cover is good soil water content and less soil errosion.

5. Conclusion

- The SWAT and components of SWAT as VIZSWAT having an interface with Arc GIS software are the most suitable tool for water basin management. The reason for it is by using the software, many factor of a water basin and it's sub-basins can be extracted such as :

surface runoff, peak rate flow, soil erodability,erosion practices, nutrient pesticides …. This parameter are importan criteria for agriculture management separetely and also for environmental management in general .

- In the study , the SWAT and VIZSWAT were applied to the Calo watershed in VinhPhuc province for the calculation of soil water content, modeling runoff and sediment yield. Using the observed data of 1973 to 2003 with a good validation, the model was executed to find soil water content, surface runoff and sediment yield for each sub basin and also for whole of the basin area . These parameters can be referenced for planning purpose of reforestation, slope agriculture cultivation , water management etc.

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