INTEGRATED HYDROLOGICAL MODELING OF PARAMBIKULAM-ALIYAR SUB BASIN, TAMIL NADU

R. VINOTHKUMAR, I. MUTHUCHAMY

Abstract: Assessment of c1imate change is recognized as one of the most serious challenges facing mankind today. It is known to be a direct threat to our food and water supplies and an indirect threat to world security. The objective of this research paper is, evaluating the impacts of climate change on streamflow in Parambikulam-Aliyar sub basin, Tamil Nadu. The Soil and Water Assessment Tool (SWAT) was selected for the estimation of streamflow in a basin. The results show that the most sensitive parameters were the Manning's 'n' value for overland and channel flow and effective hydraulic conductivity of the channel, which affect the catchment hydrology. The model calibration and validation were performed on a monthly basis, and the streamflow simulation showed a good level of accuracy for both periods. The results of model calibration and validation were obtained R^2 and Nash-Sutcliffe Efficiency values for each period were respectively 0.97 and 0.91 for 2004-2007, 0.98 and 0.98 for the period 2008-2010. The evaluation of the SWAT model response that the mean monthly flow, during the rainy seasons for 2004-2007, decreased when compared to 2008-2010.

Keywords: Calibration, Climate change, GIS, Remote Sensing, Streamflow, SWAT Model.

Introduction: Climate changes occur due to the abuse of natural resources along with release of carbon dioxide, other greenhouse gases into the atmosphere beyond the critical limits, consequently affecting the hydrological regimes causing a serious impact on the food and water security of the world. International efforts to combat climate change have played a key role in the development of the United Nations Framework Convention on Climate Change (UNFCCC) and Kyoto Protocol. Intergovernmental Panel on Climate Change (IPCC) has predicted that many parts of the world will be warmer due to climate change and most of the plants and animals will become extinct. It is believed that south Asia would be much more affected by the impact of climate change. Fifth Assessment Report of the Inter-governmental Panel on Climate Change (IPCC 2013) reported that, Climate changes will have an adverse effect on the hydrological cycle affecting both ground and surface water resources, causing drastic changes in the total amount of precipitation, its frequency and intensity. The spatial change in amount, intensity and frequency of the precipitation will affect the magnitude and frequency of stream flows; consequently, it increases the intensity of floods and droughts, with substantial impacts on the water resources at local and regional levels. These changes, when they are on the surplus side may affect the magnitude and timing of runoff, but shall create water scarcity and drought like situations when these are on the deficit side. The demands are created by increasing human population, change in agricultural practices and rapid industrialization. Decline of agricultural productivity is predicted with rainfed small and marginal farmers being most vulnerable (Agarwal, 2008).

Studies about the influence of climate and land-use change on streamflow at the basin scale have been reported by several authors (e.g. Kundzewicz *et al.* 2008, Montenegro and Ragab 2012, Braga *et al.* 2013, Silva *et al.* 2013). Previous studies on the hydrological response to climate change in basins in north western region drew attention to the risk of worsening water availability and the impact on the hydrology and social aspects in the region. We have examined this need for more sophisticated modelling procedures in the context of climate change to expose the strengths and weaknesses of linking global and regional climate models to a runoff model to calculate the discharge consistent with a future climate scenario. Thus, this study aims to assess the impact of climate change on the streamflow through GIS and remote sensing techniques coupled with the SWAT model.

Predictions of long-term impacts of climate change on streamflow are important to study different environmental conditions. Analysis of hydrological responses to climate change in a basin can be performed by combining a calibrated basin-scale model with historical data or future scenarios.

