SWAT Soil & Water Assessment Tool

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Sediment Yield Modeling using SWAT and Geospatial Technologies

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Soil - A Natural Resource

Soil

- Agriculture/Food production
- Engineering Projects
- Ecology

Soil Formation

- Weathering
- Transportation
- Deposition

Soil Erosion

- Geologic Erosion
- Accelerated Erosion

Necessity for Sediment Studies

Study of on-site & off-site effects

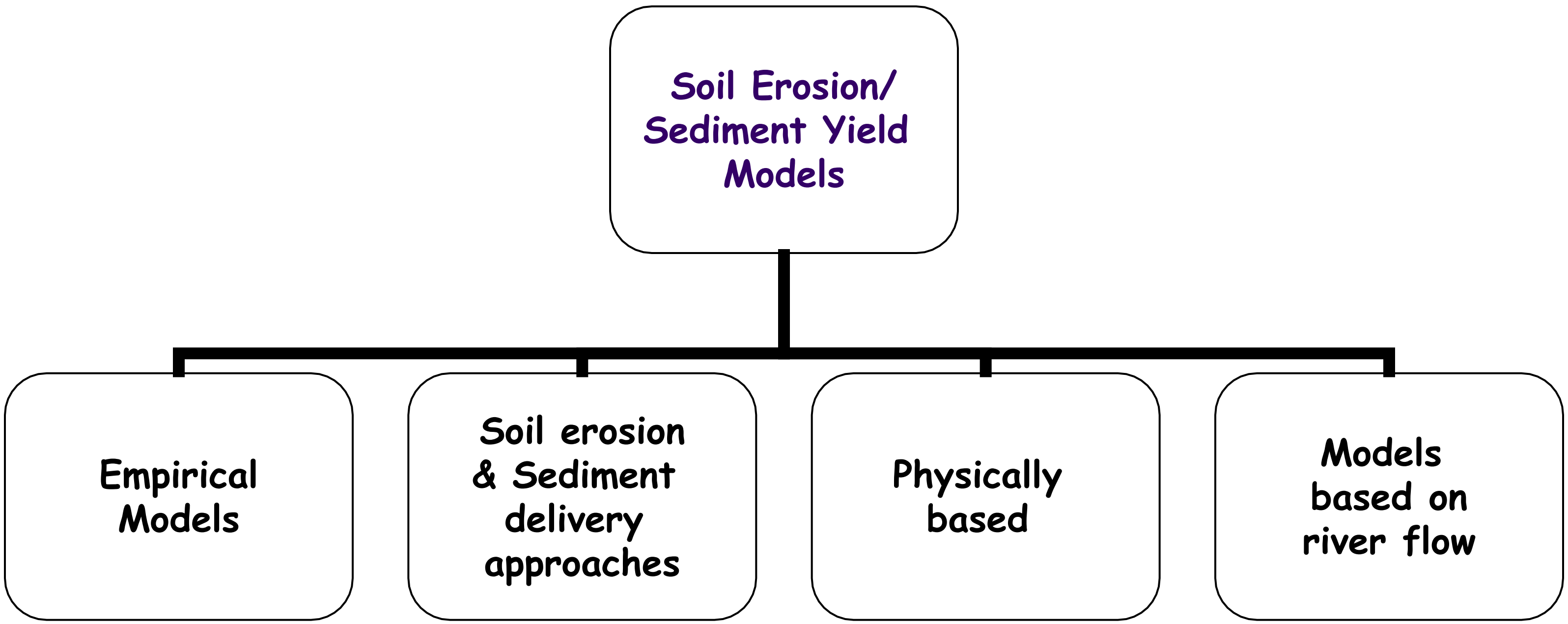
- Design of Reservoirs
- Conservation Practices
- Delivery of sediments & contaminants
- Water balance studies (ET is a major component)

Difficulties

- Soil erosion, transportation & deposition are nonlinearly related to causal factors
- Highly variable in space & time
- Monitoring is quite complex & expensive

Hence, **Modeling!**

Classification of Soil Erosion/Sediment Yield Models



Empirical Models	Soil erosion & Sediment delivery approaches	Physically based	Models based on river flow
Regression equations ANN	USLE, MUSLE	WEPP, EUROSEM	Sediment Rating Curves

Applications of Remote Sensing & GIS

Traditional – point data

Remote Sensing – spatial & temporal

merge

- Soil moisture
- Evapotranspiration
- Rainfall
- Flood mapping

Advantages: benefit/cost, time

Handling and analysis of huge & complex data… GIS

SWAT Soil & Water Assessment Tool

Objectives of the study

- **To model the runoff and sediment yield** from a watershed using the Soil and Water Assessment Tool (SWAT) with the help of remotely sensed data and GIS
- **To calibrate and validate** the SWAT model and assess its applicability in modeling the runoff and sediment yield.
- To assess the applicability of SWAT model in **ungauged watersheds**

Soil Erosion / Sediment Yield Models

1. Universal Soil Loss Equation (USLE) **(Wischmeier and Smith, 1958)**

Empirically based soil erosion model

$$A = RKLSCP$$

R → EI_{30}

Advantage: complex system → simple

A = soil loss per unit area (t/ha)
R = rainfall & runoff factor (MJ mm/hr/ha
K = soil erodibility factor (t ha/MJ/mm)
L = slope length factor
S = slope steepness factor
C = cover management factor
P = support practice factor

Limitations:

- It does not consider gully erosion
- Not applicable for slopes >40% (erosion by runoff)
- Complex interactions are not represented
- Not valid for individual storms

2. Revised Universal Soil Loss Equation (RUSLE)

(Renard et al., 1994)

Equation structure is the same as USLE

But, each factor → updated with recent data / new relations

Limitation:

Limited interactions between the factors in the equation

Both USLE and RUSLE calculates soil erosion.

To calculate the sediment yield, multiply with SDR.

3. Modified Universal Soil Loss Equation (MUSLE)

(Williams, 1975)

SDR is not necessary if rainfall energy factor (R) in the USLE equation is replaced by runoff rate factor

$$Y = 11.8\,(Qq_p)^{0.56}\,KCPSL$$

where Y = sediment yield (t/ha)

Advantages:

1. Application to individual storms
2. Elimination of need for SDR
3. Greater accuracy- as runoff accounts for more sediment yield variation than does rainfall.

SWAT Soil & Water Assessment Tool

Model Description

Soil and Water Assessment Tool (SWAT) (Arnold et al., 1998)

- It is a physically based, continuous time, watershed scale hydrologic model.
- Developed to predict impacts of land management practices on water, sediment & agricultural chemical yields in large, complex watersheds with varying soils, landuse & mgt. practices.

Water balance is the driving force in the SWAT model.

Watershed → Subbasins → HRUs

(Hydrological Response Units)

unique LU/LC, soil & slope combinations

Surface Runoff

SCS-CN method

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

$$S=254\left(\frac{100}{CN}-1\right)$$

Sediment Yield

$$sed = 11.8 * (Q_{surf} * q_{peak} * area_{hru})^{0.56} * K * C * P * LS * CFRG$$

Q_{surf} = Surface runoff volume

q_{peak} = Peak runoff rate (m^3/s)

