JOURNAL OF DEGRADED AND MINING LANDS MANAGEMENT
ISSN: 2339-076X (p); 2502-2458 (e), Volume 6, Number 2 (January 2019): 1609-1616
DOI:10.15243/jdmlm.2019.062.1609

Research Article

Baseflow and lowflow of catchments covered by various old teak forest areas

Tyas Mutiara Basuki*, Esa Bagus Nugrahanto, Irfan Budi Pramono, Wahyu Wisnu Wijaya

Watershed Management Technology Center, PO BOX 295, Jl. A. Yani-Pabelan, Surakarta, Indonesia

*corresponding author: tmbasuki@yahoo.com

Received 9 November 2018, Accepted 6 December 2018

Abstract: Drought has become a severe disaster faced by several regions in Java, Indonesia due to land cover changes including forest conversion and the increase in air temperature. In this regard, the availability of forests related to lowflow has been a controversial debate. Forest in Java is dominated by teak; however, the hydrological teak forest has not been well known. Therefore, a research has been undertaken to know the baseflow and low-flow of teak catchments covered by various old teak forest areas. The research areas were in Blora District, Central Java, Indonesia. Data of2008-2015 from five catchments with areas of 3.38, 13.47, 20.14, 27.79, 64.80, and 69.20 ha and covered by old teak forests of 82, 82, 74, 70, and 53% of the catchment were analyzed. In this study, baseflow is the delayed flow from bank storage, and low-flow is stream flow in the dry season. The results showed that baseflow is affected by the percentage of old teak plantation areas, rainfall and antecedent soil moisture condition. Areas of the old teak plantation and the baseflow show negative and non-linear correlation. High low-flow occurs in the catchments with the percentage of old teak plantation about 74 to 70%.

Keywords: *baseflow, drought, lowflow, teak forest*

To cite this article: Basuki, T.M., Nugrahanto, E.B., Pramono, I.B. and Wijaya, W.W. 2019. Baseflow and lowflow of catchments covered by various old teak forest areas. J. Degrade. Min. Land Manage. 6(2): 1609-1616, DOI: 10.15243/jdmlm. 2019.062.1609.

Introduction

Water shortage or even drought has become a severe disaster for many regions in the world (Abbaspour et al., 2009; Allen et al., 2010; Mishra and Singh, 2010), including in Java Island, Indonesia due to the increase in air temperature and human population. The increase in population density has induced land cover conversion, especially changes in forest areas due to the need of land for agricultural, settlement, industrial, and mining (Allen et al., 2010; Rientjes et al., 2011). Although the availability of forest in a watershed or catchment is essential for maintenance of environmental stability, however, its expansion has become a controversial debate (Beck et al., 2013). Decreasing water yield, base flow, as well as lowflow in dry seasons are among the negative issues related to developing plantation forest areas.Some of the previous researches showed that the increase in afforestation areas have reduced water yield in total and base flow as well as lowflow in dry seasons in several regions (Dye and Versfeld, 2007). On the contrary, some researchers have found that afforestation has a positive influence in increasing lowflow. Feng et al. (2012) have argued that the impacts of environmental restoration, more specifically afforestation on water yield varies over time and space. The variation depends on the climatic gradient (Ma et al., 2009; Feng et al., 2012). Ellison et al. (2012) have discussed in detail these two opinions regarding the impacts of forest cover on water yield.

Rolls et al. (2012) have observed that base flows can be influenced by human activities through land cover/land use changes. In this regards, the reduction of forest cover for the expansion of impermeable urban areas will decrease base flow due to a reduction of water infiltration into soils (Du et al., 2012; Rolls et al., 2012). Delgado et al. (2010) have shown that the impacts of land cover changes on hydrological response of Pyrenean headwater catchments in northeast Spain. In the study, Delgado et al. (2010) have observed that the impacts of natural succession from old crop and meadows into shrub and forested have caused a reduction in lowflows. Muñoz-Villers and McDonnell (2013) have found that forested catchment of 35 to 70% has caused higher base flow than pasture catchment during the dry months from March to April due to lower rainfall infiltration in the pasture soil. Molina et al. (2012) have examined that reduction 20 km^2 of native forest to rangeland or croplands has raised total annual of base flow as much as 25 mm. In addition, Molina et al. (2012) have found that the reduction of peak flow is due to reforestation of the degraded lands and revegetation/rejuvenation of the existing graze lands.

