ADEQUACY OF IHACRES MODEL ON STREAMFLOW RESULTING FROM LANDUSE CHANGES IN A MAURITIUS CATCHMENT

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ABSTRACT

Land use and land cover (LULC) play an important role in the catchment hydrology, regulating the transfer of water within the system. Mauritius is a tropical island of volcanic origin in the Indian Ocean which has been subjected to a considerable industrialization in the last two decades, seriously altering its LULC patterns. In this study, the authors have tried to assess the change in the hydrological regime such as surface runoff of a catchment in Mauritius with respect to the land cover changes. The IHACRES (***I***dentification of unit ***H****ydrographs* ***A****nd* ***C****omponent flows from* ***R****ainfall,* ***E****vaporation and* ***S****treamflow data)* model has been used to analyze the different scenarios associated with the catchment. Moreover, the observed and simulated runoff values over a period of 10 years are compared. Simulation results lead us to conclude that land use change have a major impact on the volume of streamflow. It has been observed that due to reduction of vegetation area the streamflow volume has nearly doubled for a time interval of one decade.

Keywords: Land use, Discharge, IHACRES, Catchment, Hydrological regime

1. INTRODUCTION

For water resources to be successfully managed, a qualitative analysis of the effect of land use practice and changes in climate conditions of an area on stream flow and water quality is essential. To study the sustainability of water resources vis-a-vis the planning and development of the region, understanding of the consequences of changes in land use and land cover scenarios is a must. The development of new patterns of land use and land cover conditions can be enhanced by careful planning for the well-being of people.

The effects of land use change on streamflow are easily overshadowed by climate variability because of the impacts of land use change can be comparatively small compared to those of climate variations. Additional factors impeding the separation of land use change impacts from the effects of climate variability on streamflow are: lack of good quality streamflow records prior to the development period of interest; lack of relevant land and water use data such as the changing density and volumes of farm dams and groundwater extractions over time; and uncertainty of simulation models that capture such effects (Letcher et al., 2001; Neal et al., 2002; Schreider et al., 2002). Impacts of land use change can also be hidden by errors in areal rainfall estimates, when those errors are larger than the effects of land use change on streamflow.

Guoqiang Wang et al. (2012) and Huicai Yang et al. (2012) used the SWAT model to assess the impacts of land use changes on runoff generation in headwaters where it was concluded that Long-term land use changes have been shown to have large effects on hydrological processes in river basins. Gary W. Coutu et al. (2007) and Carmen Vega et al. (2007) studied the impacts of land use changes on runoff generation in the east branch of the Brandywine Creek watershed using SWAT model and concluded that a decrease in forest cover areas results in an increase in surface runoff. G. N. Wijesekara et al. (2010) used the MIKE-SHE model to study the impact of land-use changes on the hydrological processes in the Elbow river watershed in southern Alberta. The study demonstrated that an increase in surface runoff and reduced infiltration creating a negative impact on ground water storages in the study area was due to increased urbanization, agricultural activities, and decreased evergreen and deciduous forest areas.

Lørup et al. (1998) and Letcher et al. (2001) used lumped conceptual hydrological models for predicting the effects of land use change on streamflow. They assessed long-term impacts of land use change and distinguished the effects of climate variability and land use change on semiarid catchments using statistical analysis and hydrological modelling, and assuming that their models could account for the influence of climate variability. However, identification of statistical significance and trends in model residuals heavily depends on the quality of the rainfall-runoff model calibration.

In this study, the performance of a conceptual rainfall-runoff model, IHACRES (***H****ydrographs* ***A****nd* ***C****omponent flows from* ***R****ainfall,* ***E****vaporation and* ***S****treamflow data*) is used together with the impact of land use change on streamflow generation in Mauritius. Mauritius is a tropical country in the Indian Ocean which has been subjected to rapid urbanization in the last two decades. IHACRES is a catchment-scale rainfall-streamflow modelling methodology whose purpose is to characterize the dynamic relationship between rainfall and streamflow, using rainfall and temperature (or potential evaporation) data, and to predict streamflow. The model can be applied over a range of spatial and temporal scales - from small experimental catchments to basins; using minute, daily or monthly timesteps.

