THEME 2

Forest Hydrology and Climate Change

<< Back to contents

9

Potential Climate Change Effects on Forest Hydrology of Indian Forests

Tajinder Pal Singh, Saibal Dasgupta and Lalit Kumar Sharma

9.1 INTRODUCTION

Climate variability over the past half-century is likely to have major effects on water quantity and timing of discharge from forests, some of these effects are already evident. In the future scenario, many river basins are likely to experience changes not only in hydrology, but it will also lead to increase in frequency of extreme hydrological events such as floods in basins due to outburst of Glacier Lakes (Gain *et al.,* 2011; Immerzeel *et al.*, 2011). Climate change effects on forests will occur through: (1) direct effects on precipitation type, snowmelt timing, and amount of precipitation; (2) indirect effects on disturbances in forests, including fire, wind, insects, and pests; and (3) indirect effects on vegetation species range including both natives and exotics.

A number of modeling studies have investigated hydrologic effects of climate change at the large watershed, regional, national, and global scales (Barnett *et al.,* 2004). Simulated future climate models for the river basin indicated a shift in the timing of water availability due to reduction in permafrost areas, earlier snowmelt, and higher evapo-transpiration in early summer, and earlier spring peak flows, leading to reductions in later months from August-September runoff volumes (Lieth and Whitfield,