Another research finding has shown that the effect of reduction forest area on water yield was small and can be ignored. Robinson et al. (2003) have observed that lowflow is not only affected by forest cover, but it is also influenced by other biophysical factors such geology, soil properties, and subsurface hydraulic properties within a watershed. The findings are in agreement with research findings conducted by Price (2011) who have examined that the quantity and time to release of base flow is affected by natural factors such as climate, geology, topography, soil properties, besides vegetation or forest. The amount of water during lowflow period will influence the need for drinking water, agricultural irrigation, industrial activities, hydropower generation, and environmental as a whole (Vogel and Kroll, 1992; Tallaksen, 1995; Staudinger et al., 2011; Beck et al., 2013). In general, previous studies have just focussed on the impact of a single land cover/land use changes on hydrological behaviour; there were limited studied that conducted on catchment with a more complex land cover pattern (Cao et al., 2009). Within a catchment with a complex land covers with their circumstances, its individual impact or integration of all together on lowflow generation will be different (Cao et al., 2009). In addition, in Java island, the dominant forest is teak which has high economic value. However, the hydrological teak forest has not been well known.

Therefore, in this paper, we present research with the purposes to study the effect of old teak plantation on baseflow and low-flow. In this paper, the term of baseflow refers to the delayed of streamflow and released as subsurface flow (Price, 2011). Low-flow refers to stream flow during the dry season of a year, and it is considered as apart a flow regime of a river (Smakhtin, 2001).

Materials and Methods

Description of the study area

Five catchments, namely Modang, Cemoro, Kejalen, Sambong, and Gagakan were chosen as the study areas. The biggest catchment is Gagakan, and the other four catchments are located inside Gagakan catchment as presented in Figure 1.

The location of the study lies between 55600 - 566100 East Longitude and 9211500 - 9222000 South Latitude. Administratively, the study areas are located in Blora Regency, Central Java Province. The teak plantations are under the management of Forest Management Unit (KPH) Cepu, Perum Perhutani Unit 1. The catchments are covered by a various percentage of old teak plantations and other land covers. The percentage of the old teak plantation is provided in Table 1. The highest percentage of teak plantation is 82% in Modang and Cemoro catchments.

Table 1. The area and the percentage of teak plantation of the study area

No	Catchment	Area (km^2)	% teak plantation area to the corresponding catchment area
1	Modang	3.4	82
2	Cemoro	13.8	82
3	Kejalen	20.1	74
4	Sambong	27.8	70
5	Gagakan	64.8	53

Source: Basuki et al. (2017)

Base flow separation

Base-flow data were obtained by using a software package of "Hydro Office" BFI+3.0. (Gregor, 2010). The daily base-flow data were separated from streamflow data. In the software, eight recursive digital filters are available, which are One parameter algorithm, Broughton two-parameter algorithm, IHACRES, BFLOW, Chapman algorithm, Furey & Gupta filter, Eckhardt filter, and EWMA filter. There are recursive digital filters with routine tools in signal analysis and processing. To obtain the low-frequency baseflow signals, the high-frequency quick flow signals were removed by the tools.