2. STUDY AREA AND DATA

Mauritius is situated in the Indian Ocean between latitudes 19^{o} 50' S and 20o 30' S, and longitudes 57^{o} 18' E and 57^{o} 46' E. It is of volcanic origin and has a surface area of 1865 km^2. The Island consists of a Central Plateau surrounded by mountain ranges and plains. The Plateau rises to a maximum elevation of about 600 m above the mean se level (msl) in the South of the Island, and has a mean elevation of about 300 - 400 m (msl), the highest peak being 828 m (msl). Mauritius receives an average annual rainfall of 1993 mm, equivalent to a volume of 3700 Mm^3 of water. Most of this rainfall is received in summer, representing about 70 % of average annual rainfall especially during cyclonic season that extend from December to April. Location of Mauritius in the Indian Ocean is shown in Fig. 1.

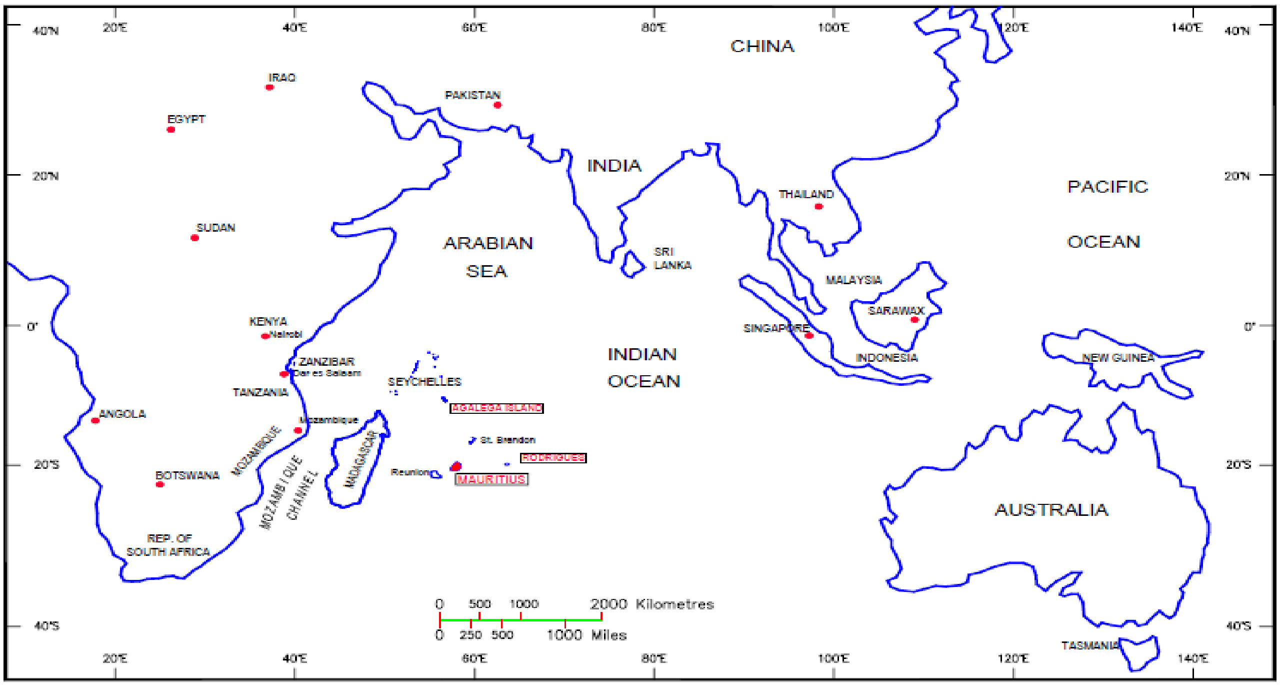

Fig. 1: Location of Mauritius Island in the Indian Ocean

The Plaine Wilhems catchment, highlighted in red in Fig. 2 is considered for this study. This region has an area of 134.64 km^2 and its main stream flows in a north-west direction from a watershed elevation varying from 300-400m above mean sea level. Average annual values for precipitation, streamflow and temperature are 161mm, 0.188m^3/s and 25^{0}C respectively. The annual evaporation has been estimated as 30%, surface runoff as 60 % and the groundwater recharge as 10%. Mauritius, being an island of volcanic origin results in the catchment comprising of superficial alluvium formations, phonolite ancient lava series, Pyroclasts and weathered basaltic flows. According to the FAO - World Reference Base for Soil Resources, there are three types of soil in this catchment Cambisol, Nitisol and Leptosol. Cambisol is a soil with a beginning of soil formation