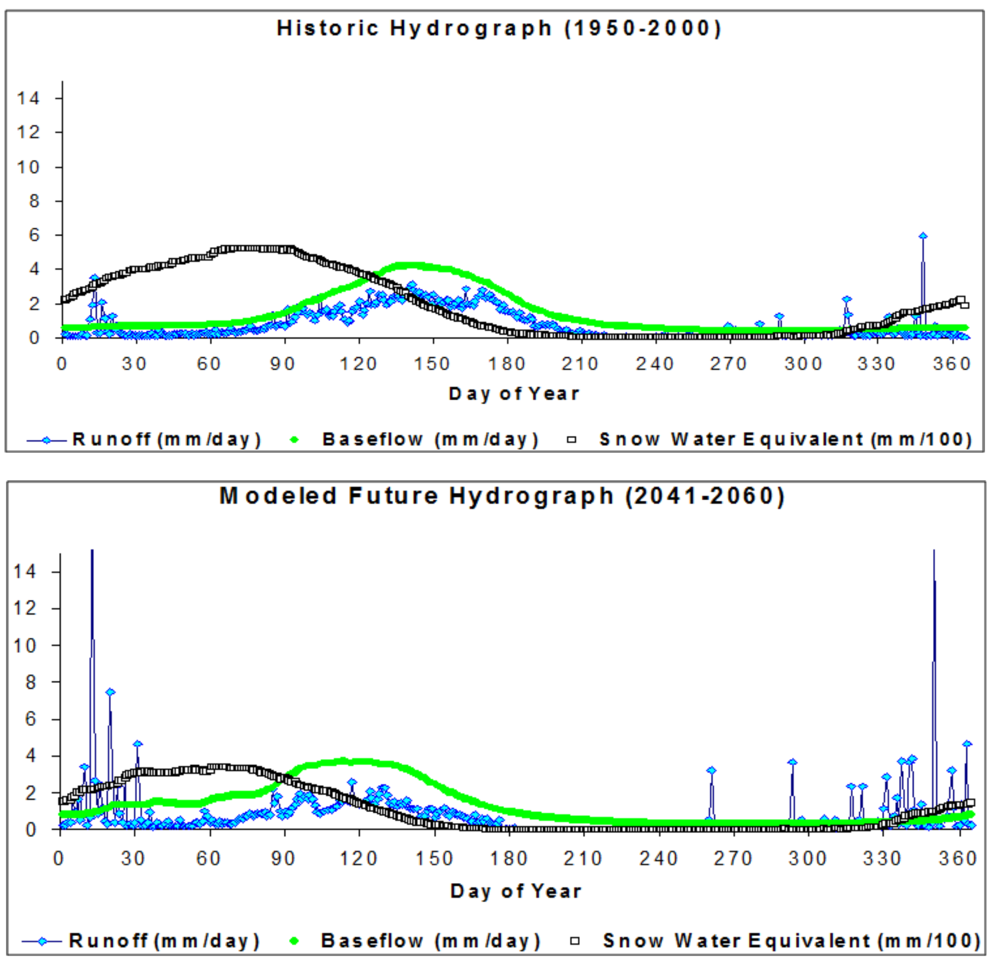


Figure 9.1: Variable inflation capacity model for understanding the hydrograph of river by using historic data and predicted futuristic model (Herbst *et al.*, 2011)

<< Back to contents

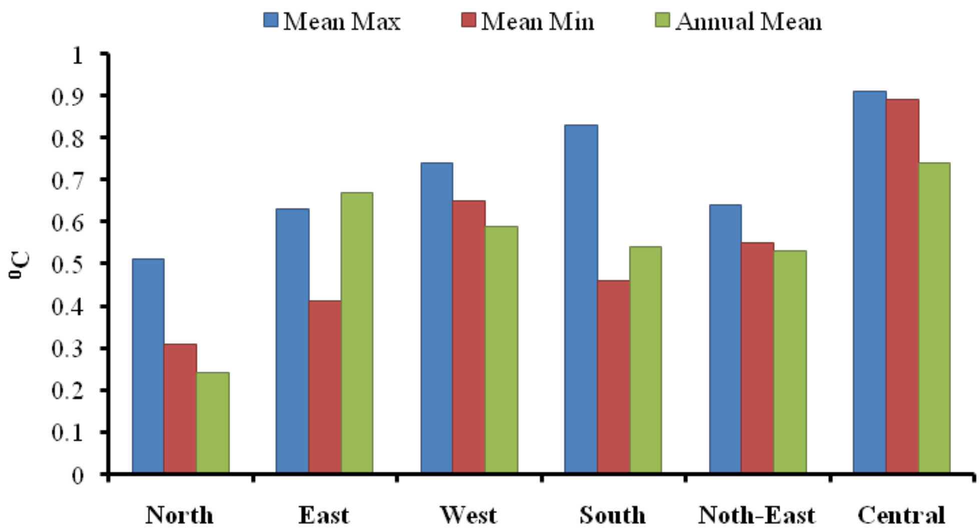


Figure 9.2: Changes in Mean of Maximum, Minimum and annual average temperature (0C) Data duration: 1931 to 2010 (80 years)
(Source: Forest Types of India: revised 2013).