K = USLE Soil Erodibility Factor

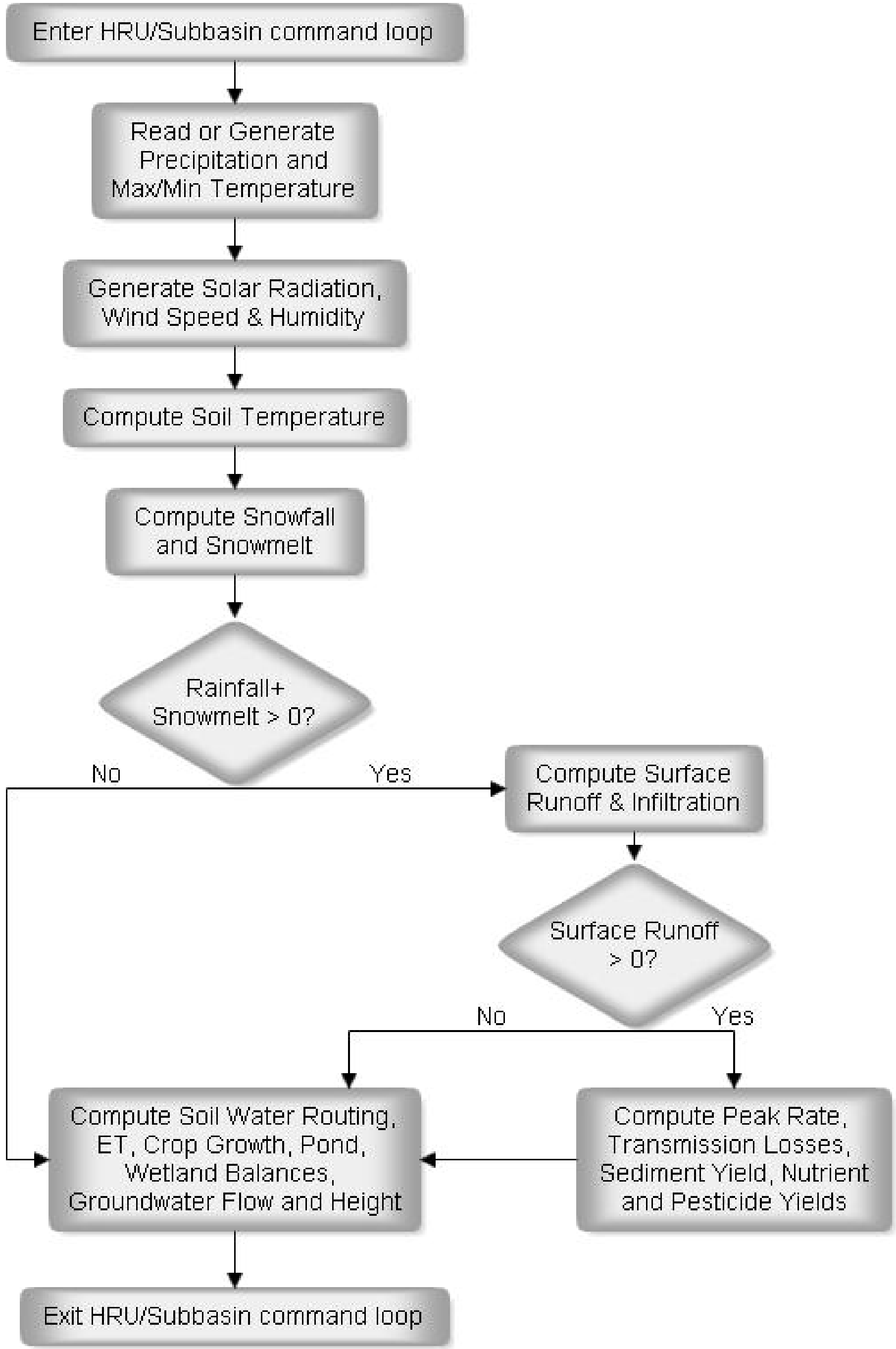
C = USLE Cover & Management Factor

P = USLE support practice factor

LS = USLE topographic factor

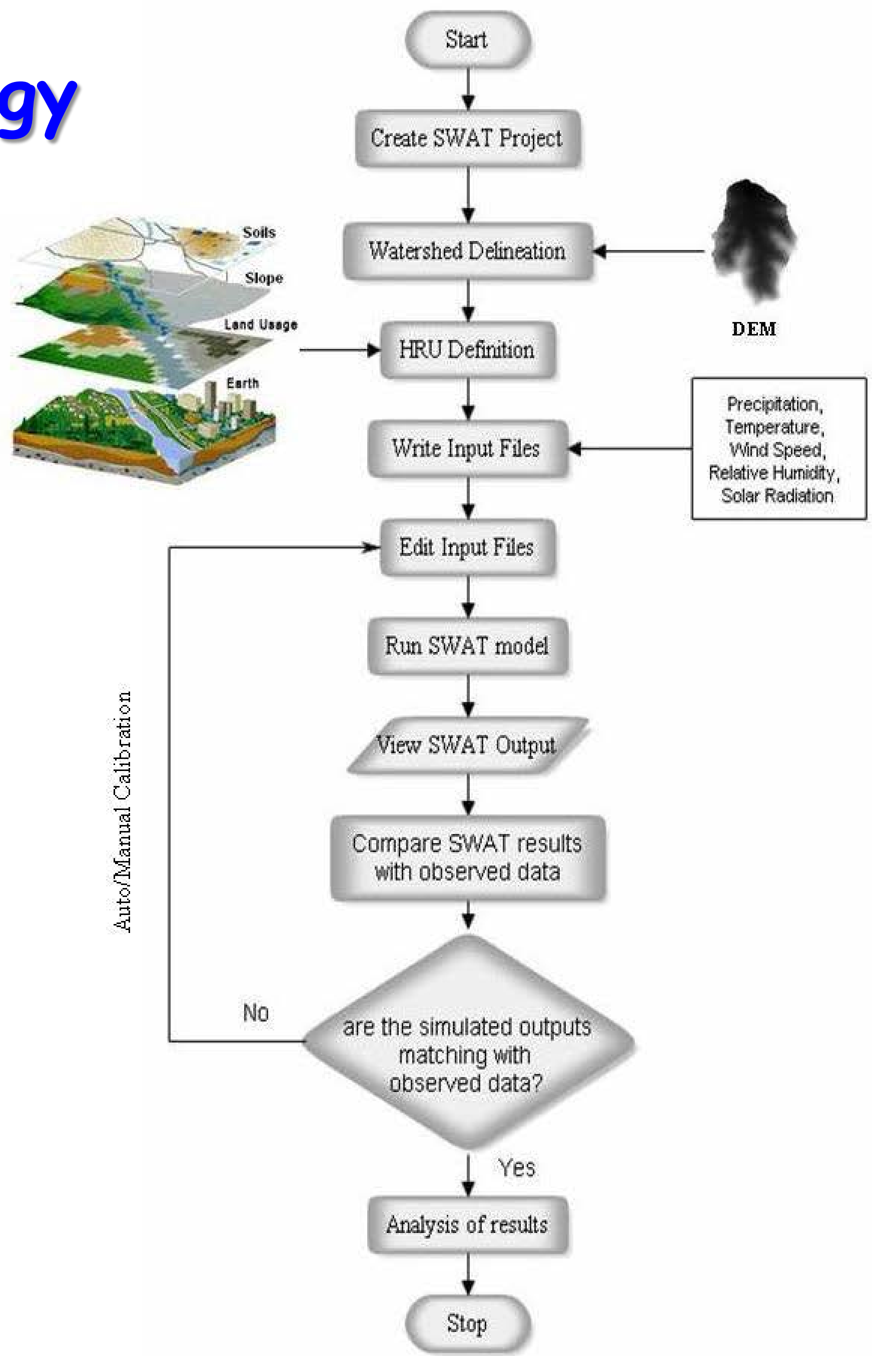
CFRG = Coarse fragment factor

HRU/Subbasin Command Loop



Methodology

SWAT Soil & Water Assessment Tool



Study Area

Khadakohol Watershed
(Nasik, Maharashtra)
Longitude: 73° 17' E to 73° 20' E
Latitude: 20° 7' N to 20° 9' N
A = 5.468 sq. km
Annual rainfall – about 2275 mm