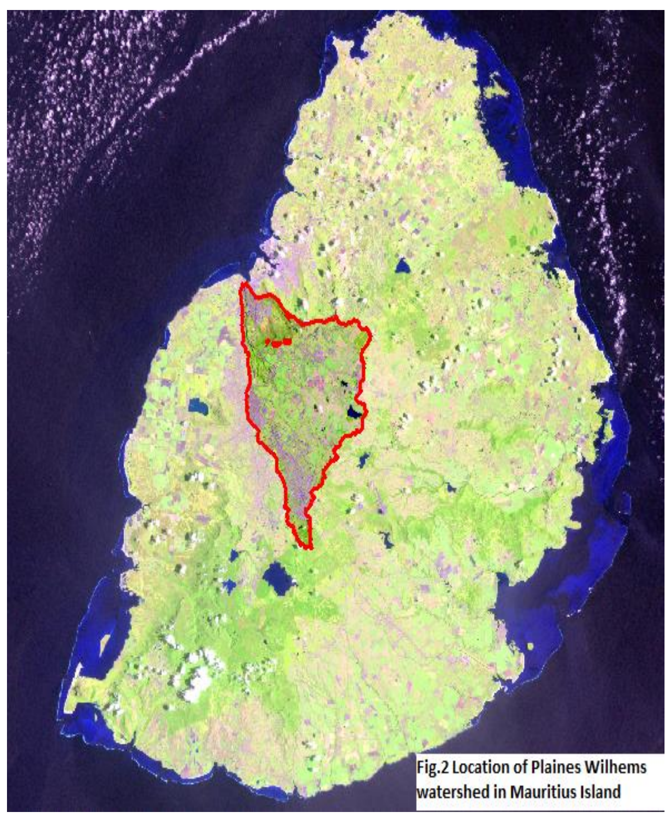

Fig.2 Location of Plaines Wilhems watershed in Mauritius Island

which is weak and mostly of brownish discoloration. Nitisol is a deep, red, well-drained soil with a clay content of more than 30% and a blocky structure.

3. METHODOLOGY

Selection of models depends on the availability of data and issue to be addressed. IHACRES is a hybrid of conceptual- metric hydrologic model that reduces the parameter uncertainty and at the same time internal process is represented in detail since it is a conceptual model. In the IHACRES, minimum data such as daily rainfall, temperature and stream discharge are taken as the input and daily discharge is the output.

To evaluate the performance of rainfall runoff process, the choice of appropriate parameters on calibration data set is essential since it affects the output dramatically. Among objective functions that are added in the IHACRES the Nash- Sutcliffe efficiency indicator is used to assess the model performance given as:

$$R^2 = 1 - \frac{\sum_i (Q_{o,i} - Q_{m,i})^2}{\sum_i (Q_{o,i} - Q_{av})^2} \tag{1}$$

where Q_{av} is the average of observed flow, Q_o the observed flow, Q_m modeled flow and R^2 the Nash- Sutcliffe efficiency indicator. It also calculates other statistical parameters such as the square root (R^2_*sqrt*), logarithm (R^2_*log*) and inverse (R^2_*inv*) of the flow objective functions which are less biased to peak flow, and more to low flows. In the catchments of arid and semi-arid zones, the objective function R^2_*sqrt* is helpful in interpretation of calibration as the occurrence of base flow component is rare in those catchments. Generally, when the value of R^2 is greater than five, it indicates that the performance of the model is acceptable.

Using the Arc GIS software, the percentage of vegetation in the Plaine Wilhems catchment was found to be 65.28% in 2000 and 53.28% in 2010, as illustrated in the Fig.3.

