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Modelling the Impacts of Land use/cover Change on Runoff and Sediment Yield of Bagmati River Basin in Kathmandu Valley

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Abstract

Kathmandu valley (KV) is suffering from rapid land-use change due to the high rate of urbanization affecting the hydrological process, which is crucial for the sustainability of limited water resources. Land use/land cover (LULC) change in a watershed greatly affects the watershed hydrology and sediment yield. KV has the potential for a rapid LULC change in the foreseeable future and requires attention. This study used the Soil and Water Assessment Tool (SWAT) as a simulation tool for modelling the impact of LULC change on the catchment hydrological as well as sedimentological behaviour of the Bagmati river basin in the KV. This study incorporates the hydrological and climate data from 2000 to 2016 for the analysis of effect of LULC change on discharge and sediment yield. LULC data of the International Centre for Integrated Mountain Development (ICIMOD) for the years 2000 and 2010 A.D was used for the historical change analysis. Calibration, validation and sensitivity analysis was carried out using SWAT Calibration and Uncertainty Procedure (SWAT-CUP). The model result for both calibration and validation have shown a good agreement with the observed values as indicated by NSE(0.9/0.89, 0.73/0.83), R^2(0.9/0.92, 0.74/0.85), bR^2(0.84/0.91, 0.56/0.68), RSR(0.32/0.34, 0.52/0.41) and PBIAS(2.7/-16.7, -9.4/-23.2) for discharge as well as sediment. LULC change analysis shows the increase of built-up area by 6.65% from 2000 to 2010 A.D while all the other land use classes shows a decreasing trend. In the change LULC context, the simulated surface runoff contribution to streamflow (SURQ) changes by (+)10%, the lateral flow (LATQ) changes by (-)6%, groundwater contribution (GWQ) changes by (-)6% and the sediment yield changes by (+)20% respectively.

Several studies has been carried out in the Bagmati basin of KV but most of those studies focuses on the implications of land use change on flow parameters only but this study assessed the implications of LULC change on both water water balance and sediment yield parameters. Quantification of water balance and sediment yield within the urban watershed is more useful for the planning of water management as well as downstream projects for the engineer, environmentalist and others.

Keywords

Land use land cover (LULC), Soil and Water Assessment Tool (SWAT), SWAT Calibration and Uncertainty Procedure (SWAT-CUP), Discharge, Sediment yield

1. Introduction

Our natural environment has been modified over the years by different human activities. The dependence of human beings on natural resources has increased exponentially since the industrial revolution takes place. The rapid rate of urbanization, limited available resources, increasing demands and the constant overall earth mass has impacted the landmass and its natural ecosystem [1].

Nepal is among the least urbanized nations on the planet; however, it is among the top ten nations with the most elevated pace of urbanization[2]. The urbanization rate of Nepal is highest in the Asia pacific region[3]. Kathmandu Valley (KV), the capital city of Nepal is the most populous and rapidly growing urban area accounting 29% of the country's urban population. Increased population density, changes in LULC and changes in urban facilities & environment are the indicators of urbanization[4].

The hydrologic cycle requires complex interactions and processes involving climate, land use, vegetation cover density, erosion rates and sediment load in the watershed. As a result of their complexity and unpredictability, natural systems such as the hydrologic cycle are difficult to understand, predict and manage. Hydrological models were created in response to the need for more scientifically sound analysis. It provides a framework to anticipate and foresee the relationships between climate, anthropogenic activities and water resources [5].

LULC change is largely influenced by urbanization. Since the industrial revolution, the urban population has exploded resulting in significant environmental changes. The change in LULC impacts various areas of hydrology including socio-economics, ecology & environment[1]. Additionally, it has a tendency to eliminate natural detention ponds and reroute river courses[6]. In this case, the discharge distribution changes over time, causing a change in flow pattern[7]. Agricultural based economics in developing countries are plagued by LULC changes[8]. As LULC changes from agriculture to settlement impervious surface increases, infiltration decreases, resulting in an increase in peak flow[9]. In addition, it accelerates soil erosion, which has a variety of negative consequences on the natural ecosystem such as increased sedimentation and also causes water, soil & air pollution [10].

Different hydrological models have been used for the various watersheds of Nepal to simulate models and to analysed impacts([11],[12],[13]). SWAT model was selected for this study as this was used for the analysis of hydrological models in the Bagmati watershed before ([14, 15]) and had proved to give reliable results. It is used all over the world for thousands of research and is regarded as one of the best model for analyzing hydrological responses (water, sediment & nutrient loss) caused by LULC change in the catchment with varying land use, soil and management conditions[16] as well as its ability to characterize surface runoff and sediment yield producing mechanisms.

LULC and climate change impacts have been studied separately and in combination on the Bagmati river in the past. Sharma & Shakya, 2006 [17] studies the impact of hydrological changes of the Bagmati river but their studies focuses only on the hydrology and their study area was the whole watershed of the Bagmati river. Lamichhane & Shakya, 2019 [18] studies the impact of both LULC and climate change on the Bagmati watershed in KV but their study focuses only on the impacts on the hydrology.

Pokhrel, 2018 [15] studies the effects of LULC change on both water balance components & sediment yield and his study area is also the same as ours. The result from his study shows the increase of surface runoff contribution to stream-flow and sediment yields by 27% and 5% respectively but the lateral flow and groundwater contribution to stream-flow are decreased by 25% and 2% respectively.

But for his study he uses the sediment data projected from load estimator (LOADEST) and also the meteorological data used was only from two stations. Whereas this study used observed sediment data of the Khokana station from the Department of Hydrology & Meteorology (DHM) and filled the missing data using sediment rating curve. Also, this study considered 21 rain gauge stations & 7 meteorological station data for the analysis. So this study will give us a more realistic scenario of the LULC change impacts on both discharge and sediment yield.

In this study the impact of LULC change dynamics of KV, upper watershed of the Bagmati river in flow, water balance changed, soil erosion mechanism and sediment flow variation will be evaluated using hydrological model.

We hope the findings of this research will give policy makers the insight of the present scenario of Kathmandu valley & other urban areas of Nepal and helps to undertake effective measures to prevent the negative impacts of the land use change.

