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Abstract: Model comparison is useful for selecting the best model which is applicable for catchments with particular catchment characteristics. In this study, “abcd” model and two parameter model are compared in three sub watersheds of Kelani basin to select the most suitable model to this particular catchment. The resulted NSE (Nash-Sutcliffe Efficiency) and MRE (Mean Relative Error) values showed that “abcd” model has better model performance compared to two parameter model in these three sub watersheds. When considering the relationships between the model performance and catchment characteristics, the model performance increases with increasing catchment area, catchment slope, forest area percentage and runoff variability. From the water resource investigation, the water shortage period was identified as December to March and the best period for cultivation was identified as June to September and October to November. Recommendation can be given to the institutes to focus on ground water resources as there is a considerable amount of ground-water resources still unused in the Kelani basin.

Keywords: Comparative analysis, model performance, hydrologic models.

1. INTRODUCTION

Hydrologic models are mainly used for predicting the behavior of the catchment and understanding the various hydrological processes as it is essential in water resource planning, management and development processes. There are different types of hydrologic models that evaluate the hydrological response due to the precipitation. Models behave differently according to the type of the model, model structure, mathematical equations used and number of parameters used. As there are various hydrologic models, it is necessary to conduct a comparative analysis to evaluate which model would be more suitable under what circumstances.

Recently, severe inundations were experienced in the downstream low lying region of Kelani River due to the heavy rainfalls in upper basin of the Kelani River. Flood inundation of low lying regions of the Kelani River is a problem identified in this region as there is a high population density. In this study, “abcd” model and two parameter model are tested for the three sub watersheds of Kelani basin; Deraniyagala, Kithulga and Holombuwa. The main objective of this study is to investigate the differences in model performance of these two models and the relationship between the model performance and catchment characteristics; catchment area, coefficient of variation (CV) of monthly runoff, catchment slope and forest area proportion.

1.1. Literature Review

Monthly water balance models have been widely applied for the conservation of rainfall into runoff for the long term forecasting of the water resources distribution. Mainly, monthly water balance models applied in three fields such as reconstruction of the hydrology of the catchments, climatic change impact assessment and evaluation of the seasonal and geographical patterns of water supply and irrigation demand.
Lihua Xiong (1999) described about the commencement of the hydrological models. Researches on monthly water balance models commenced in 1940s by Thornthwaite and that model was subsequently revised by Thornthwaite and Mather in 1955. It is a deterministic two parameter monthly water balance model which used soil moisture capacity ($\theta$) and surplus water remaining fraction ($\lambda$) as the two parameters. Then based on the framework of Thornthwaite model, different monthly water balance models were developed. In 1965, Palmer proposed a two layer soil moisture storage model based on a meteorological drought index. This model was developed with the assumption of that the soil moisture in lower layer cannot move to upper layer until all the available soil moisture in the upper layer has been exhausted. In 1973, Pitman developed a monthly water balance model with twelve parameters. Based on Thornthwaite’s conceptual framework, Thomas proposed a four parameter “abed” water balance model. In the 1990s, additional monthly water balance models were developed to study the impact of climate change on hydrological balance. According to Peng Bai (2015), then Belgium model, GR2M model, MWB-6 model, Xiong model and DWBM model were developed. Besides the conceptual MWBMs, the artificial intelligence models showed better performances than conceptual water balance models. But due to the lack of explanation capability, over parameterization and over fitting, the artificial intelligence models also have been criticized.

As there is large number of rainfall runoff models, it is necessary to provide scientific guidance on the application of hydrological models to select a suitable model for specific hydrological practice. Several model comparisons had conducted with flood forecasting models, snowmelt runoff models, daily lumped rainfall runoff models and distributed hydrological models. These models mainly focus on the hourly and daily hydrological models. According to Peng Bai (2015), Vandewiele and Xu (1992) compared monthly water balance models in 79 catchments for the comparison of monthly hydrological models and found that new proposed models have better performances than existing models. Makhlouf and Michel compared a two parameter monthly water balance model with four widely used models and concluded that the two parameter model has a better performance than the four models. Jianget al. applied six MWBMs in a humid catchment of China and found that all the models have similar performance in spite of a wide range of model complexity.

Twelve monthly water balance models were compared by Peng Bai (2015) in 153 catchments with different climatic conditions in China. They found that the most important factor impacting model performance is climatic characteristics of a catchment. The models have better performance in wet catchments than in dry catchments. They analyzed the model performances among different models with different model complexity and model structure and concluded that increasing the model complexity does not guarantee a better model performance as simple models can achieve comparable or even better performance than complex models.

According to Fapeng Li (2014), runoff predictions in ungauged catchments in southeast Tibetan Plateau were done for two rainfall runoff models (SIMHYD and GR4J) which have nine parameters and four parameters respectively. The NSE values obtained from SIMHYD, SNOW model increase with increase in precipitation, runoff coefficient and slope of flow duration curve. But it showed a decreasing trend with increase in aridity index, precipitation elasticity and base flow index. That suggested that the regionalization results tend to become better in wet catchments with higher runoff coefficient than in dry catchments with lower runoff coefficient. The NSE didn’t show any patterns with increase in forest proportion and high mountain soil proportion.