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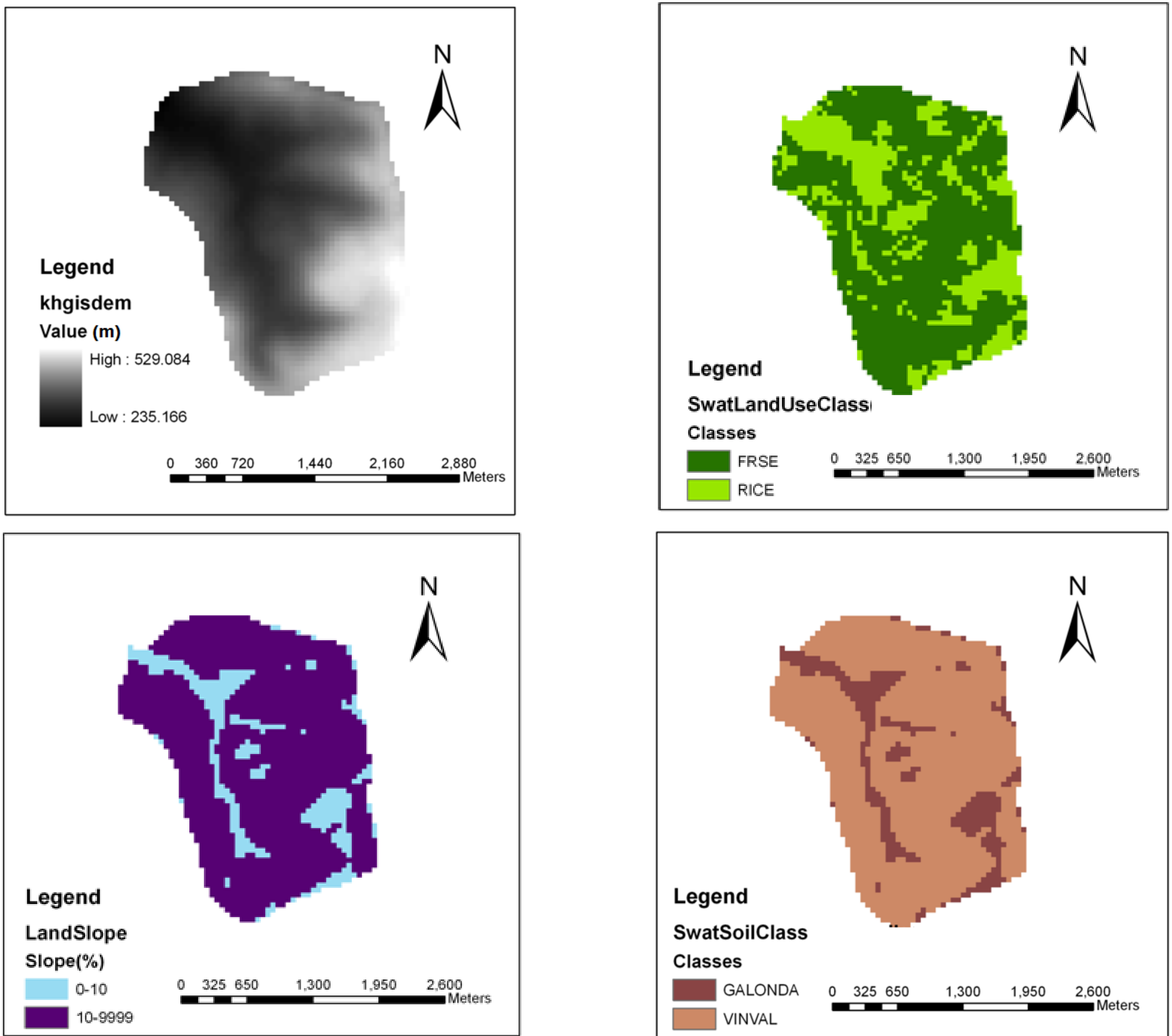
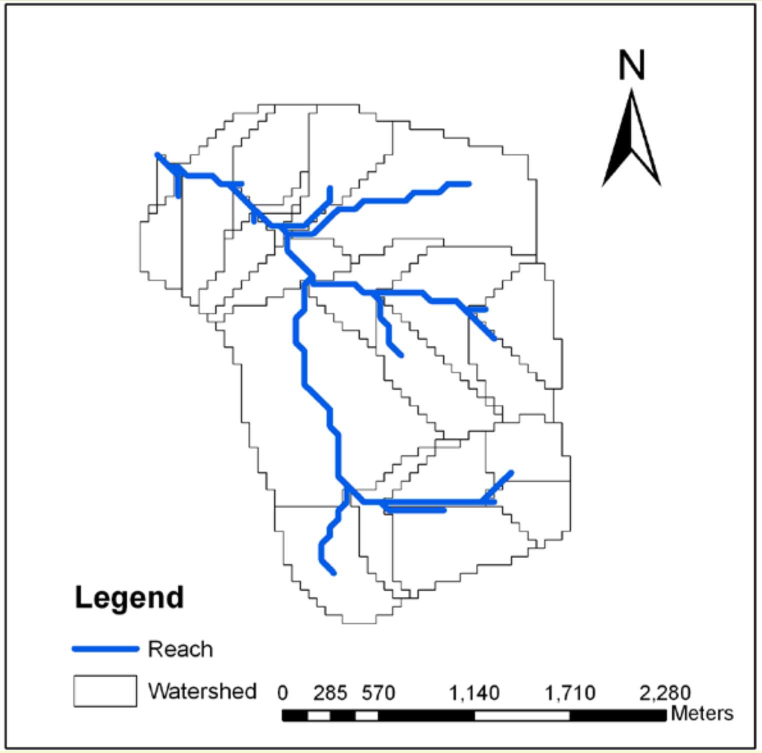
Database Preparation

Data	Khadakohol Watershed
DEM (50m)	Derived from 10m contours (toposheet 46 H/8 NW, 46 H/8 SW)
LU/LC map (23.5m)	IRS 1D LISS III, Jan 13, 1998 (23.5 m)
Soil map (50m)	Derived from slope map + information from soil survey report
Weather	Rainfall (Indo-German Bilateral Project)
	Min. & max. Temperature, relative humidity, wind speed (IMD)
	Solar radiation data from NCEP/NCAR website

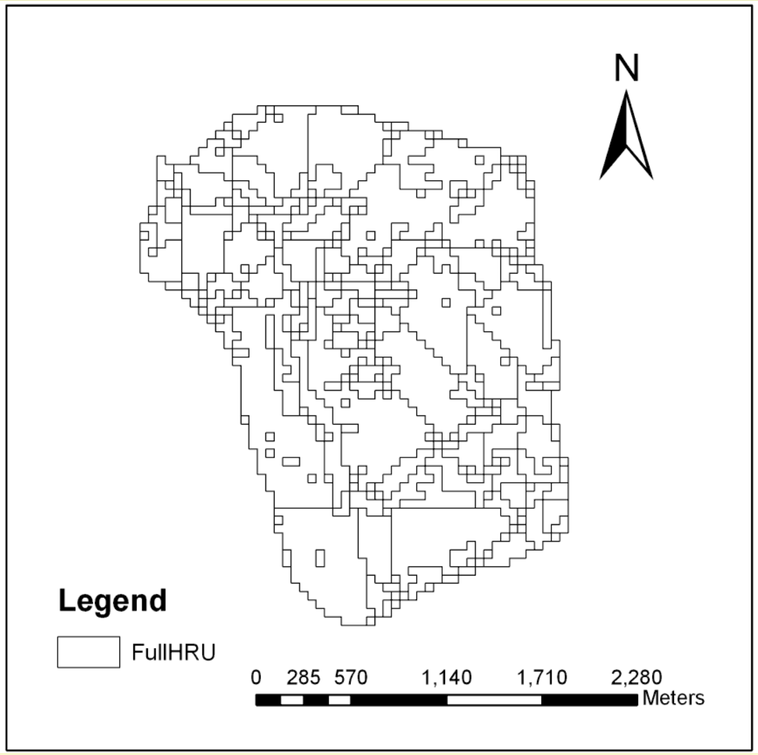


N
Legend
khgisdem
Value (m)
High : 529.084
Low : 235.166
0 360 720 1,440 2,160 2,880
Meters
N
Legend
SwatLandUseClass
Classes
FRSE
RICE
0 325 650 1,300 1,950 2,600
Meters
N
Legend
LandSlope
Slope(%)
0-10
10-9999
0 325 650 1,300 1,950 2,600
Meters
N
Legend
SwatSoilClass
Classes
GALONDA
VINVAL
0 325 650 1,300 1,950 2,600
Meters

SWAT model application to Khadakohol watershed



Watershed delineation
resulted in 23 subbasins
(threshold area = 10.9 ha)