2. Materials and methods

2.1 Study Area

Bagmati river flows through the heart of KV, the capital city of Nepal. Six major tributaries; Hanumante, Manohara, Dhobi Khola, Bishnumati, Balkhu and Nakhhu rivers drained into the Bagmati river. All the tributaries are spring-fed and rain-fed rivers flowing from north to south direction [15]. The Bagmati river originates from Shivapuri at an altitude of 2669 m and its watershed is surrounded by Mahabharat hills. The catchment of Bagmati river covers an area of 613 km^2 at Khokana station, which is situated at a Latitude of $27^0$37’4”, Longitude of $85^0$17’41”, and an altitude of 1190 m.

The climate of KV region is fairly pleasant and is categorized as a warm temperate zone. The average monthly air temperature during summer seasons reaches up to 29.3^0C and during winter seasons the

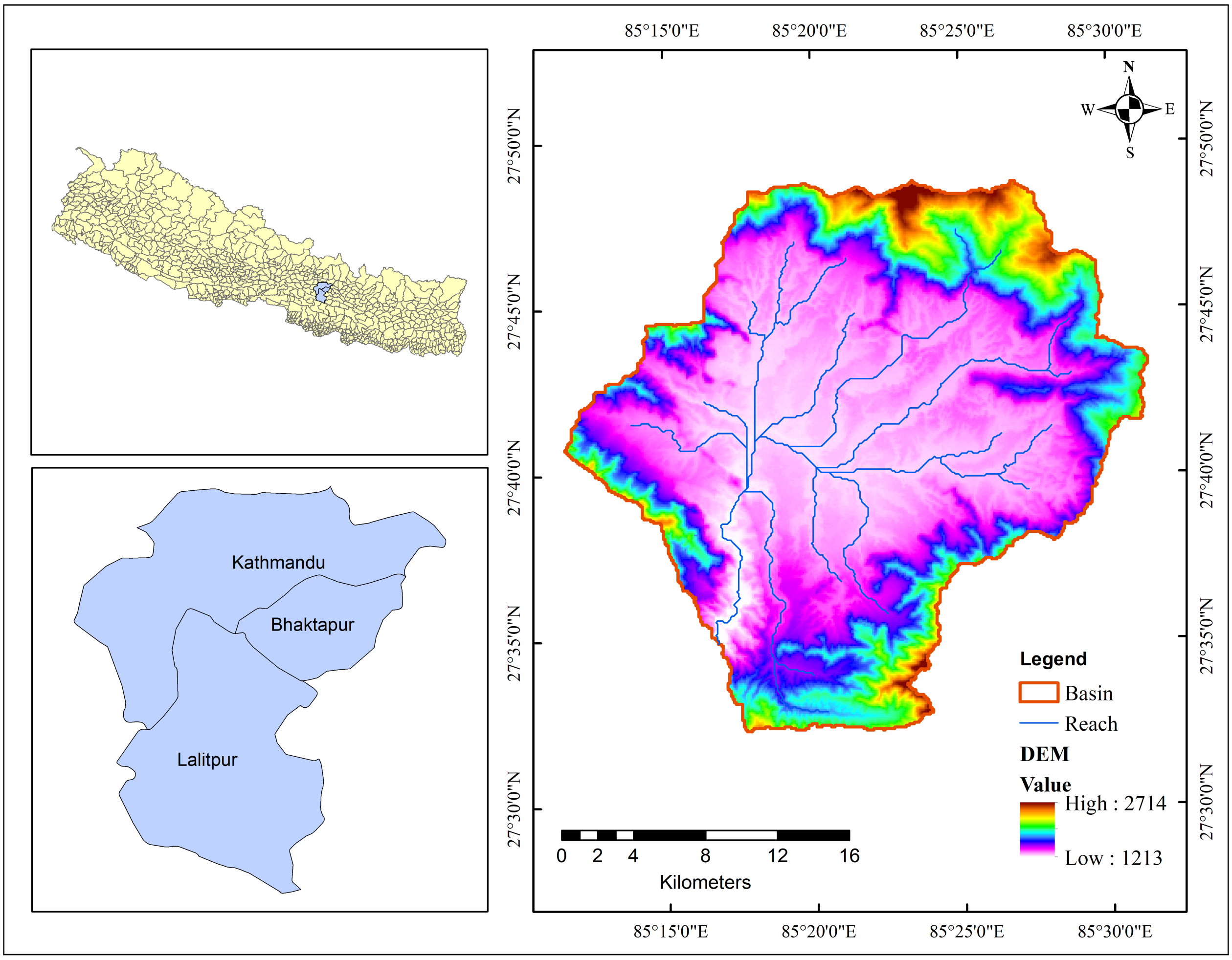

Figure 1: Location map of the Study Area

average monthly temperature falls up to 0.9^0C (DHM). The analysis of data for the study period shows the average monthly maximum precipitation of 402.1 mm in the month of July and average monthly minimum precipitation of 4.2 mm in December [19]. The maximum precipitation over that period recorded was 300.100 mm on 23rd July 2002, while the average relative humidity and wind speed recorded were 64.8% and 2.381 Km/Hr. The precipitation in the KV is mostly monsoon based and over 80% of the total average annual rainfall occurs during the monsoon season that is from the month of June to September. So the Bagmati river and its tributaries experienced a very high variation of discharge during the wet and dry period [19]. The total average annual rainfall over the study period is 1533 mm/year.

2.2 Methodology

The physically-based Soil and Water Assessment Tool (SWAT) is used as a simulation tool for the assessment of the impacts of LULC change on the water balance components and sediment yield of the Bagmati river watershed in KV. The LULC data of 2000 and 2010 from ICIMOD was used for LULC change analysis. The calibration, validation and sensitivity analysis of the model was done using SWAT-CUP, SUFI-2 optimization program.

Best fit parameters between the observed and simulated data for the model are obtained using automatic calibration process [20]. The most influential SWAT parameters identified from the global sensitivity analysis were used to calibrate the model. The calibration of the discharge and sediment yield is done using the observed monthly data obtained from DHM for 2000 to 2010 A.D with three years of warm-up period for the initialization of the model variables. A lot of parameters are available in the swat-cup to describe the certain hydrological behavior and features of the watershed. To accurately simulate the stream-flow and thus sedimentation process in the study watershed these parameters needed to be identified and calibrated. After the calibration; validation is done from 2010 to 2016. The evaluation of the model performance was done by using Nash-Sutcliffe Efficiency (NSE), Coefficient of Determination (R^2), Modified Coefficient of Determination (bR^2), RMSE-Observations Standard Deviation Ratio (RSR) and Percentage Bias (PBIAS). The methodological flowchart for the study is shown in **Figure 2**.