According to Rita Ley, 12 model structures were applied to 99 catchments in Germany. The results indicated that for some catchments many structures perform equally well, whereas for other catchments a single structure clearly outperforms the others.

2. MATERIALS AND METHODS

2.1. Study area

The Kelani basin originates from Sri Pada Mountain Range which flows through the districts of Nuwara Eliya, Rathnapura, Kegalle, Gampaha and Colombo. It has a length of 145 kilometre and ranks as the fourth longest river in the country. The selected watersheds of this study are located in the wet climatic zone of Sri Lanka.
Deraniyagala, Kithulgala, Holombuwa watersheds are the sub watersheds of Kelani basin which are about 208km², 472 km², 131km² in size respectively (Figure 1).

![Figure 1 Study Sites, Outlet Locations of the Studied Catchment](image)

2.2. Data sets

The stream flow data from 2006 to 2015 for Deraniyagala, Kithulgala and Holombuwa outlet locations were obtained from the Irrigation Department. The rainfall data from 2006 to 2015 for Laxapana, Wewattalawa, Dunedin and Annfield rainfall stations were obtained from the Meteorological Department. The evaporation data, minimum and maximum temperature data from 2006 to 2015 were also collected from the Meteorological Department.

2.3. Methodology

First, a literature review was done based on the past researches for the identified problem. Then the basin and the two models were selected to develop the model. The data that are required for the two models were collected, checked and filled the missing gaps using single mass curve. Then the two models were developed and applied the data for calibration. After that, the model was validated and compared the model performance of the two models. Also, the relationship between model performance and catchment characteristics and the applicability in water resource management were analyzed.

2.4. Model descriptions

The “abcd” model is a lumped, physics based and non-linear watershed model which inputs precipitation and potential evapotranspiration and outputs stream flow. Direct runoff, ground water outflow, soil moisture storage, ground water storage and actual evapotranspiration also represent in this model. According to Hadi Salim Al-Laffa (2013), the “abcd” model has four parameters a, b, c and d. The parameter “a” (0<=a<=1) is the propensity of runoff and recharge that occurs when the soils are under saturated. The parameter “b” (b>0) is the upper limit on the sum of soil moisture storage and actual evapotranspiration in a given month. The parameter “c” (0<c<1) is the ratio of the groundwater recharge to surface runoff. The parameter “d” (0<d<1) is the reciprocal of the average ground water residence time.

The two parameter model is a simple model which consists of two parameters; c and SC. Ground water component is not included in this model compared to the “abcd” model. Lihua Xiong (1999)
concluded that the proposed two parameter monthly water balance model is quite efficient in simulating the monthly runoff with the simple structure and two parameters. Also he concluded that this model can easily and efficiently be incorporated in the water resources planning program and the climate impact studies to simulate monthly runoff conditions in the humid and semi-humid regions.

Al-Lafta (2013) and Xiong (1999) deeply illustrated the model structure and model equations of these two models. From that, the main characteristics of these two models are summarized in Table 1. The model complexity increment of these two models with the increment of no. of parameters, no. of storage components and no. of runoff components is clearly depicted here.

Table 1 Main characteristics of the model structure of the two models

<table>
<thead>
<tr>
<th>Model</th>
<th>No. of parameters</th>
<th>No. of storages</th>
<th>No. of runoff components</th>
</tr>
</thead>
<tbody>
<tr>
<td>“abcd”</td>
<td>4</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Two parameter</td>
<td>2</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>

2.5. Model calibration, validation and assessment

Data of each catchment is split into two sub periods; five years and four years for model calibration and validation respectively. In general, Pearson correlation coefficient is used for model optimization. This coefficient measures the strength between variables and relationships. The Nash-Sutcliffe Efficiency (NSE) and Mean Relative Error (MRE) are the two objective functions that used for the model assessment criteria considering the high flow conditions and low flow conditions.

\[
\text{NSE} = 1 - \frac{\sum (Q_{\text{obs}} - Q_{\text{sim}})^2}{\sum (Q_{\text{obs}} - \bar{Q}_{\text{obs}})^2} \tag{1}
\]

\[
\text{MRE} = \frac{1}{n} \sum \left| \frac{Q_{\text{obs}} - Q_{\text{sim}}}{Q_{\text{obs}}} \right| \tag{2}
\]

Where \(Q_{\text{obs}}, Q_{\text{sim}}\) and \(\bar{Q}_{\text{obs}}\) are the observed runoff, simulated runoff and arithmetic mean of observed runoff. \(i\) is the \(i^{th}\) sample and \(n\) is the number of samples.