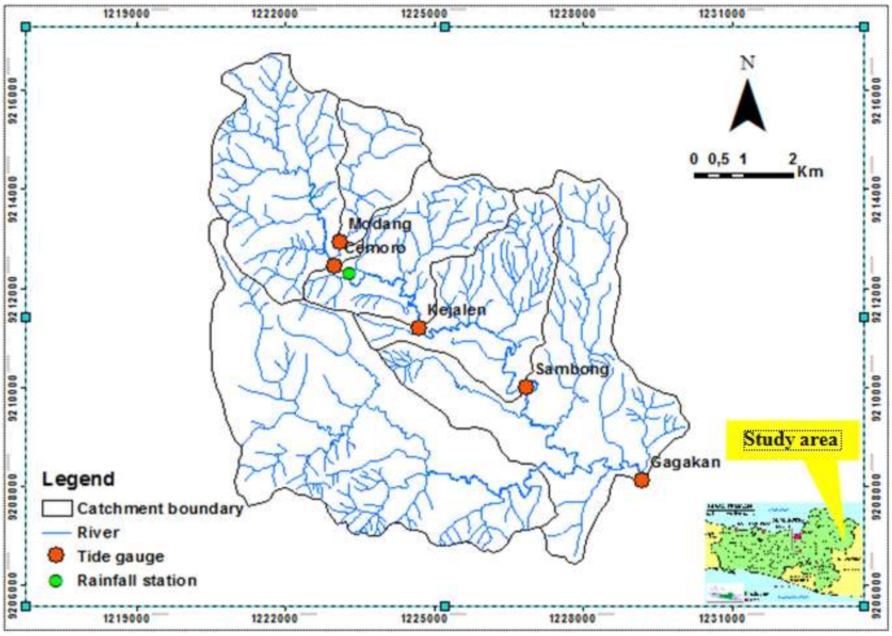

Figure 1. Stream channels of the study area. Source: Basuki (2017)

Results and Discussion

Rainfall and base flow of the teak catchments

Monthly rainfall and baseflow of the catchments covered by various old teak plantations are illustrated in Figure 2. In this paper the baseflow was separated from the total discharge from January to June and from October to December. The discharge from July to September was considered as low-flow. The discharge in June was also separated into direct flow and baseflow because in this month sometime the rainfall was still high during the study period. In general, high baseflow is found in Kejalen, Sambong, and Gagakan which old teak areas are 74, 70, and 53% of the catchments.

During the study, there was observed that the high baseflow was not always caused by high rainfall depth as shown in 2010 and 2011 (Figure 2). A possible reason for this condition is because the baseflow is not only affected by properties of rainfall and vegetation, but also other factors such as antecedent soil moisture (Pramono et al., 2017). At the beginning of the rainy season the soil dry and the rainwater is used to fill soil pores, and therefore the baseflow is not automatically increase. On the other hand, at the beginning of the dry season, the baseflow does not decrease fastly, because there is still high soil moisture content.

In this paper when the average monthly rainfall was regressed with the specific monthly baseflow for every catchment, the results show low correlation with r values ranging from 0.11 to 0.63. The effect of percentage area of teak plantations on baseflow does not clearly provide a certain pattern. For instance, the Cemoro catchment with 82% old teak coverage has higher baseflow than other catchments with lower old teak coverages only in 2008. While, the Gagakan catchment with the lowest old teak plantation (53% of the catchment) sometimes has the highest baseflow as it was in 2009, 2013, and 2014. A possible reason for this variation is due to the heterogeneity of the subsurface condition (Robinson et al., 2003).

Relationship between baseflow and teak plantation areas

A negative correlation is examined between baseflow and area of the old teak plantation as presented in Figure 3. The analysis was based on data collection from 2008 to 2015. The trend lines show that in some months with less rainfall, such as April, May, June, the trend lines are almost horizontal as indicated in Figure 3. These means the changes in area coverage of teak plantation do not profoundly influence the change of baseflow. The lower baseflow in the catchments with the higher area of teak plantation can be caused by the higher evapotranspiration. Price (2011) in his paper has argued that factors induced higher evapotranspiration will decrease baseflow, in contrast, soil properties which can increase infiltration and recharge of subsurface storage will raise baseflow.