Materials and Methods :

i. Study area: Parambikulam-Aliyar basin is located in the south western part of the Peninsular India covering areas in Kerala and Tamil Nadu States. This basin area lies within the coordinates of North latitude between 10° 18'22" to 10°42'59" and East longitudes 76°48'37" to 77°8'7". The basin is drained by eight west flowing rivers viz. Valaiyar, Koduvadiaru, Uppar, Aliyar and Palar (tributaries of Bharathapuzha river) and Parambikulam, Solaiyar and Nirar (tributaries of Chalakudi river). The Aliyar River has its source in the Anamalai Hills. It flows in a north-westerly direction for about 37 kms in Tamil Nadu and enters into Kerala and finally confluence in

Bharathapuzha. Aliyar reservoir is one among the main components in PAP with a surface area of 6.50 km^2 and is formed in the plains across the river with a gross storage capacity of 109.42 mcm. The catchment area of the Aliyar dam is 196.83 km^2. Apart from its own catchment, water can be diverted to this reservoir through the Aliyar Feeder canal and the Contour canal from the Parambikulam group of reservoirs. Total area of sub basin is 574.75 km^2 and command area is 20,536 ha covering Pollachi (North), Pollachi (South) and Anamalai blocks of Coimbatore district. Crops grown in this sub basin area are coconut, sugarcane, banana, sapota, mango, fodder, besides annual crops such as paddy, groundnut, cotton, vegetables, pulses, fodder, tomato, gaurds, Maize as I crop, and Paddy and Groundnut as II crop.

Aliyar sub basin was chosen as the study area in this research, since the management of water resources in this basin has great importance in terms of a wider range of water uses as well as downstream user requirements and environmental flows. Thus, this study aims to assess the impact of climate change on the streamflow in Parambikulam-Aliyar Sub basin (Figure 1).

ii. Data collection and analysis: Data collection and pre-processing are key elements for a good representation of the hydrological processes in a watershed.

ii. a)Hydro- Meteorological data: Monthly rainfall data of eight rain-gauge (Figure 1) stations in the Aliyar sub basin for the period of 31 years (1982-2012) had been collected from the office of State Surface & Ground Water Data Centre, Public works Department, Chennai, Tamil Nadu. Daily inflow and outflow at Aliyar dam from 1982 to 2012 were obtained from the Public Works Department (PWD), Aliyar Dam, Pollachi, Tamil Nadu state and it used for SWAT model calibration and validation.

iii. Hydrological modelling

Many basin-scale hydrologic and water quality models have been developed in recent years (Yan *et al*. 2013). The Soil and Water Assessment Tool (SWAT) is a comprehensive, semi-distributed river basin model that requires a large number of input parameters, which complicates the model parameterization and calibration. The SWAT is one of the most suitable models for simulating streamflow under land use and management scenarios (Behera and Panda 2006). A great number of SWAT applications have been used to study hydrology in small or large catchments in different regions of the world. It is a physically-based, distributed, continuous daily time step parameter model designed to predict the impact of land management practices on water, sediment and agricultural chemical yields in large and complex watersheds with varying soil, land use and management conditions over long periods of time. SWAT can be used to analyse small or large catchments by discretizing them into sub-basins, which are then further subdivided into hydrological response units (HRUs) each having homogeneous land use, soil types and slopes. The SWAT system embedded within GIS can integrate various spatial environmental data, including information about soil, land cover, climate and topographical features. Several calibration techniques have been developed for SWAT, including manual calibration procedures and automated procedures using the shuffled complex evolution method and other common methods.

iv. Evaluation of SWAT model

iv. a)Stream flow: SWAT model was calibrated and validated for stream flow at Aliyar reservoir of Aliyar sub basin based on the datasets received from the Public Works Department (PWD) for a period between 2004-2010. The first 4 years of observed data were used for calibration (2004 to 2007) and the rest of the 3 years (2008 to 2010)data was utilized for validation. The monthly statistical measures explained by Moriasi *et al.* (2007) were used in this study to calibrate and verify the model for stream flow including Percent BIAS (PBIAS), Coefficient of determination (R^2) and Nash-Sutcliffe Efficiency (NSE).