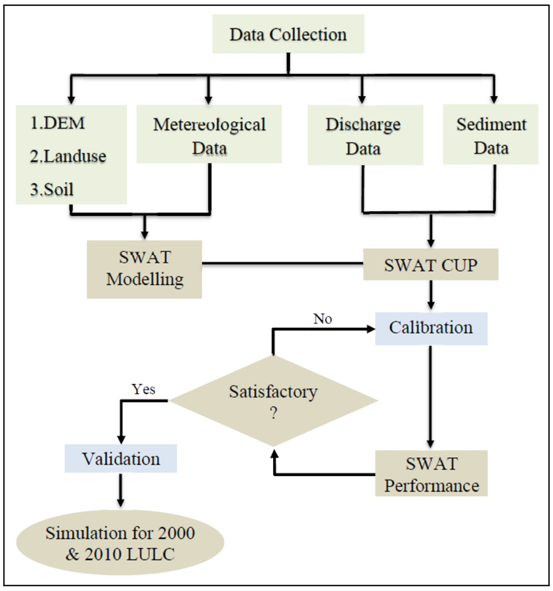

Figure 2: Methodological Framework of the Study

2.3 Data Inputs

A SWAT model requires different types of data to simulate the hydrological processes of the watershed. These data can be obtained from different sources. The Digital Elevation Model (DEM) data of 30 m spatial resolution was downloaded from ASTER (Advanced Space-borne Thermal Emission and Reflection Radiometer) satellite data (GDEM) (https://earthdata.nasa.gov/), which is required to delineate the watershed and to generate the stream reaches. It is also used to analyze the stream length/width, drainage pattern of the watershed and to categorize the slope of the basin [21]. The LULC data of 2000 and 2010 were downloaded from International Center for Integrated Mountain Development (ICIMOD, https://rds.icimod.org/). For the soil data; the Soil and Terrain database of Nepal (SOTER) is used which is derived from ISRIC World Soil Information (https://www.isric.org/) and it is clipped to the required extent for the analysis.

Hydrological data such as flow data and sediment data for the Khokana station and meteorological data such as daily precipitation, maximum & minimum temperature, relative humidity, wind speed & solar radiation data of the Bagmati basin was obtained from DHM.

Different data that has been used for this study, their duration, resolution and sources are shown in **Table1**.

2.4 SWAT Model Setup

SWAT[22] is a continuous, semi-distributed, parametric model used by many researchers all over the world for the hydrologic analysis[23]. This model is physically based and is very efficient for the simulation of the long term continuous databases [24]. The major components of the SWAT includes hydrology, weather, erosion/sedimentation, soil temperature & properties, plant growth, nutrients, pesticides, land management, stream routing and pond/reservoir routing.

The SWAT simulates the hydrologic model using water balance equation[25]:

$$SW_t = SW_0 + \sum_{i=1}^{n} (Rday - Qsurf - Ea - Wseep - Qgw) \quad (1)$$

Where,
SW_t = Final soil water content (mm)
SW_0 = Initial soil water content (mm)
Rday = Days Rainfall (mm)
Qsurf = Quantity of surface runoff (mm)
Ea = Evapotranspiration (mm)
Wseep = Seepage from the bottom soil layer (mm)
Qgw = Ground water flow (mm)

There are two methods to calculate surface runoff using the SWAT model. One is SCS curve number procedure and the other is Green & Ampt infiltration model procedure [24]. We have selected SCS curve number procedure for the analysis. For sediment flow analysis, SWAT uses Modified Universal Soil Loss Equation (MUSLE). The MUSLE equation to calculate the sediment erosion from the watershed is:

$$S = 11.8(Q \times Area \times pr)^{0.56} \times K \times C \times P \times LS \times R \quad (2)$$

Where,
S = Sediment load (mt)
Q = Surface runoff (cu.m)
pr = Peak runoff rate (cu.m)
K = USLE soil erodability factor

Table 1: Input data and their sources

S.N	Input Data	Duration	Resolution	Source
1.	Digital Elevation Model		30m×30m	ASTER-GDEM
2.	Land use land cover	2000 & 2010 A.D	30m×30m	ICIMOD
3.	Soil Data	2009 A.D	30m×30m	Soil and Terrain Database (SOTER) for Nepal
4.	Meteorological Data	2000 - 2016 A.D		Department of Hydrology and Meteorology (DHM)
5.	Discharge Data	2000 - 2016 A.D		DHM
6.	Sediment Data	2000 - 2016 A.D		DHM

Table 2: LULC Classes for 2000 and 2010 A.D

LULC Class	2000		2010		Difference	
	Area(Sq.km)	%	Area(Sq.km)	%	Sq.km	%
Built-up area	131.59	21.46	172.39	28.12	40.80	6.65
Agriculture area	255.28	41.64	224.23	36.57	-31.05	-5.06
Forest	224.22	36.57	215.17	35.09	-9.06	-1.48
Barren area	1.52	0.25	1.21	0.20	-0.31	-0.05
Water Body	0.49	0.08	0.11	0.02	-0.38	-0.06
Total:	613.11		613.11			