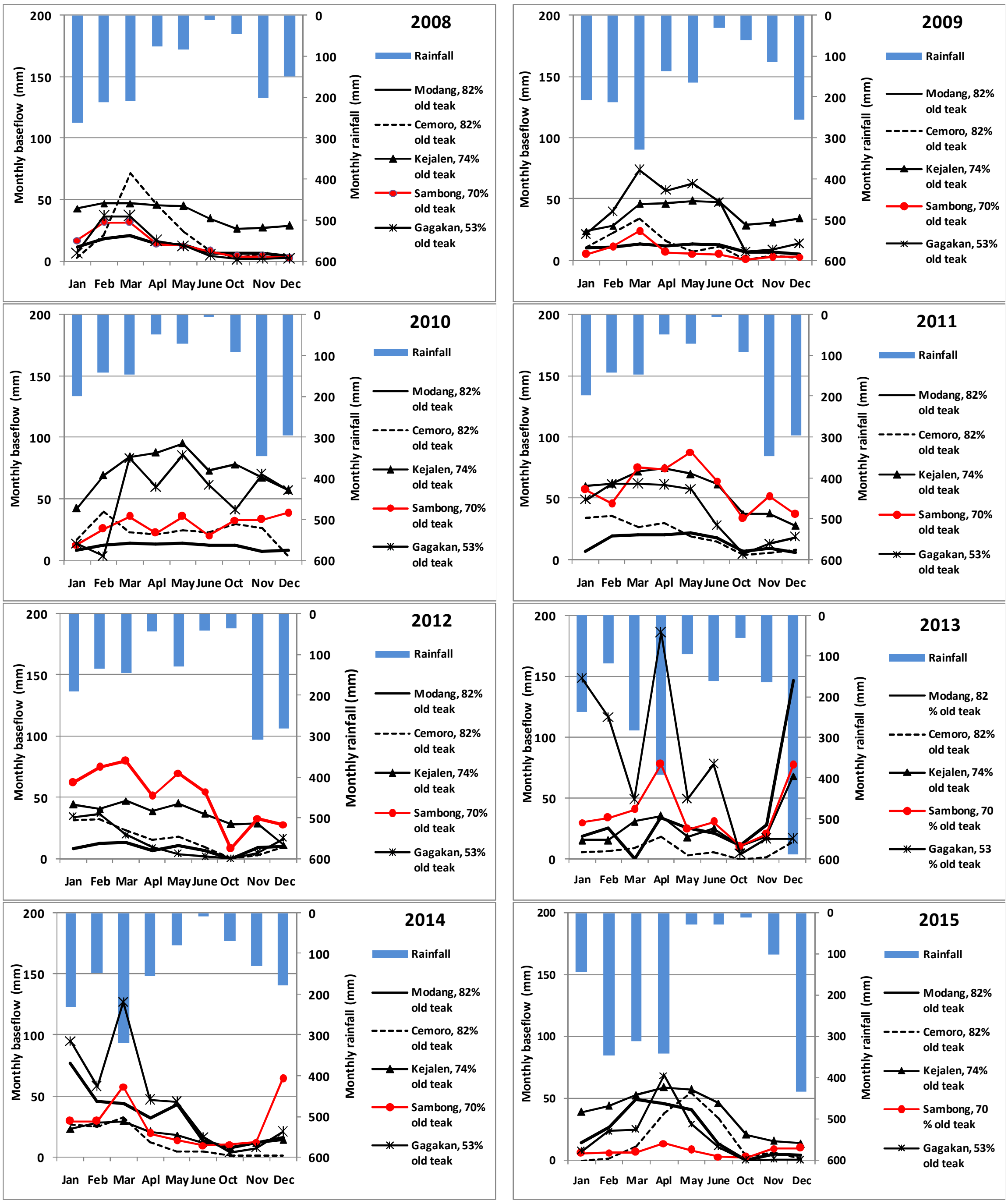

Figure 2. Monthly rainfall and baseflow of the study area

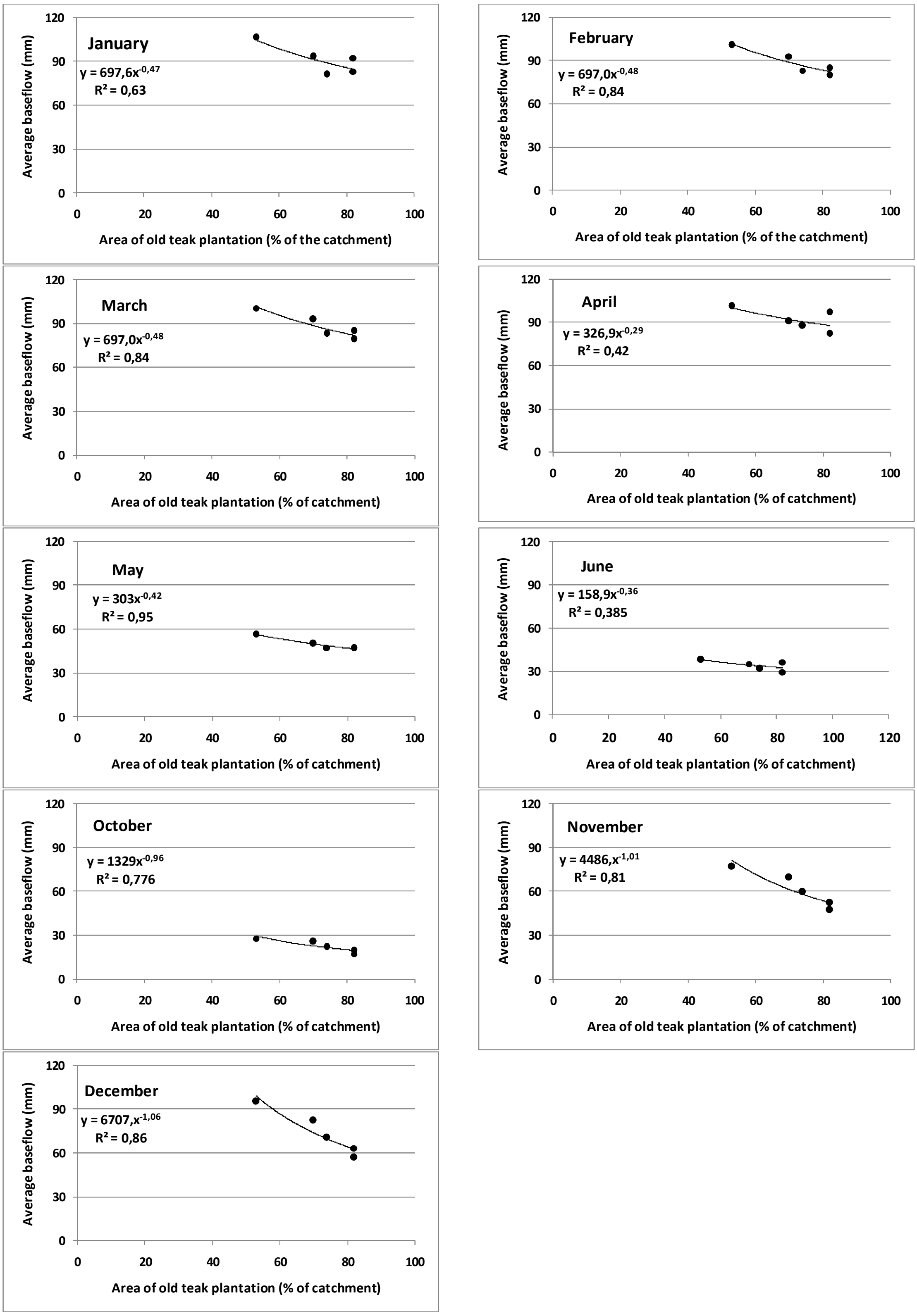

Figure. 3. Relationship between area of old teak plantation and average baseflow based on 2008-2015 data

Lowflow of the observed catchments

The first highest lowflow in July, August, and September at the dry and wet years is found in Kejalen catchment with 74% old teak coverage as provided in Table 2. The exception is found in July 2013, in this month the highest lowflow occurs in Gagakan catchment (Table 2). The second highest is found in Sambong catchment (70% old teak coverage). In this regards, catchments with the highest (82%) and the lowest (53%) of teak plantation produce lower lowflow than the catchments with old teak coverages between 74 to 70% both in the wet year (2010, 2013) or dry years (2011, 2012).

Table 2. Lowflow of the observed catchments