1. Percent BIAS (PBIAS) was calculated as

$$\text{PBIAS} = \left[\frac{\sum_{t=1}^{T}(f_t - y_t)}{\sum_{t=1}^{T}(y_t)}\right] \times 100 \text{ ---- (3.11)}$$

where f_t is the model simulated value at time t, and y_t is the observed data value at time t (t = 1, 2,..., T). PBIAS measures the average tendency of simulated data to be larger or smaller than the observed counterparts (Gupta *et al*., 1999). PBIAS values with small magnitude are preferred. Positive values indicate model overestimation bias, and negative values indicate underestimation model bias (Gupta *et al*., 1999).

2.Nash-Sutcliffe Efficiency (NSE) was calculated as follows

$$NSE = 1.0 - \sum_{t=1}^{T}\frac{(y_t - f_t)^2}{\sum_{t=1}^{T}(y_t - \bar{y})^2} \quad \text{---- (3.12)}$$

Where $y_t$is the observed data values for time period t, $f_t$is the simulated data values for the same period, $\bar{y}$ is the mean observed data values per time period, and T is the number of time periods. NSE indicates how well the plot of observed versus simulated values fits the 1:1 line. It ranges from - ∞ to 1 (Nash and Sutcliffe, 1970). The maximum NSE value possible is 1.0 and occurs if simulated values perfectly match observed values. The lower the NSE value, the lesser the goodness of fit between the simulated and observed time series. The larger NSE values denote better model performance.

3. Coefficient of determination (R^2) was calculated as follows

$$R^2 = \left\{\frac{\sum_{t=1}^{T}(y_t-\bar{y})(f_t-\bar{f})}{\left[\sum_{t=1}^{T}(y_t-\bar{y})^2\right]^{0.5}\left[\sum_{t=1}^{T}(f_t-\bar{f})^2\right]^{0.5}}\right\}^2 \text{ ---- (3.13)}$$

Where $\bar{y}$ is the mean of observed values for the entire evaluation time period and $\bar{f}$ is the mean of simulated values for the entire evaluation time period. The other symbols have the same meanings as defined in the preceding equation. The R^2 value is equal to the square of Pearson's product-moment correlation coefficient (Legates and McCabe, 1999). It represents the proportion of total variance in the observed data and R^2 ranges from 0.0 to 1.0. Higher values equate to better model performance.

Results and Discussion :

3.1 Calibration and validation of SWAT for Aliyar Dam: To analyse the impact of climate change on the hydrology over 31 years, SWAT was used to simulate the scenarios 2004-2007 and 2008-2010. The SWAT receives daily input data, but operates with daily and monthly output intervals. In this study, the monthly output intervals were used to better graphically represent the results. The consistency of the simulated and measured values is clear. The monthly calibration and validation efficiencies have been tested by the statistical measures such as Percent BIAS (PBIAS), Nash Sutcliff efficiency and coefficient of determination (R^2). Comparison between observed and SWAT simulated average monthly stream flow at different gauge stations in the Aliyar sub basin (Table 1) revealed that the simulated stream flow matches well with the observed values. Comparison between observed and simulated average monthly stream flow is presented in (Figure 2). The R^2 value is more than 0.90 during calibration and validation period for all the stream gauge stations which indicated good agreement between observed and simulated flows. Percent BIAS (PBIAS) values for monthly stream flow during calibration and validation periods were found to be between 0.93 to 7.67 %. This indicates that the SWAT model could be well used to predict the average monthly values of stream flowand the model simulation is good as the PBIAS is < ±20 per cent. Nash Sutcliffe Efficiency (NSE) gave very high values during the simulation period under calibration and validation (0.91 to 0.98) for the two control points indicating the good predictability of stream flow by the SWAT model. The coefficients of determination (R^2) values are also very high (0.97 to 0.98) showing very close similarity between simulated and observed stream flow. The statistical measures (NSE, R^2) for monthly stream flow are above 90 per cent indicating very high predictability of the model. The values of NSE, PBIAS, and R^2 statistics are well within the range limits as suggested by Moriasi *et al.* (2007).