HRU Definition
resulted in 74 HRUs
(threshold area = 10%)

Results and Discussion

Simulation results with default parameter set for (2002)

2002		Observed		Simulated	
	Rainfall (mm)	Runoff (mm)	Sediment (t/ha)	Runoff (mm)	Sediment (t/ha)
June	682.4	400.29	1.83	369.25	6.72
July	300.8	145.79	0.11	78.50	1.07

Management Operations for agriculture land (RICE) and forest land (FRSE)

Current Management Operations

	Year	Month	Day	Operation	Crop
▶	1	5	20	Tillage operation	
	1	6	9	Plant/begin. growing se	RICE
	1	7	15	Fertilizer application	
	1	10	3	Kill/end of growing seas	
*					

Current Management Operations

	Year	Month	Day	Operation	Crop
▶	1	2	3	Kill/end of growing seas	
	1	3	21	Plant/begin. growing se	FRSE
*					

Simulation results after scheduling management operations by date (2002)

2002		Observed		Simulated	
	Rainfall (mm)	Runoff (mm)	Sediment (t/ha)	Runoff (mm)	Sediment (t/ha)
June	682.4	400.29	1.83	357.55	1.33
July	300.8	145.79	0.11	74.88	0.19

Runoff is under-predicted. Hence go for calibration

Sensitivity Analysis results for Khadakohol watershed

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Parameter	Range	Default Value	Flow rank	Sed. Rank	Explanation
Alpha_Bf	0 - 1	0.048	3	2	Baseflow alpha factor (days)
Biomix	0 – 1	0.2	33	33	Biological mixing efficiency
Blai	0 – 8	V	13	13	Maximum potential LAI
Canmx	0 - 100	0	6	4	Maximum canopy storage (mm)
Ch_Cov	-0.05 - 0.6	0	33	33	Channel cover factor
Ch_Erod	0 – 1	0	33	33	Channel erodibility factor
Ch_K2	-0.01 - 500	0	2	5	Channel effective hydraulic conductivity (mm/hr)
Ch_N2	-0.01 - 0.3	0.014	7	7	Manning's "n" for main channel
Cn2	35 – 98	V	1	6	Initial SCS CN II value
Epco	0 – 1	1	14	19	Plant uptake compensation factor
Esco	0 – 1	0.95	8	15	Soil evaporation compensation factor
Gw_Delay	0 – 500	31	9	18	Groundwater delay (days)
Gw_Revap	0.02 - 0.2	0.02	17	20	Groundwater ‘revap’ coefficient
Gwqmn	0 - 5000	0	5	8	Threshold water depth in the shallow aquifer for flow
Revapmn	0 – 500	1	15	33	Threshold water depth in the shallow aquifer for ‘revap’
Sftmp	-5 - 5	1	33	33	Snowfall temperature
Slope	0 - 0.6	V	16	3	Average slope steepness (m/m)
Slsubbsn	10 - 150	V	18	9	Average slope length (m/m)
Smfmn	0 – 10	4.5	33	33	Melt factor for snow on December 21
Smfmx	0 – 10	4.5	33	33	Melt factor for snow on June 21
Smtmp	-5 – 5	0.5	33	33	Snow melt base temperature
Sol_Alb	0 – 0.25	V	33	33	Moist soil albedo
Sol_Awc	0 – 1	V	12	16	Available water capacity (mm H2O/mm soil)
Sol_K	0 - 2000	V	10	14	Saturated hydraulic conductivity (mm/hr)
Sol_Z	0 - 3500	V	11	12	Soil depth (mm)
Spcon	0.0001 – 0.01	0.0001	33	10	Lin. re-entrainment parameter for channel sediment routing
Spexp	1 – 1.5	1	33	11	Exp. re-entrainment parameter for channel sediment routing
Surlag	1 – 24	4	4	17	Surface runoff lag time (days)
Timp	0 – 1	1	33	33	Snow pack temperature lag factor
Tlaps	0 – 50	-6	33	33	Temperature lapse rate
Usle_C	0.001 – 0.5	V	33	33	Minimum USLE cover factor
Usle_P	0 - 1	1	33	1	USLE support practice factor

Note: V=Variable parameter as per the user inputs

Calibration of the model

Manual calibration – when modeler knows about watershed parameters
Auto calibration – when less information is available
Combined approach - beneficial

Auto-calibration

20 parameters are chosen for auto-calibration from SA results

Simulation results after autocalibration for (2002)

2002		Observed		Simulated	
	Rainfall (mm)	Runoff (mm)	Sediment (t/ha)	Runoff (mm)	Sediment (t/ha)
June	682.4	400.29	1.83	369.38	0.73
July	300.8	145.79	0.11	81.80	0.11

not much improvement

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Manual calibration

Parameter values after manual calibration

.hru file	
CANMX = 4.055	
ESCO = 0.44	
EPCO = 0.313	
OV_N = 0.035 for Rice	
.rte file	
CH_N2 = 0.04	
CH_K2 = 6	
CH_COV1 = 0.025	
CH_COV2 = 0.953	
CH_EROD = 0.205	
.mgt file	
For Agriculture	*Forest*
CN2 = 89	CN2 = 80
USLE_P = 0.8	USLE_P = 0.9
	LAI_INIT = 1
	BIO_INIT = 995
General watershed parameters	
SURLAG = 1.627	
SPCON = 0.003	
SPEXP = 1.454	

Simulation results after manual calibration (2002)

2002		**Observed**		**Simulated**	
	Rainfall (mm)	Runoff (mm)	Sediment (t/ha)	Runoff (mm)	Sediment (t/ha)
June	682.4	400.28	1.83	406.65	1.32
July	300.8	145.37	0.11	102.79	0.19

Results are satisfactory

Model Validation - 2003

(before validation, simulated with default parameter set)

Simulation results with default parameter set (2003)

2003		Observed		Simulated	
	Rainfall (mm)	Runoff (mm)	Sediment (t/ha)	Runoff (mm)	Sediment (t/ha)
June	434.40	359.98	0.98	196.78	2.23
July	613.30	570.43	1.82	326.61	6.28

Not satisfactory

Validation results for the year 2003

2003		Observed		Simulated	
	Rainfall (mm)	Runoff (mm)	Sediment (t/ha)	Runoff (mm)	Sediment (t/ha)
June	434.40	359.98	0.98	245.10	0.58
July	613.30	570.43	1.82	371.74	0.69

Not satisfactory

↓

82%
93%

Try validating for another year

Model Validation - 2004

Simulation results with default parameter set (2004)

2004		Observed		Simulated	
	Rainfall (mm)	Runoff (mm)	Sediment (t/ha)	Runoff (mm)	Sediment (t/ha)
June	391.50	193.19	0.22	169.37	2.96
July	604.80	513.44	1.82	297.45	2.87

Validation results for the year 2004

2004		Observed		Simulated	
	Rainfall (mm)	Runoff (mm)	Sediment (t/ha)	Runoff (mm)	Sediment (t/ha)
June	391.50	193.19	0.22	188.89	0.26
July	604.80	513.44	1.82	341.51	0.23

Validation is satisfactory

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Summary of the simulations for Khadakohol watershed

Year/ Month	Rainfall (mm)	Observed		Using Default Parameters		Calibration		Validation	
		Runoff (mm)	Sediment (t/ha)	Runoff (mm)	Sediment (t/ha)	Runoff (mm)	Sediment (t/ha)	Runoff (mm)	Sediment (t/ha)
2002									
June	682.4	400.29	1.83	369.25	6.72	406.65	1.32		
July	300.8	145.79	0.11	78.5	1.07	102.79	0.19		
2003									
June	434.4	359.98	0.98	196.78	2.23			245.1	0.58
July	613.3	570.43	1.82	326.61	6.28			371.74	0.69
2004									
June	391.5	193.19	0.22	169.37	2.96			188.89	0.26
July	604.8	513.44	1.82	297.45	2.87			341.51	0.23