Year	Month	Lowflow (mm)				
		Modang (82% old teak)	Cemoro (82% old teak)	Kejalen (74% old teak)	Sambong (70% old teak)	Gagakan (53% old teak)
2008	July	5.6	8.8	30.3	6.4	4.0
	August	5.6	3.8	30.5	3.9	3.4
	September	4.8	9.6	27.4	5.1	3.1
2009	July	9.9	16.9	45.4	6.2	24.0
	August	8.6	6.7	34.2	2.0	12.9
	September	5.4	3.1	27.4	1.4	7.6
2010	July	12.8	19.6	80.9	18.8	56.6
	August	10.9	47.7	93.0	16.2	21.7
	September	12.6	50.9	16.2	37.7	37.3
2011	July	16.3	7.4	56.7	53.3	13.2
	August	10.4	5.6	40.7	42.0	8.7
	September	10.0	4.5	33.9	37.0	5.6
2012	July	0.0	2.4	32.3	41.2	0.2
	August	0.0	0.4	29.9	31.9	0.0
	September	5.3	0.4	27.4	6.3	0.0
2013	July	23.3	59.7	84.9	89.0	67.2
	August	20.8	19.3	61.8	55.0	32.4
	September	4.4	0.0	55.0	38.5	12.3
2014	July	12.7	26.2	56.5	33.3	27.0
	August	11.4	16.3	54.6	39.2	17.7
	September	8.8	10.2	41.7	35.6	7.4
2015	July	11.6	19.8	40.4	2.0	9.9
	August	9.4	12.5	37.0	1.5	8.5
	September	3.2	5.0	33.7	0.8	0.5