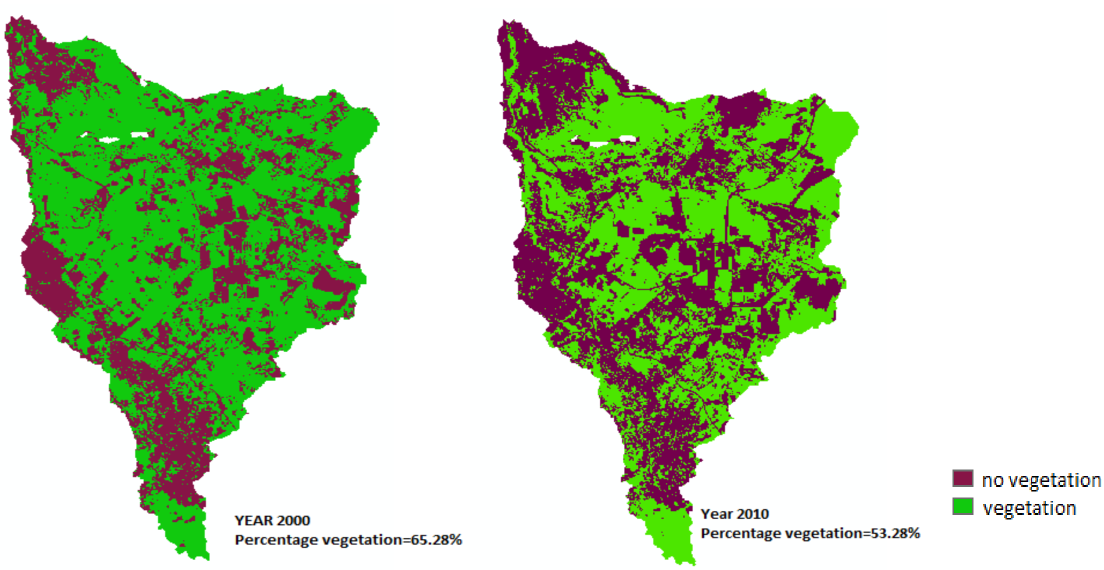

Fig. 3 Map showing the percentage reduction in vegetation area between 2000 and 2010

In this study, daily observed rainfall and streamflow data were obtained from the Water Resources Unit of Mauritius. Historical land-use data were obtained from Landsat-7 and Landsat-8 satellite imagery acquired in the years 2000-2016. Digital Elevation Model files (SRTM 30m) were downloaded from CGIARCSI.

4. MODEL CALIBRATION AND VALIDATION

Daily rainfall, discharge and temperature data from January 1, 2000 to December 31, 2010 were given as the input in the IHACRES model. The simulated streamflow result from the IHACRES model was calibrated over a period from 2003 to 2008. Depending on the cross-correlation function from the IHACRES model and the nature of catchment (highly ephemeral), delay time was adjusted since it improved the model performance. There are five classic module parameters namely, drying rate at reference temperature, temperature dependence of drying rate, reference temperature, moisture threshold for producing flow and power on soil moisture. The values of these parameters are corrected in such a way that better results of R^2, R^2_*sqrt* etc can be obtained after calibration.

5. RESULTS AND DISCUSSION

IHACRES model results, expressed in relation to Nash- Sutcliffe efficiency indicator (R^2) are shown in Fig. 4. An R^2 value of 0.7362 has been obtained which shows the good performance of the IHACRES model. Hence the IHACRES model can be used to simulate streamflow/runoff under different situations and the results can be considered as acceptable.