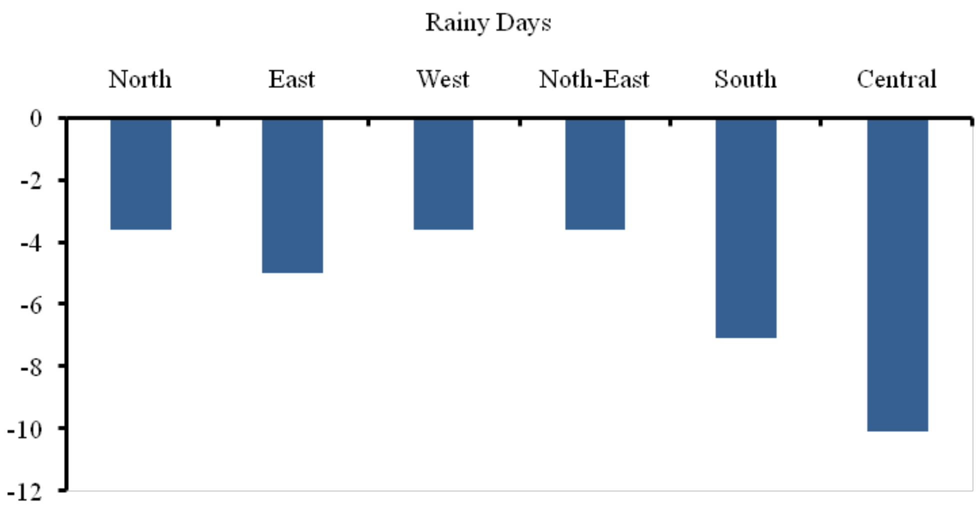


Figure 9.3: Changes in total annual rainfall (in mm) Data duration: 1931 to 2010 (80 years)
(Source: Forest Types of India: revised 2013).

1998; Dettinger *et al.,* 2004; Herbst *et al.,* 2011) (Figure 9.1). These changes are expected to exacerbate conflicts over limited dry season river flows among energy production, irrigation, and recreational uses. Simulated hydrologic effects of climate change have also predicted the change in distribution and extirpation of many species including micro and macro species (Hansen *et al.*, 2001). The indirect and interacting effects of climate change such as forest fire, widespread outbreak of invasive species infestation and forest disturbance may also affect water yield and quality in forest river basin or catchment area (Aber *et al.,* 1995).

Intensive spring studies were taken up in the 1980s predominantly in the western Himalaya and focusing on aspects related to spring discharge in relation to rainfall patterns and catchment degradation (Singh and Rawat, 1985; Singh and Pande, 1989; Sahin and Hall, 1996; Negi and Joshi, 1996, 2004; Tambe *et al.,* 2012) indicated that spring discharge was a function of both the rainfall pattern and the recharge area characteristics. In many snowmelt-dominated watersheds, temperature increase has shifted the magnitude and timing of hydrological events. In addition, climate change is expected to alter forest productivity and species composition. As per an ICFRE publication *Forest Types of India* (revised 2013), the forest species composition is changing in many areas of North-Western Himalayas and in Hill States of North East India. Studies have indicated that by altering the productivity and species composition of forests, climate change may indirectly modify water quantity and quality.

The analysis of the climatic data from 1901 to 2009 suggests that annual mean temperature of India has risen by 0.56^0C and/but during the period 1931-60 and 1961-90, a steady rise in the temperature in most of the regions ranging between 0.2^0C to 1^0C was recorded (Figure 9.2). Of the 88 metrological stations which are distributed to the spatial extents of the country, 42 stations have shown reduction in rainfall during the period 1961-1990 as compared to the previous 30 years with the variation ranging between 10 per cent and 20 per cent within the stations (Figures 9.3, 9.4). These changes will drastically affect the physiology of the plants by way of changing the evapotranspiration rate which will have greater consequences on the forest hydrology (Barnett