As observed in Table 2, there are indications that the wider the areas of the old teak plantation in catchments, the decrease in lowflow will be smaller. This is because root systems in the teak plantation may absorb more infiltrated water than other land uses such as dry agricultural crops. Therefore water holding capacity under teak plantation will be higher than other land uses and the water will be released to the river will be more continue in dry months. Smakhtin (2001) has observed that independent variables that influence lowflow are catchment area, annual rainfall, gradient of river, drainage density, forest area, heterogeneity of soil properties, geology, the main river length, catchment shape, and the average catchment height. In this research, the variation in rainfall, slope gradient, drainage density, geology, and soil are assumed similar; therefore, the dominant factor is the percentage of the old teak plantation in the catchments. While He et al. (2012) have argued that the relationship between forest cover and water yield, in general, is complicated and it can be different depends on variation in climates, geological condition and forest types which influence the amount of interception, evapotranspiration as well as the storage of soil water.

Conclusion

In our study area, baseflow is not only influenced by a single factor, i.e. rainfall but also affected by the area of old teak plantation and antecedent soil moisture condition. A negative and non-linear correlation is observed between the percentage of old teak plantation areas and the baseflow. High lowflow occurs in the catchments with the percentage of old teak plantation about 74 to 70%, both in the wet years and dry years.

Acknowledgement

We would like to thank the Watershed Management Technology Center for funding the research.

References

Abbaspour, K.C., Faramarzi, M., Ghasemi, S.S. and Yang, H. 2009. Assessing the impact of climate change on water resources in Iran. *Water Resources Research* 45: 1-16, W10434, doi:10.1029/ 2008WR007615.

Allen, C.D., Macalady, A.K., Chenchouni, H., Bachelet, D., McDowell, N., Vennetier, M., Kitzberger, T., Rigling, A., Breshears, D.D., Hogg, E.H.T., Gonzalez, P., Fensham, R., Zhang, Z., Castro, J., Demidova, N., Lim, J.-H, Allard, G., Running, S.W., Semerci, A. and Cobb, N. 2010. A global overview of drought and heat-induced tree mortality reveals emerging climate change risks for forests. *Forest Ecology and Management* 259(4): 660-684.

Basuki, T.M. 2017. Sediment yield and alternatives soil conservation practices of teak catchments. *Journal of Degraded and Mining Lands Management* 5(1): 965-973.

Basuki, T.M., Wijaya, W.W. and Adi, R.N. 2017. Specific peak discharge of two catchments covered by teak forest with different area percentages. *Forum Geografi* 31: 118-127. https://doi.org/10.23917/forgeo.v31i1.3236.

Beck, H.E., Bruijnzeel, L.A., Van Dijk, A.I.J.M., McVicar, T.R., Scatena, F.N. and Schellekens, J. 2013. The impact of forest regeneration on streamflow in 12 mesoscale humid tropical catchments. *Hydrology and Earth System Sciences* 17(7): 2613-2635. https://doi.org/10.5194/hess-17-2613-2013.

Beck, H.E., van Dijk, A.I.J.M., Miralles, D.G., deJeu, R.A.M., Bruijnzeel, L.A., McVicar, T.R. and Schellekens, J. 2013. Global patterns in base flow index and recession based on streamflow observations from 3394 catchments. *Water Resources Research* 49: 7843-7863.

Cao, W., Bowden, W.B., Davie, T. and Fenemor, A. 2009. Modelling impacts of land cover change on critical water resources in the Motueka River catchment, New Zealand. *Water Resources Management* 23(1): 137-151.

Delgado, J., Llorens, P., Nord, G., Calder, I.R. and Gallart, F. 2010. Modelling the hydrological response of a Mediterranean medium-sized headwater basin subject to land cover change: the Cardener River basin (NE Spain). *Journal of Hydrology* 383(1-2): 125-134.

Du, J., Qian, L., Rui, H., Zuo, T., Zheng, D., Xu, Y. and Xu, C.-Y. 2012. Assessing the effects of urbanization on annual runoff and flood events using an integrated hydrological modeling system for Qinhuai River basin, China. *Journal of Hydrology* 464: 127-139.