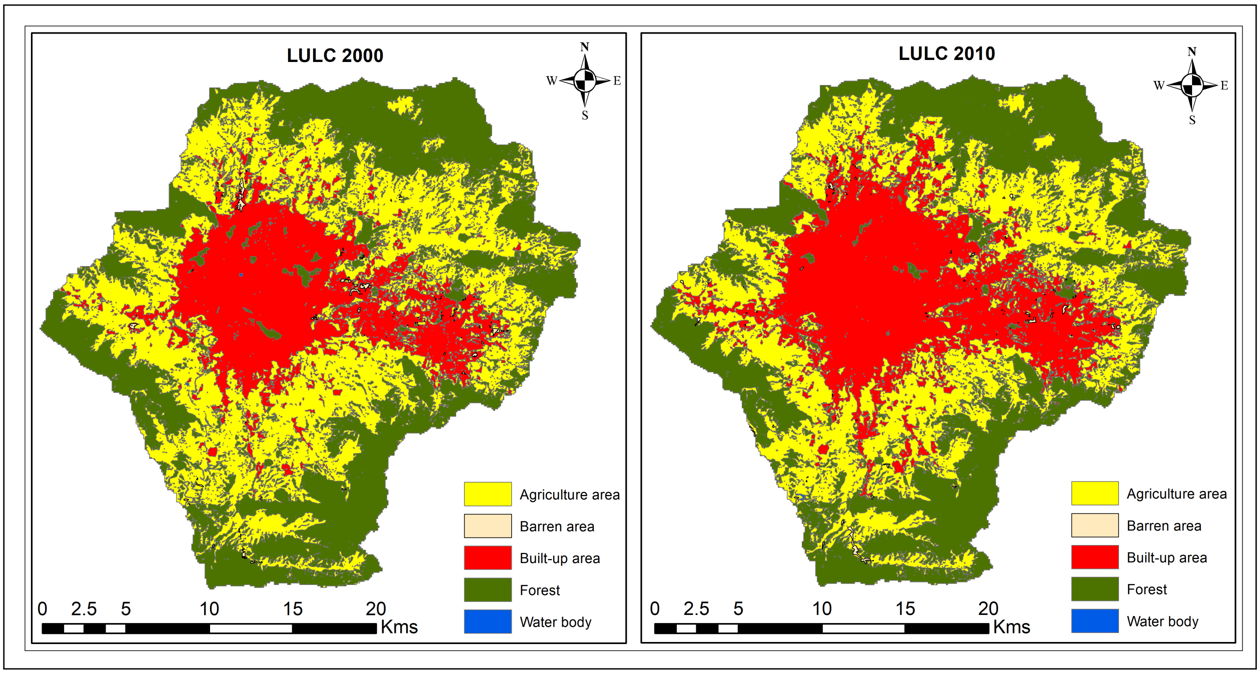

Figure 3: LULC map of the study area from ICIMOD for 2000 A.D and 2010 A.D

C = Cover and management factor
P = Support practice factor
LS = Topographic factor (gradient, length)

A watershed delineation and a hydrologic response units(HRUs) determination function in used in ArcSWAT to pre-process GIS data for the SWAT model.

2.4.1 Watershed Delineation

It is the process of dividing the watershed into discrete sub-basins and stream reaches. DEM data is used by the SWAT to delineate the watershed into several hydrologically connected sub-watersheds or sub-basins. The Watershed delineation process provides the geographic relationship between upstream & downstream and also enables researchers to give the specific location of input and output so that it can be used for scientific research and management purposes. Before the delineation process the DEM data should be projected and also the pits and depressions should be filled if required.

The Watershed delineation process in our study area creates 65 sub-basins. A 500 hectares area of threshold is given in defining the beginning of the stream.

2.4.2 Hydrologic Response Unit Analysis

Hydrologic Response Units(HRU) are the areas of land that are assumed to respond similarly to weather inputs and are unique combinations within each sub-basin of land use, soil and slope. Creating HRU's requires four GIS layers: Sub-basins, land use land cover, soils and slope. These data are loaded in the projected grid file format in the SWAT interface. The land cover and soil classes are defined using the look-up table. The land slope classes were also integrated in defining the hydrologic response units. The sediment transport capacity is directly proportional to the slope of the land surface. The Bagmati basin in Kathmandu Valley is a bowl-shaped basin surrounding by hills and has more or less flat terrain in the center. More than 70% of land is below 20 % slope. So Only three classes of slope have been defined; (0 – 20) %, (20 – 40)% & greater than 40% based on the watershed's suggested minimum, maximum, mean and median slope statistics and the slope grids are reclassified. The same DEM data which was used for the watershed delineation is used for the slope reclassification. Then, finally, the reclassified land use, soil and slope grids were overlaid to create the HRU's.

The HRU definition is the final step in the HRU analysis. In this study, the HRU definition was established by assigning multiple HRU to each sub-watershed. In multiple HRU definitions, the HRU thresholds are kept zero so that every unique combination of land use, soil and slope will be considered a unique HRU. The HRU definition process creates 1210 HRU's in our study area.

2.4.3 Importing climate data

Climatic variables are the essential components of the hydrologic cycle which affects the overall water balance of the watershed. Five most important weather database is needed for the analysis of the model; precipitation, temperature (max/min), solar radiation, wind speed and relative humidity. The weather databases required should be in a specific file format. Solar radiation, wind speed and relative humidity data are needed for the calculation of potential evapotranspiration. A Solar radiation database is also needed to analyze the plant growth but that is not the part of our study. A continuous high-quality daily weather database is needed for the accurate analysis of the model. So, we have imported only those stations database which has the required qualities together with their weather location in the model. A total of 21 rain gauge stations, 7 meteorological stations and 1 hydrological station in and around the Bagmati watershed is used in our study. The weighted average rainfall representing all 21 rain gauge station data is calculated by applying Thissien polygen method to correlate the discharge and sediment yield from the river at a partucular time with corresponding rainfall.

2.4.4 Model Simulation

After gathering all the input data together and processing some of the data to create sub-basins and HRUs, very specific input files with precise formatting is created. Thus created SWAT formatted input files were used in running the SWAT model and creating the outputs. The model is simulated from 2000 to 2016 with three years of NYSKIP. The values of many variables at the beginning of the simulation are also important. There is an amount of water in the soil moisture, in reservoir and aquifers at the beginning of the simulation for which we often do not have data, so the model was run for three years at the beginning of the simulation as a warm-up period to get the hydrologic cycle fully operational.