4. Conclusions: The climate change impact assessment on hydrological characteristics can be best handled through the simulation of the prevailing hydrological conditions in the selected area with the help of SWAT (Soil and Water Assessment Tool) model. The SWAT model is used to perform basin simulation and project stream flow at the gauging station. Use of GIS and remotely sensed data were found to be helpful to detect and analyse spatio-temporal changes in a basin.A SWAT model for the Parambikulam-Aliyar sub basin was calibrated and validated for streamflow analysis. Based on the results obtained, the coefficient of determination (R^2) for the monthly streamflow was obtained as 0.97 for the calibration period and 0.98 for the validation period. The Nash Sutcliff efficiency (NSE) value in estimating the monthly streamflow during calibration period was computed as 0.91 and 0.98 for the validation period. The values of R^2 can be considered reasonably satisfactory for estimating streamflow from a remote watershed with scarce data.

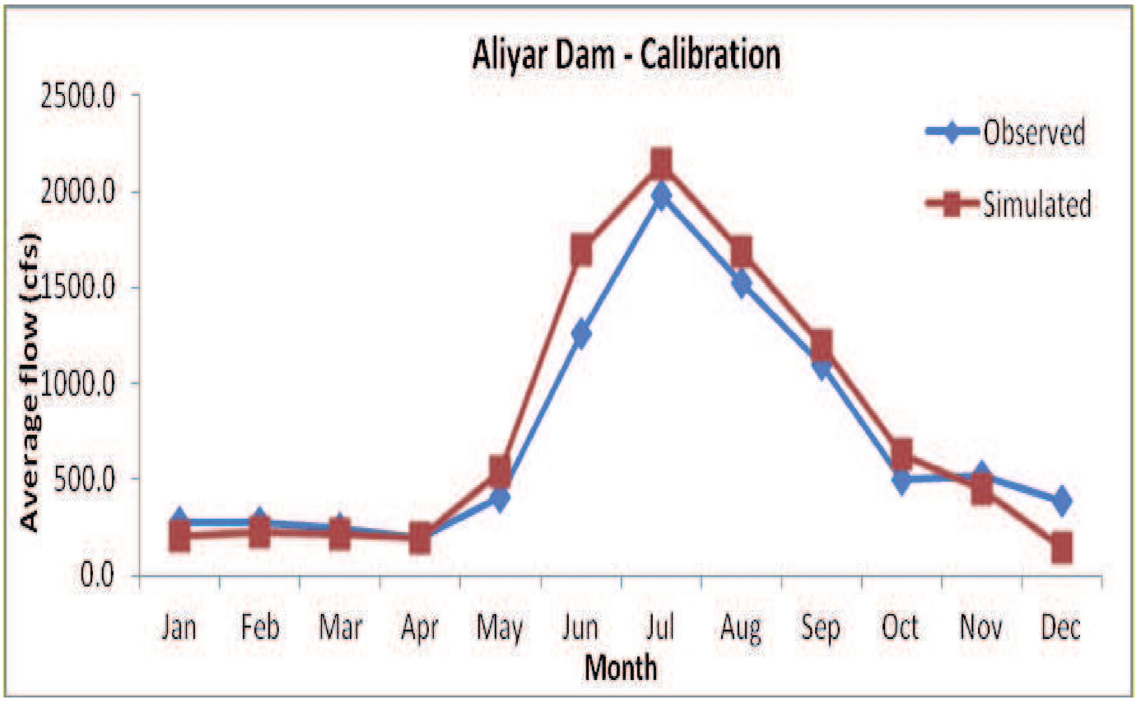
References:

1. 1. Agarwal. 2008. Dealing with climate change. LEISA INDIA.
2. Behera, S., Panda, R.K. 2006. Evaluation of management alternatives for an agricultural watershed in a sub-humid subtropical region using a physical process based model. Agriculture, Ecosystems & Environment 113(1–4), 62–72.
3. Braga, A.C.F.M., Silva, R.M., Santos, C.A.G., Galvao, C.O., Nobre, P. 2013. Downscaling of a global climate model for estimation of runoff, sediment yield and dam storage: A case study of Pirapama basin, Brazil. Journal of Hydrology 498(1), 46–58.
4. Gupta, H.V., Sorooshian., S. Yapo, P.O. 1999. Status of automatic calibration for hydrologic models: Comparison with multilevel expert calibration. Journal of Hydrologic Engineering 4(2), 135-143.
5. *Sayantikar, indrajit Ghosh, Shreyasi Mondal, Kamalika Chakraborty, Tania Bhattacherjee, Amitava Ghosh, Pritam Aitch,Gupinath Bhandari,* Effect of Domestic Effluent in River Ganga, West Bengal on The Morphological and Biochemical Parameters of Mung Bean (Vigna Radiate) ; Life Sciences International Research Journal , ISSN 2347-8691, Volume 3 Issue 2 (2016): Pg 94-97
6. IPCC (Intergovernmental Panel for Climate Change). 2013. The Physical Science Basis. Working group I Contribution to the Fifth Assessment Report of the Intergovernmental

Panel on Climate Change. Cambridge University Press, Cambridge, UK.
7. Kundzewicz, Z.W., Mata, L.J., Arnell, N.W., Doll, P., Jimenez, B., Miller, K., Oki, T., Sen, Z., Shiklomanov, I. 2008. The implications of projected climate change for freshwater resources and their management. Hydrological Sciences Journal 53(1), 3–10.
8. *Uma Aulwar, Awasthi R.S,* Role of Biosurfactant in Bioremediation ; Life Sciences international Research Journal , ISSN 2347-8691, Volume 2 Issue 1 (2015), Pg 130-134
9. Legates, D.R., McCabe, G.J. 1999. Evaluating the use of"goodness-of-fit" measures in hydrologic and hydroclimatic model validation. Water Resource Research 35(1): 233–241.
10. Montenegro, S. M. G. L.,Ragab, R. 2012. Impact of possible climate and land use changes in the semi-arid regions: A case study from North Eastern Brazil. Journal of Hydrology 434(1), 55–68.
11. Moriasi, D.N., Arnold, J.G., Van liew, M.W., Bingner,R. L., Harmel, R.D., Veith,T. L. 2007. Model evaluation guidelines for systematic quantification of accuracy in watershed simulations. American Society of Agricultural and Biological Engineers, 50(3): 885–900.
12. *Shweta Sharma ,* Street Food: A Solution for Urban Food Security; Life Sciences International Research Journal , ISSN 2347-8691, Volume 2 Issue 2 (2015): Pg 107-111
13. Nash, J.E., Sutcliffe, J.V. 1970. River flow forecasting through conceptual models: Part 1. A discussion of principles. Journal of Hydrology 10(3): 282-290.
14. Silva, R.M., Santos, C.A.G., Silva, V.C.L., Silva, L.P., 2013. Erosivity, surface runoff, and soil erosion estimation using GIS-coupled runoff-erosion model in the Mamuaba catchment, Brazil. Environmental Monitoring and Assessment 185(65), 8656–8676.
15. Yan, B., Fang, N.F., Zhang, P.C., Shi, Z.H. 2013. Impacts of land use change on watershed streamflow and sediment yield: an assessment using hydrologic modelling and partial least squares regression. Journal of Hydrology 484(1), 26–37.