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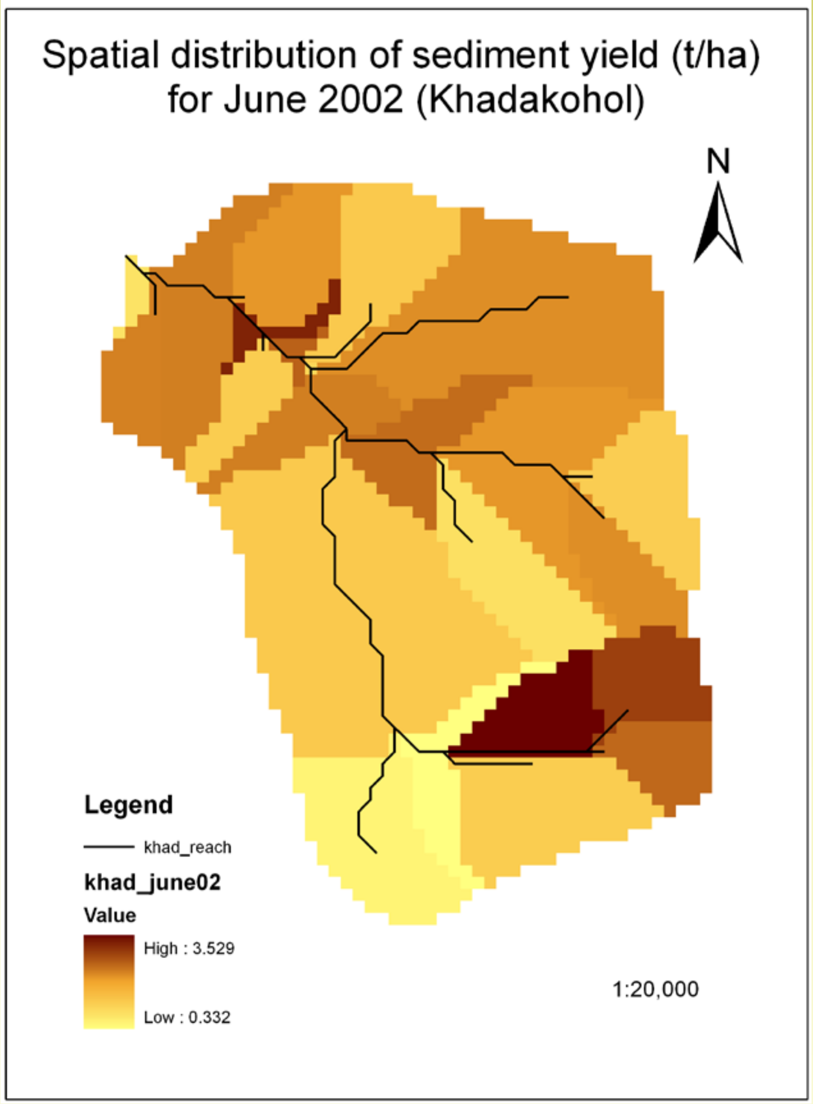
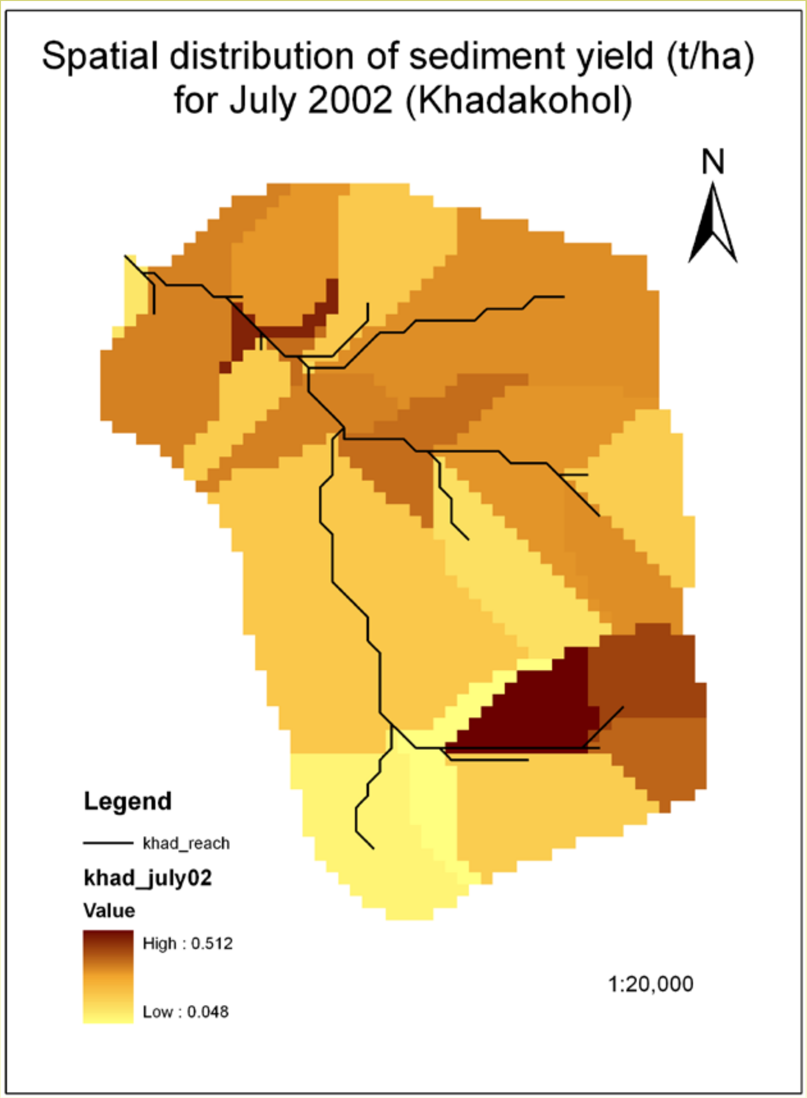
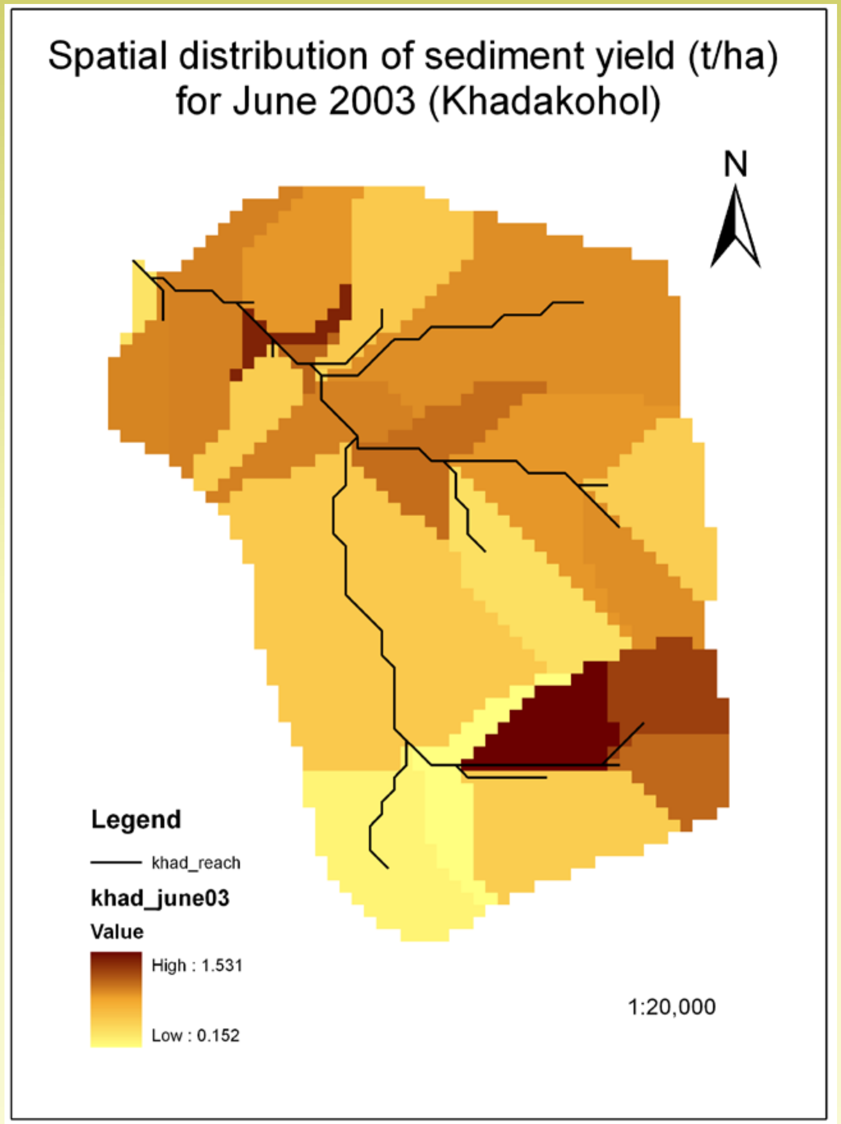
Spatio-temporal analysis of sediment yield distribution (t/ha)