2.5 SWAT-CUP Model Setup

SWAT-CUP [26] is an automatic calibration tool used worldwide for fitting the model parameters and their uncertainty analysis. Uncertainty analysis is a process of propagating and quantifying the errors in the model inputs through the calibration process. Various factors can be responsible for the uncertainty in the model. The uncertainty can be due to the variables used, error in the input data (discharge, sediment, soil, landuse, rainfall etc.) for the analysis, simplifications of the processes included in the model, unknown model parameters or the missing processes (wetland, dam, glacier melts etc.)[24]. Various analysis programs like Particle Swarm Optimization (PSO), Sequential Uncertainty Fitting version 2 (SUFI-2), Parameter Solution (ParaSol), Markov Chain Monte Carlo (MCMC) and Generalized Likelihood Uncertainty

Estimation (GLUE) are integrated in the SWAT-CUP [27]. The integration of these algorithms makes the program exceptionally flexible to analyze various aspects of the model. The quality of the model output for the SWAT-CUP calibration and uncertainty analysis is measured by the P factor and R factor at a 95% prediction uncertainty (95PPU) [26]. The P factor represents the percentage of measured data captured by 95PPU and its value of 1 indicates the perfect model simulation. The R factor measures the quality of the calibration results and its value of zero represents the direct fit of the observed and simulated data (discharge, sediment or nutrients)[27].

TxtInOut file formed after the SWAT simulation in ArcSWAT is given as an input for the SWAT-CUP. SUFI-2 analysis program is considered to give the widest margin of the parameter uncertainty[28], so it is used for our study.

2.5.1 Model Performance Assessment

A total of eleven objective functions are available in SWAT-CUP to analyse the the model performance. One objection function (Nash-Sutcliffe) and five major criteria were used to accessed the evaluation of the model performance: coefficient of determination (R^2), Modified coefficient of Determination (bR^2), RMSE – observations standard deviation ratio (RSR), Nash-Sutcliffe Efficiency (NSE) factor and Percent Bias (PBIAS) equation as suggested by [29] [30].

1. **Coefficient of determination** : It describes the level of variance between the simulated and observed data. It is not suggested to use as a single criteria for the evaluation of the model performance as it can give same R^2 value for different magnitude data set.

$$R^2 = \frac{[\sum_{i=1}(Q_{m,i}-\bar{Q_m})(Q_{s,i}-\bar{Q_s})]^2}{\sum_{i=1}(Q_{m,i}-\bar{Q_m})^2\sum_{i=1}(Q_{s,i}-\bar{Q_s})^2} \quad (3)$$

2. **Modified coefficient of determination** : This function takes into account the magnitude of data sets as well as their linearity by multiplying the magnitudes by regression constant(b) so, this function is considered better than R^2.

$$\phi = \begin{cases} |b|R^2 & \text{if } |b| \le 1 \\ |b|^{-1}R^2 & \text{if } |b| > 1 \end{cases} \quad (4)$$

3. **Nash - Sutcliffe Efficiency (NSE)** : It indicates the goodness of fit of the plot between the measured and simulated datasets [31].

$$NS = 1 - \frac{[\sum_{i=1}(Q_m-Q_s)_i^2]}{[\sum_{i=1}(Q_{m,i}-\bar{Q_m}]} \quad (5)$$

4. **RMSE – observations standard deviation ratio (RSR)** : RSR is calculated by dividing the RMSE (Root Mean Square Error) by the standard deviation of the observed data.

$$RSR = \frac{\sqrt{[\sum_{i=1}^{n}(Q_m-Q_s)_i^2]}}{\sqrt{[\sum_{i=1}^{n}(Q_{m,i}-\bar{Q_m})^2]}} \quad (6)$$

5. **Percent bias (PBIAS)** : The tendency for observed data to be greater (or lesser) than the simulated data is measured by PBIAS[32].

$$PBIAS = 100 * \frac{[\sum_{i=1}^{n}(Q_m-Q_s)_i]}{[\sum_{i=1}^{n}Q_{m,i}]} \quad (7)$$

Where, Q is a parameter (eg., discharge, sediment), 'm' stand for measured data & 's' stand for simulated data respectively .

3. Results and Discussion

3.1 Sensitivity Assessment of the SWAT Model

The parameters are considered to represent the processes in the watershed. Sensitivity analysis is actually the method of determining the dominant process in the watershed. Sensitivity analysis is carried out before calibration of the model to find out the significance of one or a combination of parameters that have significant impacts on the objective function or the model output [33]. This can be carried out by one at a time sensitivity analysis or by global sensitivity analysis. As the sensitivity of one parameter depends on the values of the other parameters; in our case, we have conducted a global sensitivity analysis to achieve the desired objective function. Initially, 24 parameters were considered on the basis of different literature reviews, initial global sensitivity analysis result, location & conditions of the study area and their known role in different hydrologic processes. The studies carried out by different researchers are also considered most notably by [15] who studied in the same watershed as ours and the parameters suggested by [26]. After carrying out Global Sensitivity Analysis, of those parameters with 2000 iterations; only 20 sensitive parameters were considered for the analysis. Continuous iterations of those 20 parameters are done until the best fit result is obtained with respect to R^2, NSE, bR^2, RSR and PBIAS indicating the end of the simulation.

Of those 20 parameters, the most sensitive parameters were the Manning's roughness coefficient for the main channel (CH-N2), soil evaporation compensation factor (ESCO), Saturated hydraulic conductivity (Sol-K), SCS runoff curve number (CN2), available soil water capacity (SOL- AWC), surface runoff lag coefficient (SURLAG) from the surface runoff parameters and baseflow alpha-factor (ALPHA-BF), groundwater revap co-efficient (GW-REVAP), threshold depth of water in the shallow aquifer for return flow (GWQMN) from the subsurface response parameters.

Among channel erosion parameters, linear parameter and exponent parameter for calculating the maximum amount of sediment that can be re-entrained during channel sediment routing (SPCON) & (SPEXP) were leading the group among all sediment parameters with second and third rank among overall parameters followed by Channel erodability factor (CH-ERODMO) and Channel cover factor (CH-COV2). The support practice factor (USLE-P) of the Universal soil loss equation has been discovered to be the most sensitive landscape soil erosion variable.

The parameter is considered more sensitive when the absolute value of t-stat is higher and the p-value is smaller[26]. The t-stat indicates the degree of sensitivity, whereas the p-value determines the significance of the parameter's sensitivity. The statistics of the parameter sensitivity are obtained using multiple regression analysis. The result of the sensitivity analysis is shown in **Figure 4**.