Table 1. Observed and SWAT simulated average monthly stream flow at different gauging stations of Aliyar sub basin during calibration (2004-2007) and validation (2008-2010)

Reservoir	Average stream flow (cfs)		PBIAS (%)	NSE	R^2
Calibration	**Observed**	**Simulated**			
Aliyar dam	720.43	775.68	7.67	0.91	0.97
Validation	**Observed**	**Simulated**			
Aliyar dam	579.17	584.58	0.93	0.98	0.98



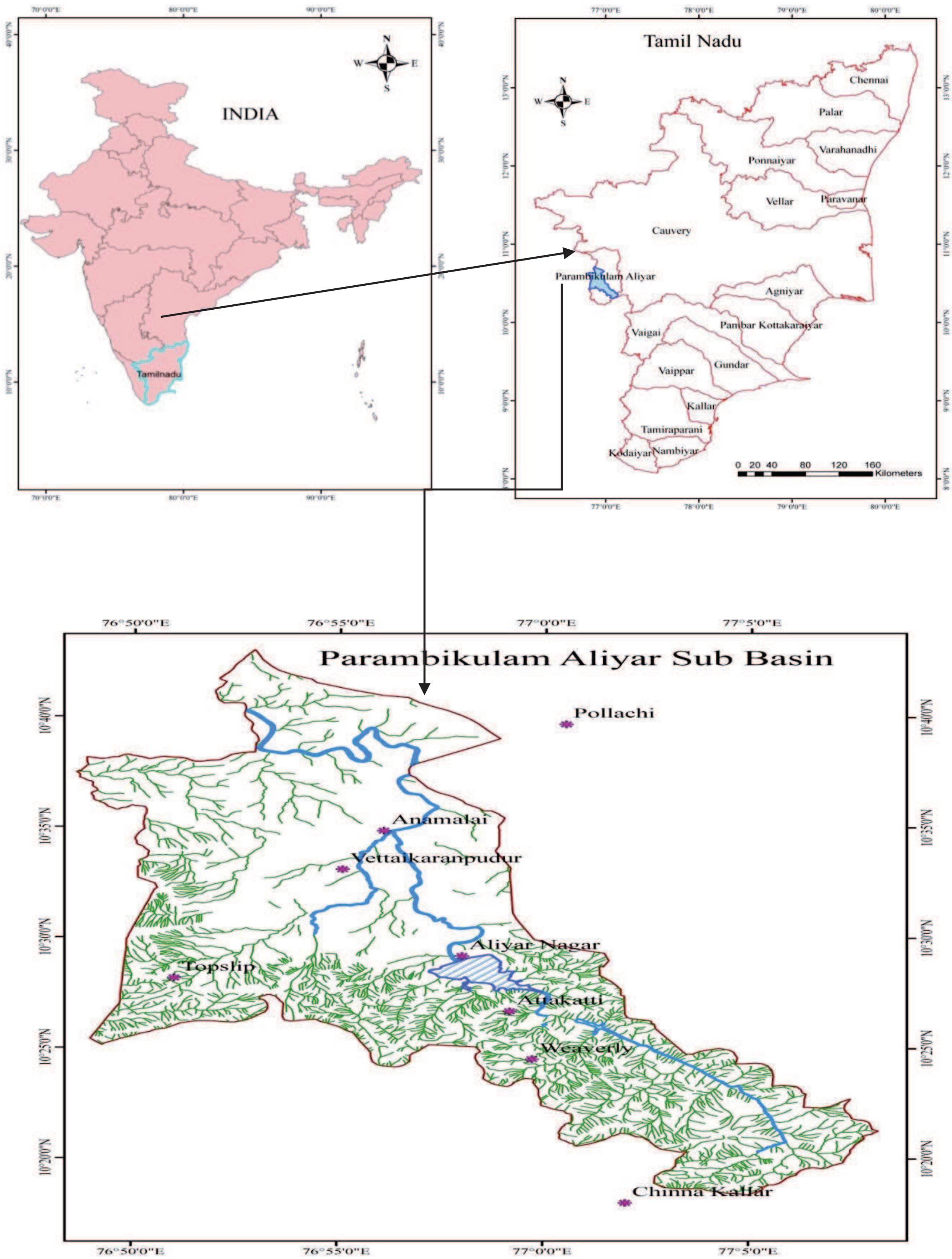

INDIA
Tamilnadu
Tamil Nadu
Chennai
Palar
Varahanadhi
Ponnaiyar
Vellar
Paravanar
Cauvery
Parambikulam Aliyar
Agniyar
Pambar Kottakaraiyar
Vaigai
Gundar
Vaippar
Kallar
Tamiraparani