Subbasin	Area (ha)	June02	July02	June03	July03	June04	July04
1	2.75	0.655	0.092	0.294	0.337	0.129	0.086
2	27.75	1.672	0.242	0.728	0.863	0.324	0.231
3	21.00	1.519	0.222	0.663	0.791	0.296	0.218
4	12.00	1.647	0.241	0.717	0.862	0.321	0.238
5	5.00	2.322	0.336	1.013	1.208	0.452	0.415
6	11.75	0.952	0.140	0.421	0.505	0.188	0.181
7	2.25	1.859	0.258	0.809	0.918	0.355	0.275
8	25.50	0.996	0.145	0.439	0.515	0.195	0.178
9	0.25	0.837	0.113	0.368	0.406	0.159	0.114
10	71.00	1.571	0.229	0.689	0.820	0.307	0.287
11	16.75	1.671	0.240	0.729	0.855	0.323	0.283
12	19.00	1.784	0.258	0.777	0.923	0.346	0.317
13	35.25	1.529	0.223	0.670	0.800	0.299	0.284
14	22.25	0.925	0.135	0.408	0.485	0.182	0.172
15	16.25	1.579	0.229	0.690	0.819	0.307	0.281
16	26.75	0.705	0.103	0.316	0.371	0.140	0.130
17	103.25	1.004	0.147	0.440	0.523	0.196	0.184
18	15.25	0.332	0.048	0.152	0.176	0.067	0.062
19	17.50	3.529	0.512	1.531	1.815	0.685	0.627
20	17.25	2.090	0.302	0.914	1.085	0.407	0.369
21	13.25	1.819	0.265	0.795	0.954	0.356	0.334
22	32.25	0.941	0.135	0.414	0.481	0.183	0.160
23	32.50	0.479	0.070	0.216	0.250	0.095	0.090

Subbasin 19: Total area = 17.5 ha
Agricultural area = 9.75 ha (55.71%)
Area with slope > 10% = 14 ha (80%)


Spatial distribution of sediment yield (t/ha)
for June 2002 (Khadakohol)
N
Legend
khad_reach
khad_june02
Value
High : 3.529
Low : 0.332
1:20,000


Spatial distribution of sediment yield (t/ha)
for July 2002 (Khadakohol)
N
Legend
khad_reach
khad_july02
Value
High : 0.512
Low : 0.048
1:20,000


Spatial distribution of sediment yield (t/ha)
for June 2003 (Khadakohol)
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Legend
khad_reach
khad_june03
Value
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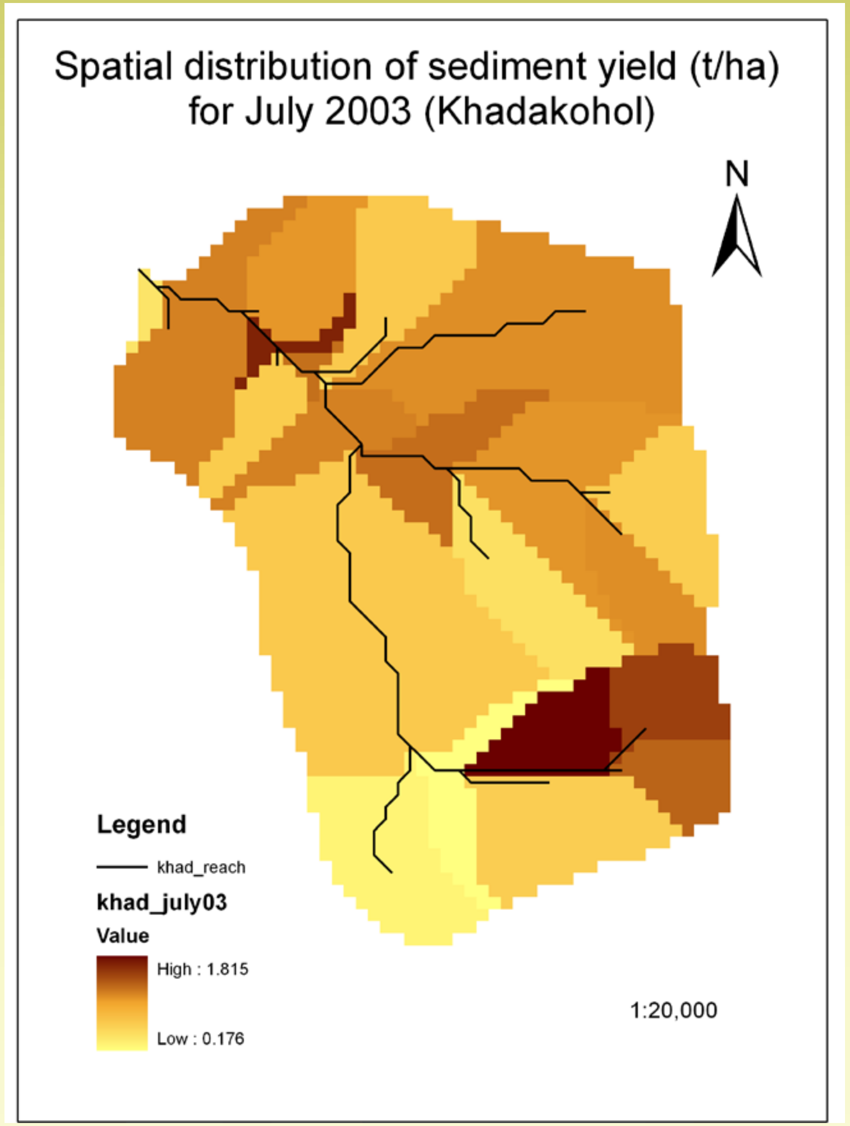
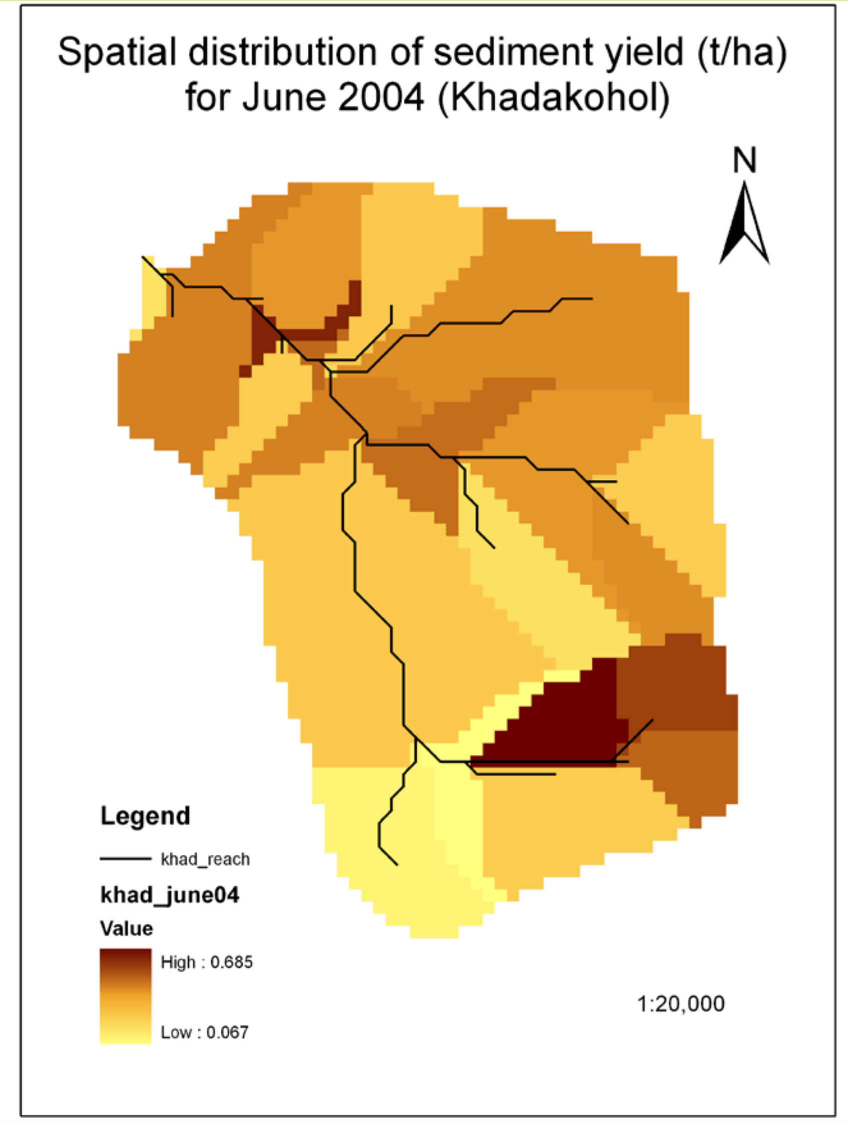
1:20,000