3.2 Calibration, Validation and Evaluation of Model Performance

In this study, the calibration is done using SWAT-CUP software with the SUFI-2 optimization program. **Table4** shows the parameter's list and their fitted values obtained after the calibration. The validation of the parameters obtained from the calibration of the model was done by using so obtained parameters value for the known monthly discharge and sediment data from 2011 to 2016 A.D. **Figure 5** & **Figure 7** shows the simulation of the runoff and sediment yield for the calibration and validation period respectively. **Figure 6** & **Figure 8** shows the correlation performance of the runoff and sediment yield for the calibration and validation period respectively.

According to [29] performance evaluation criteria, the values obtained shows very good result in the calibration period with (NSE = 0.9, R^2 = 0.9, PBIAS = 2.7) for discharge and good result with (NSE = 0.73, R^2 = 0.74, PBIAS = -9.4) for sediment yield. Except for some peak discharges, where there were discrepancies, the simulated discharge follows the observed patterns to some extent. The simulated sediment yield also shows good agreement with observed data to the large extent. The peak sediment yield in the first year of the simulation period is slightly over predicted and the opposite happens in the last two years. The simulated base flow for both discharge and sediment shows good agreement with the measured flow. Overall the hydrographs in the calibration period for both discharge and sediment show a more accurate depiction of peak and base flows as well as median flows.

The model's performance is also good during the period of validation. The NSE and R^2 values obtained during validation for both discharge (NSE = 0.89, R^2 = 0.92) and sediment yield (NSE = 0.83, R^2 = 0.85) can be classified as very good and the PBIAS value of -16.7% & -23.2% for discharge and sediment respectively as satisfactory and good. The simulated discharge is consistent with the observed discharge with slightly more base flow in a certain periods. The simulated sediment flow is also consistent with the observed sediment flow with better statistical parameters than that of the calibration period. Overall the calibrated parameters seem quite fit for validation.

3.3 Impact of LULC change on the Discharge

Land use/cover data of 2000 and 2010 A.D from ICIMOD is used for the impact assessment of the LULC alterations on the hydrology and sediment yield of the Bagmati basin. The comparison (**Table1**) of LULC change for the decade shows an overall increase of Built-up area of the Kathmandu valley by 40.8 Sq.km (6.65%). All the other land use classes are in decreasing trend. Increasing urbanization pattern can be seen in **Figure 3**, mostly affects the agriculture area and forest area which shows 5.06% and 1.48% decrease from 2000 to 2010 A.D.

The impact of this change of LULC classes on the discharge and sediment yield is examined after the calibration and validation of the model. The annual

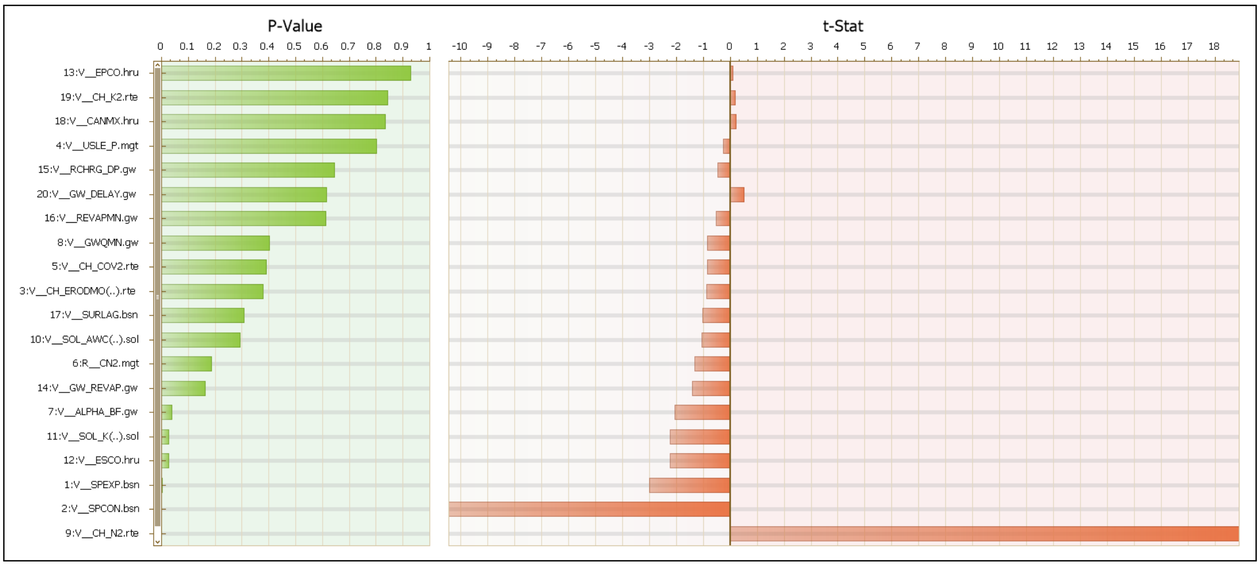

Figure 4: Global Sensitivity Analysis Result of the Model Parameters

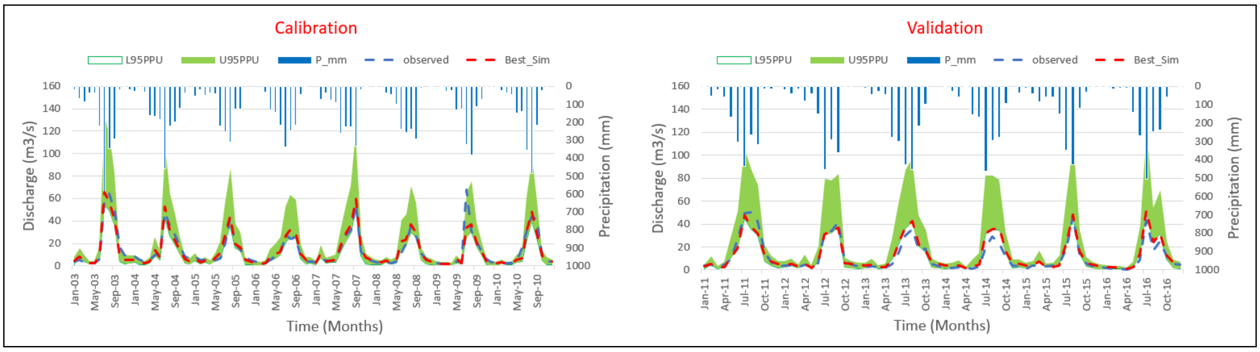

Figure 5: Calibration and Validation of Discharge at Khokana Station of Bagmati Basin