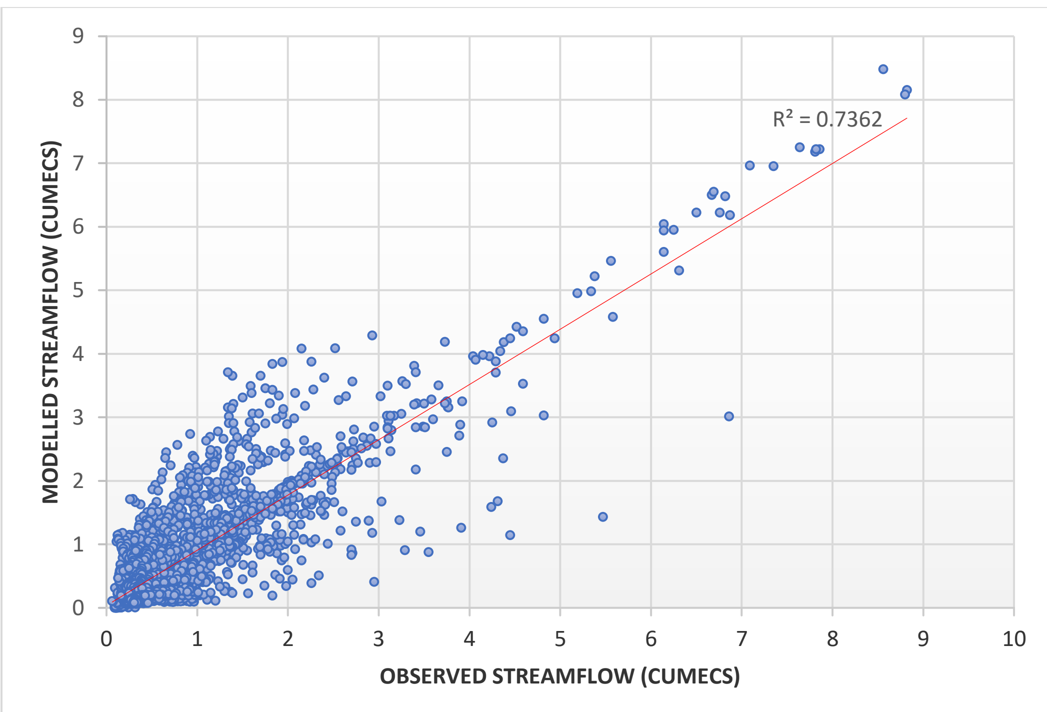

Fig. 4 The plot of observed streamflow against modelled streamflow

In Fig. 5, the observed and modelled streamflow values have been plotted against the number of days, showing the variation of streamflow daily over the time interval of ten years. The graph shows that there is good correlation between the observed and modelled values especially for the peak flows. However, this is not the case at low intensity flows such as for the time interval of 3070 days till 3862 days.