Kodaiyar
Nambiyar
0 20 40 80 120 160 Kilometers
Parambikulam Aliyar Sub Basin
Pollachi
Anamalai
Vettaikaranpudur
Aliyar Nagar
Topslip
Attakatti
Weaverly
Chinna Kallar
76°50'0"E
76°55'0"E
77°0'0"E
77°5'0"E
10°40'0"N
10°35'0"N
10°30'0"N
10°25'0"N
10°20'0"N

Figure 1.Location map of study area

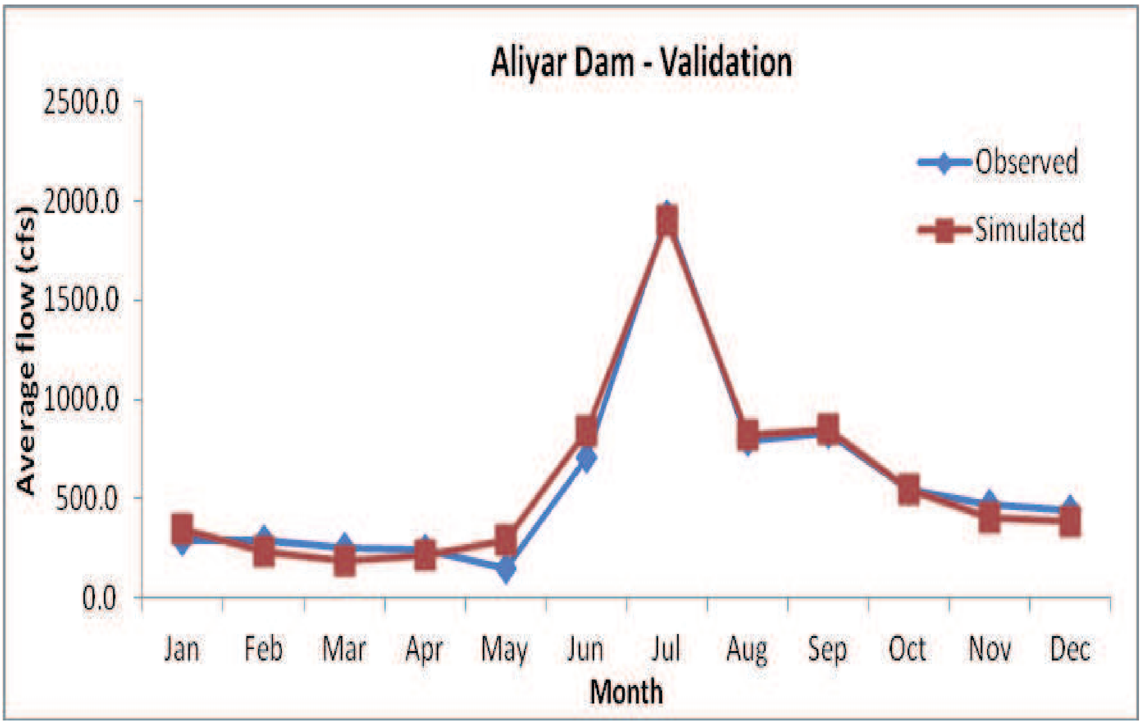


Figure 2.Comparison of observed and simulated average monthly stream flow over calibration (2004-2007) and validation (2008-2010) time periods

R. Vinothkumar, I. Muthuchamy
Department of Soil & Water Conservation Engineering, Tamil Nadu Agricultural University, Tamil Nadu