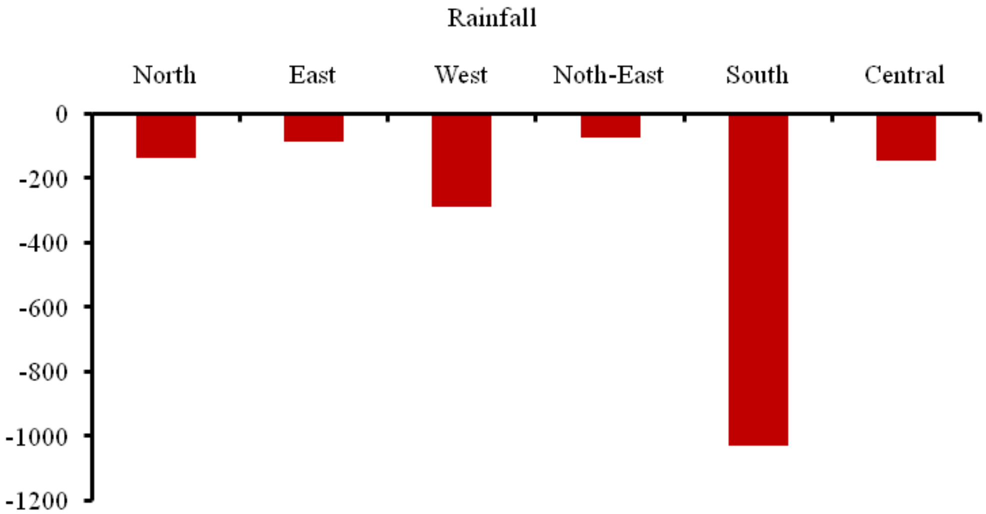


Figure 9.4: Changes in number of annual rainy days Data duration: 1931 to 2010 (80 years)
(Source: Forest Types of India: revised 2013)

et al., 2004). Studies have reveals that many forests are moving towards drier conditions, particularly the temperate forests which are a cause of concern.

The watersheds are critical catchments that regulate hydrological flows to some of the world's most densely populated agricultural lands and cities. As an adaption, the Sustainable Land and Ecosystem Management (SLEM) activities related to integrated watershed management and ground water recharge can play a vital role in maintenance of hydrological flow in forest areas as well as agricultural lands. Adoptions and mainstreaming of SLEM approaches on watershed or landscape basis and river basins treatment are likely to effect carbon sequestration in forest areas and to mitigate impacts such as floods and droughts due to climate variability/change.

9.2 METHODOLOGY

9.2.1 Watershed management for long-term sustainability under SLEM project

Studies have indicated that climate change is likely to have both direct as well as indirect effects on water resources in India and elsewhere (Brain *et al.,* 2004; Sun *et al.,* 2008). The direct effects on water resources will depend upon how climate change alters the amount and timing of precipitation and how this influences the baseflow, streamflow, groundwater recharge,forest hydrology and the floods. Based on the long-term study conducted in different parts of the world, suggested increase in average annual streamflow is linked to greater precipitation (IPCC, 2007). The major river systems of the Indian subcontinent, namely Brahmaputra, Ganga and Indus which originate in the Himalayas, are expected to be vulnerable to climate change because of substantial contribution from snow and glaciers into these river systems.

Due to climate change, the increasing temperature resulting in increased plant water use via transpiration and evaporation, and hence resulting in decrease in residual precipitation available for streamflow or groundwater recharge. The increasing CO_2 concentration typically decreases stomatal aperture in plants (Beerling, 1996; Prentice and Harrison, 2009). The warmer temperature will also influence the duration and timing of snowmelt, which is critical factor for ecosystems since, snowmelt influences the hydrologic processes. Due to effect of climate warming, the physiology of plants also gets affected which will in the long run result in shifts in tree species composition as well as in distribution in forest ecosystems. Studies have proved that water use differs significantly among tree species. The shift from deciduous hardwood to evergreen conifer forests may result in greater water use by evergreen conifer forests due to year round transpiration and interceptions loss (Stoy *et al.,* 2006).

The vulnerability of the Indian subcontinent to the impact of changing climate is of vital importance because the major impact of climate change in this continent would be on the hydrology, affecting both water resources and the agricultural economy. However, very little work has been carried out in India where the impact of climate change on hydrology has been studied. The current understanding about the impact of climate change on forest ecosystems is largely based on the studies conducted on watershed management in United States (Moran *et al.,* 2008). Today, forest land managers are facing the challenges of how to manage forests to adapt and to mitigate the effects of the future climate change on a variety of ecosystem services. Management activities implemented on forest ecosystems today will influence ecosystem responses to future climate change. So the managers of natural resources require new insights into management implications and potentially new approaches to silviculture and other management practices (Vose *et al.,* 2011).

9.3 RESULTS AND DISCUSSION

9.3.1 Forest management for maintaining the hydrological regime through SLEM interventions

The best forest management practices have the potential to alter the hydrological responses to climate change by influencing biological factors that determine the evapotranspiration and the physical characteristics of the watershed. Under the SLEM-CCP, various activities were carried out by the project partners for the watershed management with respect to soil and water conservation. The intervention under the watershed management will necessarily help in combating the climatic variabilities. The project wise management activities carried out by the SLEM partners for watershed management are described ahead.