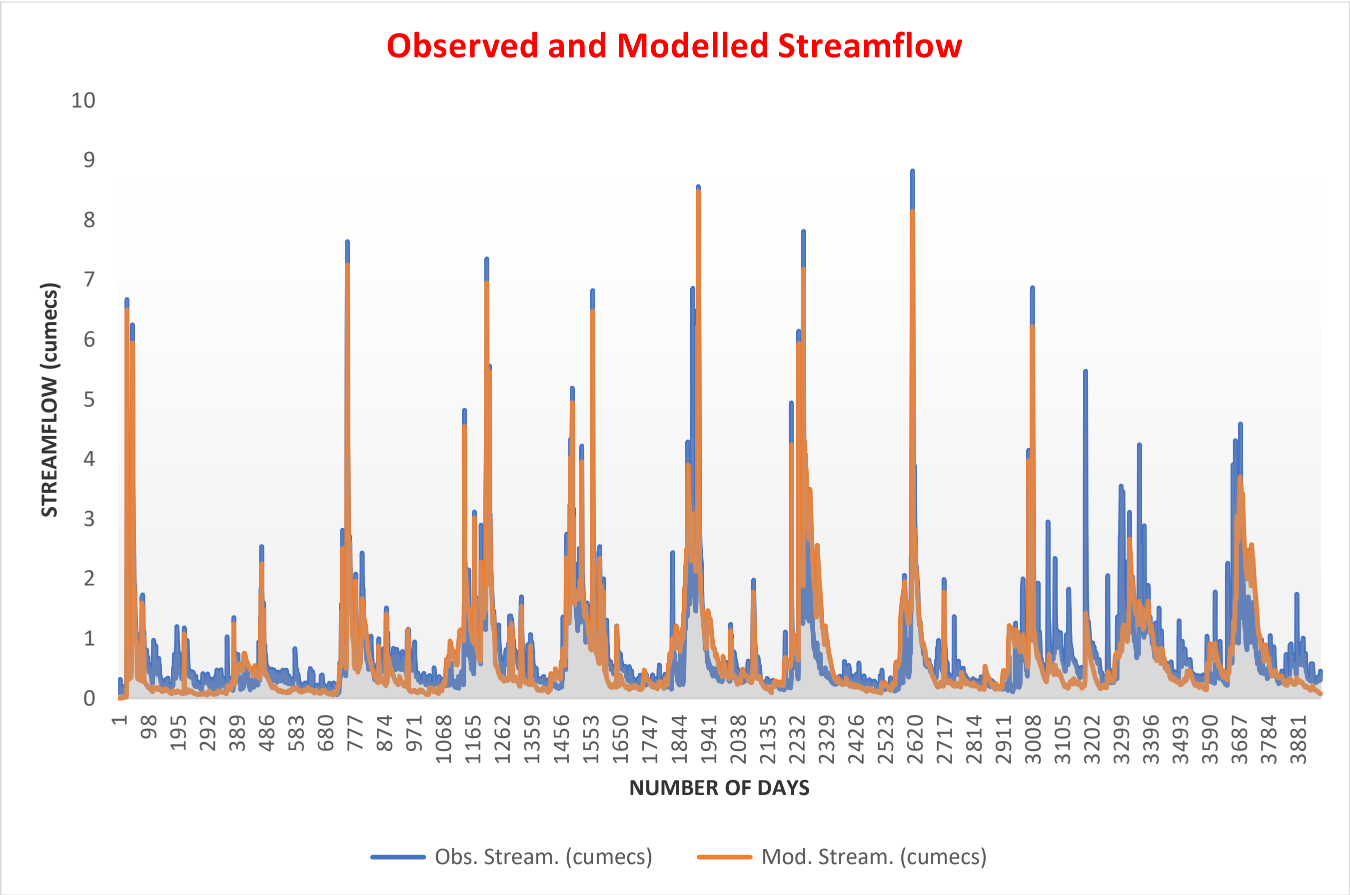

Fig.5 Plot of Observed and Modelled Streamflow against Number of days

Further, the modelled streamflow for year 2000 and year 2010 have been plotted in Fig.6 showing the impact of change in land use on the volume of streamflow generated. Moreover, the detailed month wise values of the observed versus simulated results using IHACRES for the rainy months from January to April for all the ten years from 2000 to 2010 are given in Table 1, showing the impacts of LULC on streamflow.

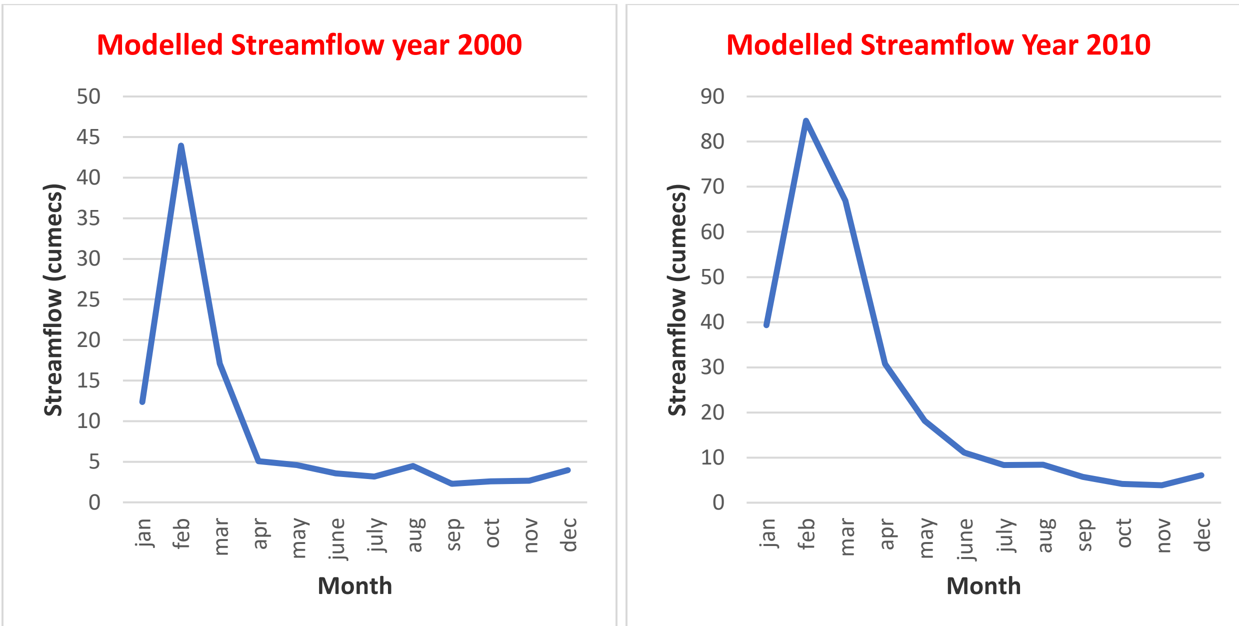

Fig. 6 Graphs showing the variation of modelled streamflow for the years 2000 and 2010.

From the graphs, we can deduce that there has been a 92 percent increase in the peak streamflow over the ten years in comparison to the 2000 base year.

6. CONCLUSIONS

The following important conclusions can be drawn from the present study.