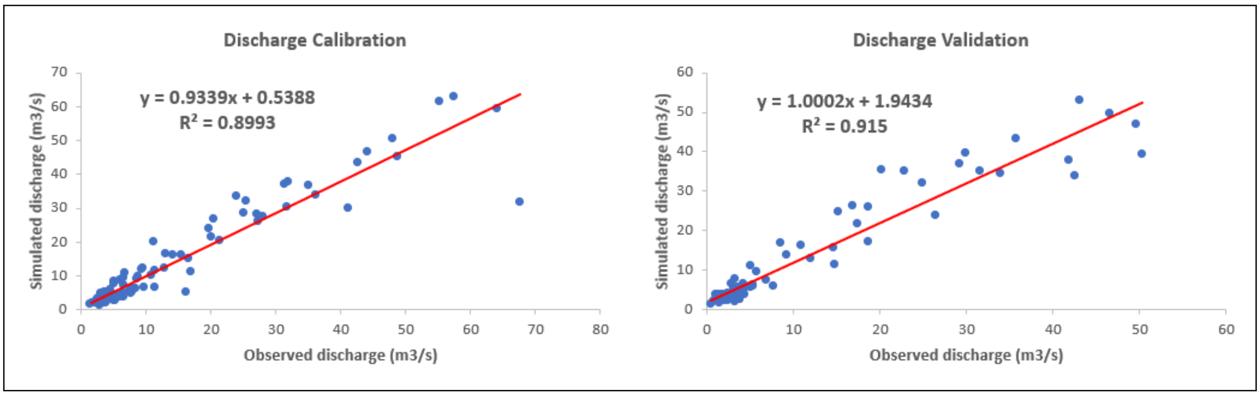

Figure 6: Correlation performance of discharge during calibration & validation period

Table 3: Calibration and Validation statistics of the SWAT model using monthly Discharge data

Stage of Model	Evaluated Parameters						
	p-factor	r-factor	R2	NSE	bR2	RSR	PBIAS
Calibration(2000-2010)	0.79	0.32	0.90	0.90	0.84	0.32	2.70
Validation(2011-2016)	0.56	0.38	0.92	0.89	0.91	0.34	-16.7

Table 4: List of Calibrated parameters and their values for Stream flow and Sediment yield

Parameters used to calibrate stream flow	Description of Parameters	Range of Values	Fitted Values
CN2	SCS runoff curve number	-0.1 to 0.1	0.008
ALPHA_BF	Baseflow alpha factor	0 to 1	0.851
GW_Delay	Groundwater delay time (days)	0 to 500	40.875
GWQMN	Threshold depth of water in the shallow aquifer for return flow (mm)	0 to 5000	1918.750
CH_N2	Manning's roughness coefficient for the main channel	-0.01 to 0.3	0.160
SOL_AWC	Available soil water capacity	0 to 1	0.300
SOL_K	Saturated hydraulic conductivity(mm/hr)	0 to 2000	409.500
ESCO	Soil evaporation compensation factor	0 to 1	0.060
EPCO	Plant uptake compensation factor	0 to 1	0.904
GW_REVAP	Groundwater revap coefficient	0.02 to 0.2	0.131
RCHRG_DP	Deep aquifer percolation fraction	0 to 1	0.197
REVAPMN	Threshold depth of water in the shallow aquifer for "revap" or percolation to the deep aquifer to occur (mm)	0 to 500	238.875
SURLAG	Surface runoff lag coefficient	0.05 to 24	1.002
CANMX	Maximum canopy storage	0 to 100	41.725
CH_K2	Effective hydraulic conductivity in the main channel	-0.01 to 500	135.618
Parameters used to calibrate sediment yield			
SPEXP	Exponent parameter for calculating sediment reentrained in channel sediment routing	1 to 1.5	1.469
SPCON	Linear parameter for calculating the maximum amount of sediment that can be reentrained during channel sediment routing	0.0001 to 0.01	0.000172
CH_ERODMO	Channel erodability factor	0 to 1	0.365
USLE_P	USLE equation support parameter	0 to 1	0.009
CH_COV2	Channel cover factor	-0.001 to 1	0.442

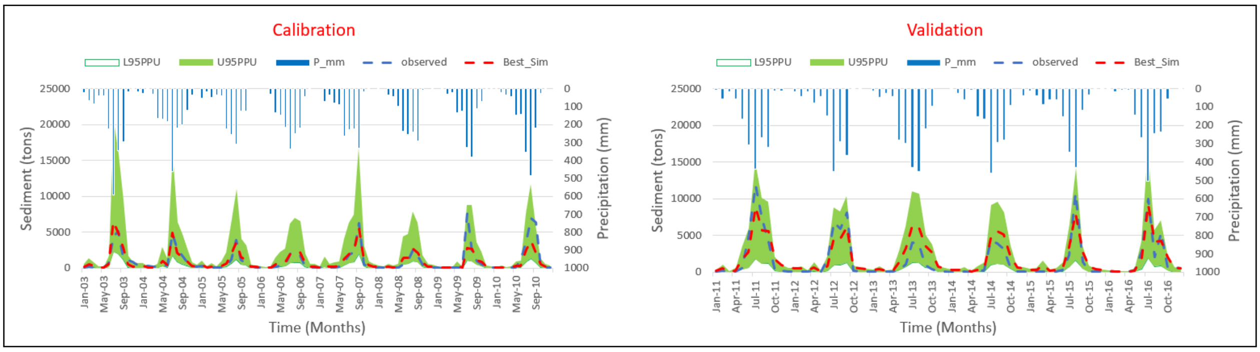

Figure 7: Calibration and Validation of Sediment yield at Khokana Station of Bagmati Basin

average values of three water flow components (surface flow, lateral flow & groundwater flow) were analyzed as shown in (**Table6**). The analysis of the result shows the increase of surface runoff(SURQ) by 9.81% from 2000 to 2010 A.D. The lateral flow contribution to steam flow(LATQ) and groundwater contribution (GWQ) to the stream flow shows a decrease of 5.89% & 5.8% respectively.