Esse(2013) have shown that the catchment characteristics strongly affect the model performance. The “abcd” model and two parameter model were compared according to different basis such as catchment area, forest area proportion, catchment slope and coefficient of variation (CV) of monthly runoff series. Peng Bai (2015) illustrated about CV as described below. ‘The CV represents the runoff variability which is defined as the ratio of the standard deviation \(\sigma\) to the mean \(\mu\); \(CV = \sigma/\mu\). High CV indicates high variability in flows and vice versa. In general, catchments with higher rainfall variability or larger catchment area tend to have higher CV of monthly runoff.’ (Peng Bai 2015:1033)

3. RESULTS AND DISCUSSION

3.1. Simulation results

While adjusting the parameters of the two models, the simulation results of observed and simulated stream flow graphs were checked, values of objective functions were checked and the FDC curves were checked, till better simulations outcome. Figure 2 and Figure 3 present the graphs of simulated runoff, observed runoff and precipitation of Deraniyagala sub watershed for “abcd” model in calibration and validation period respectively.
Flow duration curves were used to further adjust the parameters, considering the high flow conditions in this region. The FDC curves for “abcd” model and two parameter model of Deraniyagala watershed in the validation period is presented in Figure 4.

3.2. Model performance assessment

The average values of Pearson correlation coefficient, NSE and MRE values of the three sub watersheds in the validation period are summarized in the Table 2. The Pearson correlation coefficient generally showed approximate values for the two models while NSE and MRE values showed
significantly different values for the two models. All three coefficients; Pearson correlation coefficient, MRE and NSE showed better results in “abcd” model compared to the two parameter model. The “abcd” model performs best, yielding the largest NSE and lowest MRE. Peng Bai (2015) showed that no single model performs better in all the catchments. but, in these sub catchments of Kelani basin, the results showed that the “abcd” model performance is better than two parameter model in all three sub catchments. Therefore, it is required to further extend this study with large number of catchments to conclude which model performs better in different catchments.

<table>
<thead>
<tr>
<th>Table 2 The average values of Pearson, NSE and MRE values of the three sub watersheds in validation period</th>
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<tbody>
<tr>
<td>Objective functions</td>
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<td>---------------------</td>
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<td></td>
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<tr>
<td>Pearson</td>
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<tr>
<td>NSE</td>
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<tr>
<td>MRE</td>
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</table>

3.3. The relationship between the model performance and catchment characteristics

The model performance variation with different catchment characteristics; catchment area, runoff variability, catchment slope and forest area proportion is graphically summarised in Figure 6.

With the increment of the catchment area, forest area proportion, catchment slope, NSE and MRE values perform better ((Figure 6a and e), (Figure 6c and g), (Figure 6d and h)) concluding that the model performance in larger, forestry and steep catchments are better than that in small area, less forestry and mild slope catchments. Also the models performs better when the runoff variability is high. (Figure 6b and f ) These results have been reported by previous studies, such as that made by Peng Bai (2015) and Martinec and Rango (1989).

**Figure 6 Resulted NSE and MRE Values Variation of Three Sub Catchments in Validation Period with Different Catchment Characteristics; Catchment Area (A And E), Runoff Variability (B And F), Forest Area Proportion (C And G) and Catchment Slope (D And H)**

Peng Bai(2015) concluded that increasing model complexity does not guarantee a better model performance. But when moving from two parameters to four parameters, model performance is high in four parameter model though model complexity is somewhat high in “abcd” model.
3.4. Effect of model complexity on model performance

Model complexity depends on the model structure and mathematical equations used in the model. The model structures are different in these two models as showed in Table 1. In the two parameter model, there is a very little flexibility to control runoff and seepage as part becomes runoff and remainder somehow has to become the seepage. But in “abcd” model, there have a control over how much seeping into subsurface layer and out of that, how much is again added to the riverflow. These two storage components can control separately and independently in “abcd” model. That is more closer to what is actually happening in the reality. The Pearson, NSE, and MRE values resulted from the “abcd” model performed well as in Table 2.

3.5. Applicability in water resource management

Under the water resources investigation, the soil moisture content, ground water storage, surface runoff and ground water flow are considered as the main components and can be readily get those as an output from the “abcd” model. Those components were plotted in stack bar graphs which represent the precipitation as the sum of each component in a column. From that, December to March is the water shortage period that was identified in this analysis which is a valuable information for farmers as they can prepare with an alternative in that period. The period which is better for cultivation was identified as June to September and October to November because soil moisture storage is high in this period.

The resulted ground water component was nearly a percentage of 40 from the total precipitation which indicate that there is a considerable amount of ground water available, that we can recommend the institutes to focus on ground water resources.

4. CONCLUSIONS

In this study, a comparative analysis of model performance was done for two lumped parameter models; “abcd” model and two parameter model for three sub catchments of Kelani basin. The relationship between the model performance and the catchment characteristics also analyzed and possible reasons for the difference in model performance was discussed. The main conclusions are summarized as below.

- The resulted values of NSE, MRE and Pearson showed that “abcd” model performs better than two parameter model.
- The model performance increases with increasing catchment area, catchment slope, forest area percentage and runoff variability.
- Water shortage period was identified as December to March. The best period for cultivation was identified from June to September and October to November. Recommendation to focus on ground water resources can be given to the institutes as there is a considerable amount of ground water.

5. ACKNOWLEDGEMENTS

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6. REFERANCES