- The Plaines Wilhems Watershed of Mauritius has undergone an urbanization process during the 10-year period. The percentage of vegetation in the watershed has reduced from 65.28% in the year 2000 to 53.28% in 2010.
- This urbanization tendency in the watershed entails significant increases in the production of streamflow. The peak streamflow value was 43.94 cumecs in year 2000 which increases to 84.64 cumecs in 2010. Hence, it can be deduced that a decrease in vegetation cover leads to an increase in streamflow.

- IHACRES has the potential to generate useful information on prediction of stream flow, however, it is important to have longer data set to model the scenarios confidently.
- The study is limited to the non-availability of daily rainfall data over the catchment.

REFERENCES

1. Gary W. Coutu, Carmen Vega (2007), "Impacts of land use changes on runoff generation in the East Branch of the Brandywine Creek Watershed using a GIS-based hydrologic model", *Middle States Geographer Journal, Vol No. 40, pp 142-149, 2007*
2. Eyad Abushandi, Broder Merkel (2010), "Application of IHACRES rainfall-runoff model in semi-arid areas of Jordan", *ResearchGate, Conference Paper-February 2010, DOI: 10.13140/RG.2.1.2356.4241*
3. Rajesh Vijaykumar Kherde (2016), "Rainfall runoff modelling – Modellers Guide", *International Journal of Applied Engineering Research* ISSN 0973-4562 Volume 11, Number 3 (2016) pp 1900-1907
4. G. N. Wijesekaraa, A. Guptab, C. Valeoc, J. G. Hasbanid, D. J. Marceaue (2010), "Impact of land-use changes on the hydrological processes in the Elbow river watershed in southern Alberta", *2010 International Congress on Environmental Modelling and Software Modelling for Environment's Sake, Fifth Biennial Meeting, Ottawa, Canada*. http://scholarsarchive.byu.edu/iemssconference/2010/all/210
5. Gayathri K Devia, Ganasri B Pa, Dwarakish G Sa, "A Review on Hydrological Models", *International Conference On Water Resources, Coastal And Ocean Engineering (Icwrcoe 2015) doi: 10.1016/j.aqpro.2015.02.126*
6. G.S. Dwarakish, B.P. Ganasri (2015), "Impact of land use change on hydrological systems: A review of current modeling approaches", *Cogent Geoscience (2015), 1: 1115691*, http://dx.doi.org/10.1080/23312041.2015.1115691
7. Patra K.C (2015), Hydrology and Water Resources Engineering , Narosa Publishing House, India
8. Keith Beven (2012), Rainfall-Runoff Modelling, John Wiley & Sons, Ltd Publication, UK
9. G. P. Zhang and H. H. G. Savenije (2005), "Rainfall-runoff modelling in a catchment with a complex groundwater flow system: application of the Representative

ElementaryWatershed (REW) approach", *Journal of Hydrology and Earth System Sciences, Vol No. 9, pp 243–261, 2005*

10. Kim, H.S., Croke, B.F.W., Jakeman, A.J, Chiew, F.H.S, "Towards model adequacy for identifying the impacts of climate and land use on catchment hydrology", *18th World IMACS / MODSIM Congress, Cairns, Australia 13-17 July 2009*
11. Hossein Kheirfam, Raoof Mostafazadeh, Seyed Hamid Reza Sadeghi, "Daily Discharge Prediction Using IHACRES Model in Some Watersheds of Golestan Province", *Journal of Watershed Management Research Vol. 4, No. 7, Spring and Summer 2013*
12. B. F. W. Croke, F. Andrews, A. J. Jakeman, S. Cuddy, A. Luddy, "Redesign of the IHACRES rainfall-runoff model", *29th Hydrology and Water Resources Symposium 21–23 February 2005, Canberra*
13. Golmar Golmohammadi, Shiv Prasher, Ali Madani, Ramesh Rudra, "Evaluating Three Hydrological Distributed Watershed Models: MIKE-SHE, APEX, SWAT", *Journal of Hydrology* ***2014****, 1, 20-39; doi:10.3390/hydrology1010020*.
14. Xiaohua Wei, Wenfei Liu, Peicong Zhou, "Quantifying the Relative Contributions of Forest Change and Climatic Variability to Hydrology in Large Watersheds: A Critical Review of Research Methods", *Journal: Water 2013, Vol No.5, pp 728-746; doi:10.3390/w5020728*
15. Alice E. Brown, Thomas A. McMahon, Geoffrey M. Podger, Lu Zhang, "A methodology to predict the impact of changes in forest cover on flow duration curves", *CSIRO Land and Water Science Report 8/06 February 2006*