These result shows the negative impact of urbanization on the water balance components of the Bagmati watershed. An increase in impervious surfaces due to urbanization decrease the percolation

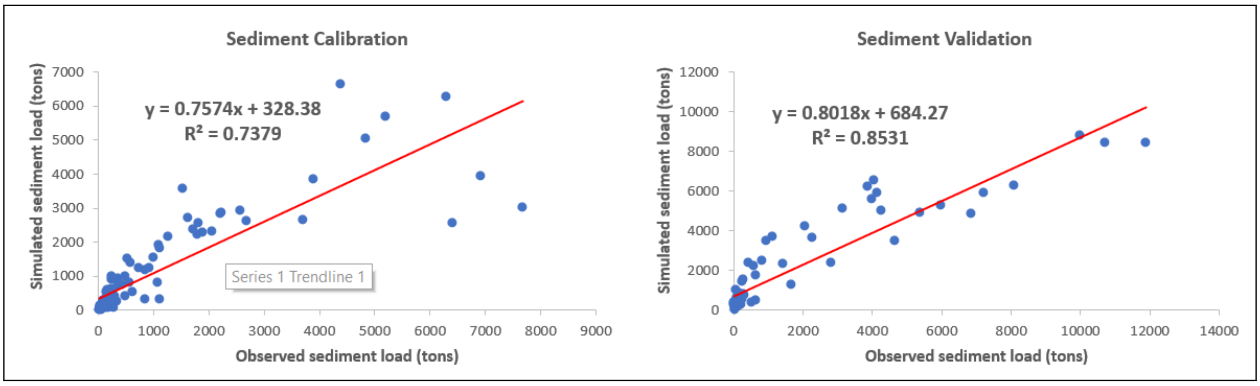

Figure 8: Correlation performance of sediment during calibration & validation period

Table 5: Calibration and Validation statistics of the SWAT model using monthly Sediment data

Stage of Model	Evaluated Parameters						
	p-factor	r-factor	R2	NSE	bR2	RSR	PBIAS
Calibration(2000-2010)	0.99	1.61	0.74	0.73	0.56	0.52	-9.40
Validation(2011-2016)	0.94	1.03	0.85	0.83	0.68	0.41	-23.2

of rainwater into the ground sub-surface resulted in a decrease in groundwater recharge. Also the lack of reliable water supply in the KV and the dependency on groundwater for water supply purpose further reduces the ground water table which finally contributes to low groundwater flow (GWQ).

3.4 Impact of LULC change on sediment yield

Similarly, the impact of LULC change on the sediment yield is evaluated for both time periods using the validated sediment yield results. The annual sediment yield values of the Bagmati watershed is increased from 5.59 mt/ha in 2000 LULC to 6.71 mt/ha for 2010 LULC with an overall increase of 20.04% due to the change in land use/cover. This is the implication of an increase in overland flow (SURQ) because of the increase of impervious surfaces as a result of urbanization resulting from LULC change which accelerates the erosion process resulting in an increase in sediment yield. This causes a decline in the water quality and increases the price of water treatment for its potable uses.

4. Conclusions

In this study, the impacts of LULC change on discharge and sediment yield of the Bagmati watershed in the Kathmandu valley was explored which have significant religious and socio-cultural importance but is under stress due to rapid increase of urbanization. In order to calibrate and validate the SWAT model, the SUFI-2 algorithm was used in a mothly time step at Khokana station. The model setup, as well as the model calibration and validation runs, were done with readily available datasets and information. Parameters were considered on the basis of different literature reviews, initial global sensitivity analysis result, location & conditions of the study area and their known role in different hydrologic processes. Global sensitivity analysis was performed with 2000 iterations to finalized the parameters for the model. The Manning's roughness coefficient for the main channel (CH_N2), soil evaporation compensation factor (ESCO) and saturated hydraulic conductivity (SOL-K) were the three most sensitive parameters influencing the discharge. Similarly, linear (SPCON) & exponent parameter (SPEXP) for calculating the maximum amount of sediment that can be re-entrained during channel sediment routing followed by channel erodability factor (CH-ERODMO) were the three most sensitive parameters influencing the sediment yield.

The statistical parameters for both calibration and validation of Discharge and Sediment flow shows the reasonable results for the parameters selected for the analysis. For both calibration and validation all the statistical parameters shows the accuracy of above

Table 6: Estimated discharge and sediment yield for different land use classes

Component	Land use		% Change
	2000	2010	
Surface runoff contribution to stream flow SURQ (mm/year)	171.39	188.2	9.81
Lateral flow contribution to stream flow LATQ (mm/year)	399.27	375.77	-5.89
Ground water contribution to stream flow GWQ (mm/year)	212.21	199.9	-5.80
Sediment yield (mt/ha/year)	5.59	6.71	20.04

70%. The performance rating during calibration period for discharge is very good and that for sediment flow is good. Similarly, the performance rating during validation period for both discharge and sediment flow is good [29]. Overall, the model shows good agreement between observed and simulated discharge & sediment values.

The LULC change analysis shows the rapid rate of urbanization in the Kathmandu valley with increase of 40.80 sq.km (6.65%) from 2000 A.D to 2010 A.D. All the other landuse classes shows the decreasing trend specially agricultural area. This trend of conversion of landuse from agricultural & forest areas to built-up areas results in increasing impervious surfaces due to urban physical infrastructures like roads & buildings resulting in decreasing lateral flow (-5.89%) and ground water flows (-5.8%) and increasing surface flows (+9.81%). The increase of impervious surfaces due to rapid rate of urbanization have been causing serious problems in the groundwater flows. The insufficient water supply in the KV, reduction of recharge areas and the dependence to groundwater for drinking water will further accelerates the depletion of groundwater table. Conversion of agricultural fields to barren housing plots and increase in surface flow will also aids the erosion process resulting the increase in sediment yield which is further proved by our model simulation result with increase of 20.04% sediment yield in the study period.

In the future the pressure for land use change seems to grow more rapidly in the Kathmandu valley. So the evaluation of it's impact and implementation of sustainable land & water management practices are recommended and should be integrated in the decision making.

Future scope of the study is to incorporate LULC change scenarios and projected climate data for future dynamics of water balance components.

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