Dye, P. and Versfeld, D. 2007. Managing the hydrological impacts of South African plantation forests: an overview. *Forest Ecology and Management* 251(1-2): 121-128. https://doi.org/10.1016/j.foreco.2007.06.013.

Ellison, D.N., Futter, M. and Bishop, K. 2012. On the forest cover-water yield debate: from demand- to supply-side thinking. *Global Change Biology* 18(3): 806-820.

Feng, X.M., Sun, G., Fu, B.J., Su, C.H., Liu, Y. and Lamparski, H. 2012. Regional effects of vegetation restoration on water yield across the Loess Plateau, China. *Hydrology and Earth System Sciences* 16: 2617-2628.

Gregor, B.M. 2010. Bfi+ 3.0. User's Manual. Department of Hydrogeology, Faculty of Natural Science, Comenius University, Bratislava, Slovakia. 21p.

He, Z., Zhao, W., Liu, H. and Tang, Z. 2012. Effect of forest on annual water yield in the mountains of an arid inland river basin: a case study in the Pailugou catchment on northwestern China's Qilian Mountains. *Hydrological Processes* 26(4): 613-621.

Ma, X., Xu, J., Luo, Y., Prasad Aggarwal, S. and Li, J. 2009. Response of hydrological processes to land-cover and climate changes in Kejie watershed, south-west China. *Hydrological Processes* 23(8):1179-1191.

Mishra, A.K. and Singh, V.P. 2010. A review of drought concepts. *Journal of Hydrology* 391(1-2): 202-216.

Molina, A., Vanacker, V., Balthazar, V., Mora, D. and Govers, G. 2012. Complex land cover change, water and sediment yield in a degraded Andean environment. *Journal of Hydrology* 472: 25-35.

Muñoz-Villers, L.E. and McDonnell, J.J. 2013. Land use change effects on runoff generation in a humid tropical montane cloud forest region. *Hydrology and Earth System Sciences* 17:3543-3560. https://doi.org/10.5194/hessd-10-5269-2013.

Pramono, I.B., Budiastuti, M.T.S., Gunawan, T. and Wiryanto. 2017. Base flow from various area of pine forest at Kedungbulus Sub watershed, Kebumen District, Central Java, Indonesia. *International Journal of Development and Sustainability* 6(3): 99-114.

Price, K. 2011. Effects of watershed topography, soils, land use, and climate on baseflow hydrology in humid regions: A review. *Progress in Physical Geography* 35(4): 465-492.

Rientjes, T.H.M., Haile, A.T., Kebede, E., Mannaerts, C.M.M., Habib, E. and Steenhuis, T.S. 2011. Changes in land cover, rainfall and stream flow in Upper Gilgel Abbay catchment, Blue Nile basin-Ethiopia. *Hydrology and Earth System Sciences* 15(6): 1979-1989.

Robinson, M., Cognard-Plancq, A.-L., Cosandey, C., David, J., Durand, P., Fu¨hrer, H.-W., Hall, R., Hendriques, M.O., Marc, V., McCarthy, R., McDonnell, M., Martin, C., Nisbet, T., O'Dea, P., Rodgersh, M. and Zollnerk, A. 2003. Studies of the impact of forests on peak flows and baseflows: a European perspective. *Forest Ecology and Management* 186(1-3): 85-97.

Rolls, R.J., Leigh, C. and Sheldon, F. 2012. Mechanistic effects of low-flow hydrology on riverine ecosystems: ecological principles and consequences of alteration. *Freshwater Science* 31(4): 1163-1186.

Smakhtin, V.U. 2001. Lowflow hydrology: a review. *Journal of Hydrology* 240(3-4): 147-186.

Staudinger, M., Stahl, K., Seibert, J., Clark, M. P. and Tallaksen, L.M. 2011. Comparison of hydrological model structures based on recession and lowflow simulations. *Hydrology and Earth System Sciences* 15(11): 3447-3459.

Tallaksen, L.M. 1995. A review of baseflow recession analysis. *Journal of Hydrology* 165(1-4): 349-370.

Vogel, R.M. and Kroll, C.N. 1992. Regional geohydrologic-geomorphic relationships for the estimation of low-flow statistics. *Water Resources Research* 28(9): 2451-2458.