Spatial distribution of sediment yield (t/ha)
for July 2003 (Khadakohol)
N
Legend
khad_reach
khad_july03
Value
High : 1.815
Low : 0.176
1:20,000


Spatial distribution of sediment yield (t/ha)
for June 2004 (Khadakohol)
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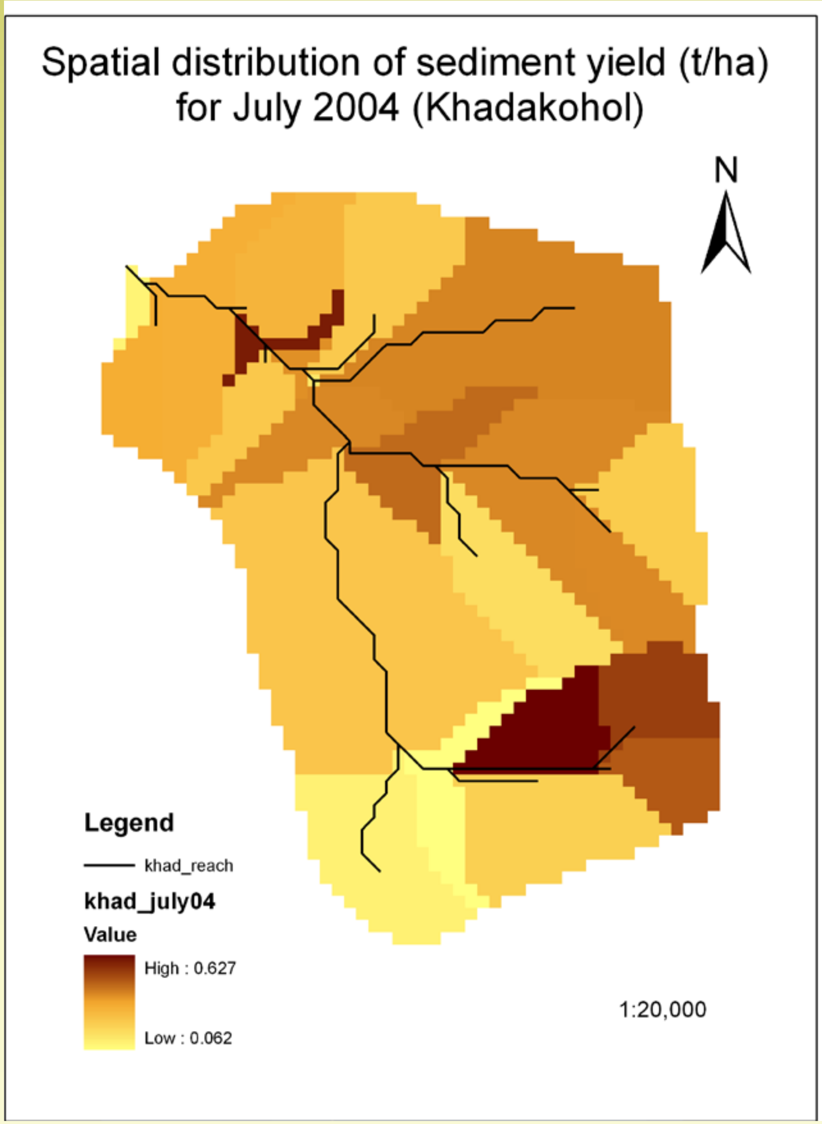
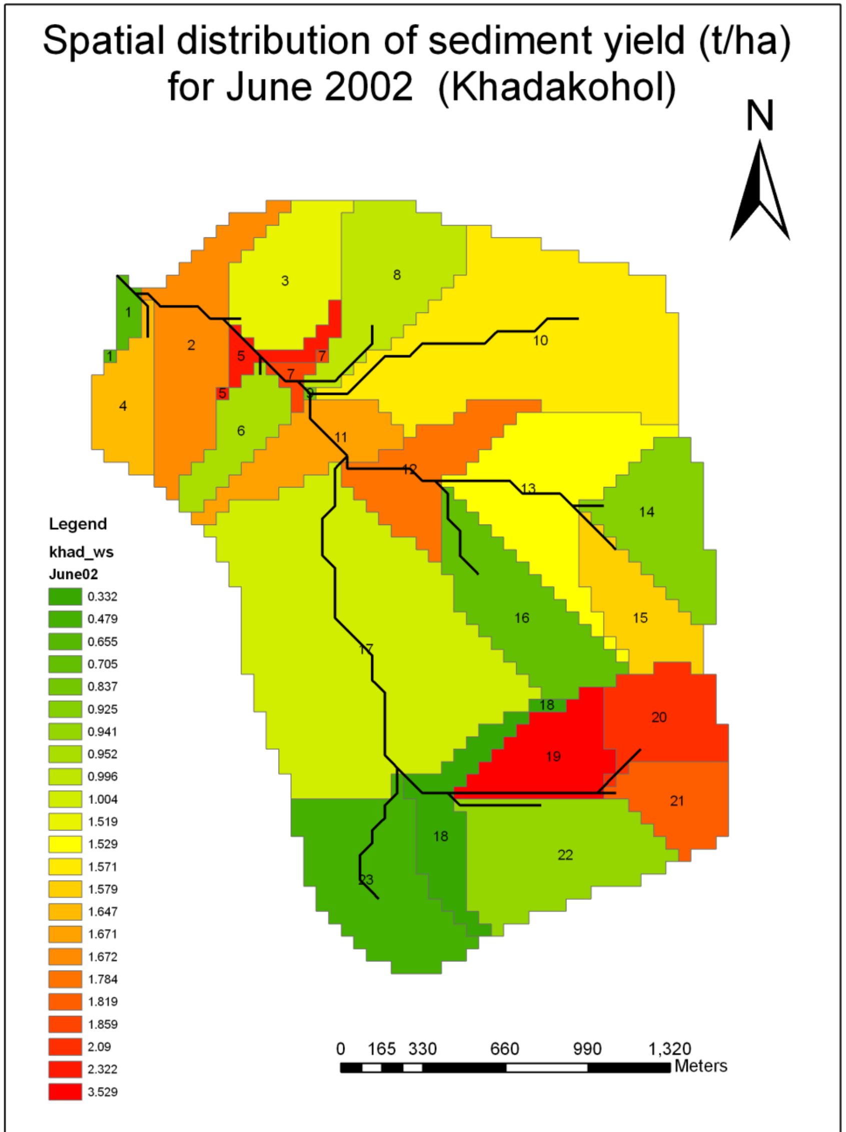
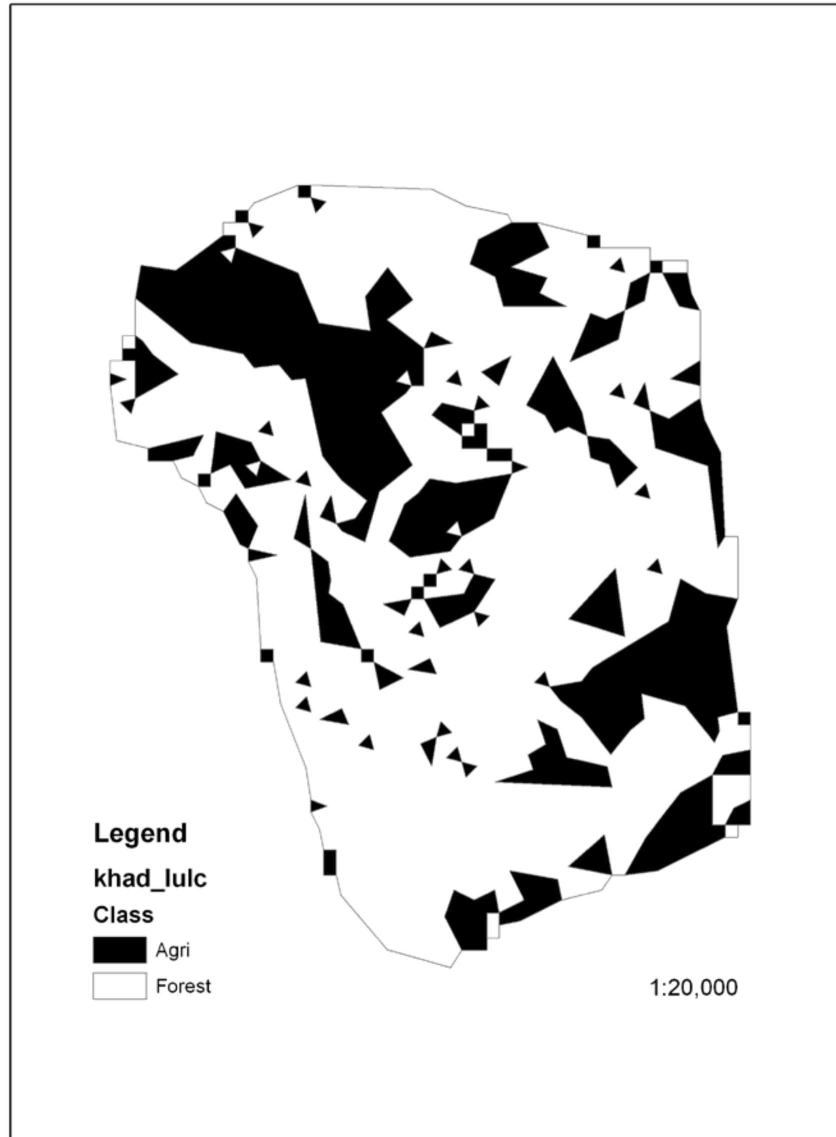
Legend
khad_reach
khad_june04
Value
High : 0.685
Low : 0.067
1:20,000


Spatial distribution of sediment yield (t/ha)
for July 2004 (Khadakohol)
N
Legend
khad_reach
khad_july04
Value
High : 0.627
Low : 0.062
1:20,000


Spatial distribution of sediment yield (t/ha)
for June 2002 (Khadakohol)
N
Legend
khad_ws
June02
0.332
0.479
0.655
0.705
0.837
0.925
0.941
0.952
0.996
1.004
1.519
1.529
1.571
1.579
1.647
1.671
1.672
1.784
1.819
1.859
2.09
2.322
3.529
0 165 330 660 990 1,320
Meters


Legend
khad_lulc
Class
Agri
Forest
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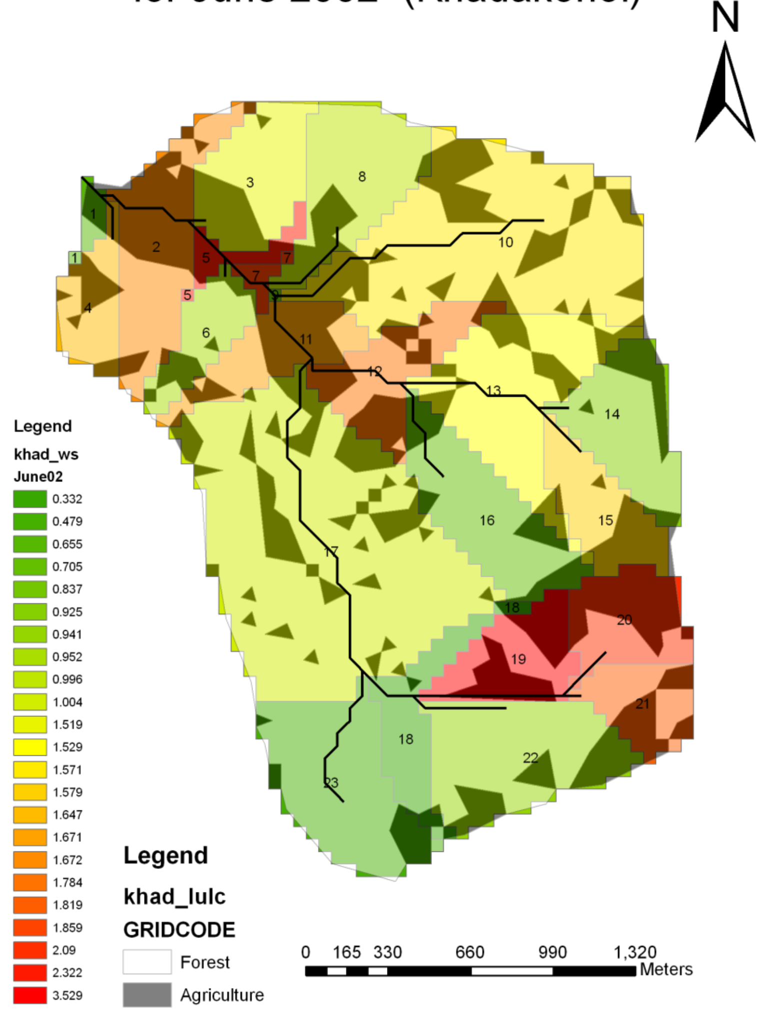
Spatial distribution of sediment yield (t/ha) for June 2002 (Khadakohol)



LU/LC-wise contribution to sediment yield

Month	LU/LC	Area (ha) contributing to sediment yield of			
		(0-1) t/ha	(1-2) t/ha	(2-3) t/ha	(3-4) t/ha
June-02	Forest Agriculture	132.50 36.75	229.50 108.25	8.50 13.75	7.75 9.75
July-02	Forest Agriculture	378.25 168.50	- -	- -	- -
June-03	Forest Agriculture	369.25 155.00	9.00 13.50	- -	- -
July-03	Forest Agriculture	362.00 145.00	16.25 23.50	- -	- -
June-04	Forest Agriculture	378.25 168.50	- -	- -	- -
July-04	Forest Agriculture	378.25 168.50	- -	- -	- -

SWAT Soil & Water Assessment Tool

Conclusions

1. Computer model such as SWAT integrated with GIS and remote sensing is very effective in runoff and sediment yield simulation of watersheds.

2. The SWAT model gives satisfactory results without even calibration, specifically for runoff as it was observed from several simulations with default parameter sets for various time periods.
The results improve with more manual input in the data representative of the watershed. Hence, SWAT model can be used in ungauged watersheds to predict the effect of land management practices on water and sediment.

3. Data of longer duration having wet and dry periods is desirable to calibrate the model. If the data used for auto/manual calibration is too less, the best parameter set obtained will not be representative of the watershed. Hence, the validation results using that parameter set may not match with the observed data.

4. Representation of management practices has a great impact on simulated sediment yield than runoff.

5. The analysis of spatio-temporal distribution of sediment yield shows that the subbasins having agricultural areas combined with steep slopes (>10%) yield more sediment.


Thank you