9.3.1.1 Sustainable Land Water and Biodiversity Conservation and Management for Improved Livelihoods in Uttarakhand Decentralized Watershed Management

Under the project, 20 mini-watersheds were selected for the treatment and following efforts were made to maintain the hydrology regime, soil conservation and to control land degradation: 1) In total, 491 vegetative check dams or brushwood check dams have been constructed. 2) In total, 21,182.98 cum (cubic metre) dry stone check dams were constructed in the catchment of the *nallahs*. 3) About 89,130 contour trenches have been dug. 4) In total, 10,675.05 cum diversion drains and about 8,630.25 cum of cross barrier (cement, crate wire and dry) and retaining wall (cement, crate wire and dry) have also been constructed for maintaining the water availability during the water stress time of the year. For the river bank protection, crate wire (18,988.08 cum), bonded wall (944.84 cum), mortar work (4,082.92 cum) and crate wire spur construction works (1,939.18 cum) were carried out. Due to various drainage line treatment and soil and moisture conservation works, an area of 182 ha of agricultural land in the watersheds has been protected and a soil loss of 93,371 tons was reduced (Annual Report, 2012-13). So far, forest plantation has been carried out in 830 ha of land and aided natural regeneration of oak has been carried out in 115 ha of forest area under the afforestation activity.

9.3.1.2 Integrated Land and Ecosystem Management to Combat Land Degradation and Deforestation in Madhya Pradesh

Under the objective Sustainable Watershed Management of forest with high conservation values and non-forest land, an area of 3,000 ha has been treated with various soil and water conservation measures such as construction of vegetative, brushwood and crate wire check dams, contour trenches, and plantation of various species such as bamboo, *amla, mohua, neem*, etc., was carried out for overall improvement of the watershed (Annual Report, 2012-13).

The watershed treatment activities carried out under the project will help in regulating the hydrological regime which will help in combating climate variability. Hansen *et al.* (2001) and Moran *et al.* (2008) presented various significant hydrological alternations in the forested watersheds which were climate change induced. Vose *et al.* (2012) suggested that watershed treatment is an effective management intervention in the United States to mitigate climate change effects on forest water resources.

Watershed activities such as afforestation will play a significant role in maintaining the hydrology as well as in preventing soil erosion and hence will prevent land degradation. The forested watersheds of Himalayan regions are highly vulnerable to threats posed by rapid glacier melt and can lead to drastic change in hydrological regime of the forest by way of high runoff during early summer and low discharge during the later half of the year (Gosain *et al.,* 2006). For example, the recent floods in the Garhwal region of Uttarakhand may have drastically altered the hydrological regime of the region. Studies conducted elsewhere in the US indicated that it is important to develop adaptation strategies to combat climate change with respect to forest hydrology since water regime in forest plays a significant role in the long-term survival of forest and associated ecological services.

9.4 CONCLUSION

The forested watersheds of the Himalayan regions are highly vulnerable to threats posed by rapid glacier melt and can lead to drastic change in hydrological regime of the forest by way of high runoff during early summer and low discharge during the later half of the year. So, it is important to develop a management framework to prioritize stream types for building resilience and protection of most vulnerable watersheds by riparian and meadow restoration, protecting groundwater infiltration paths, reducing soil loss/debris flows by managing grazing, logging and disturbance such as roads, etc. Most importantly, it is vital to identify biological indicators which will provide a strong foundation for detecting change in forests (biodiversity and trait sensitivities to hydro-climate change). Since the SLEM approach was found to be effective in watershed management to combat externalities in states such as Uttarakhand, it is important to adopt such practices and mainstream them for developing adaptation strategy at watershed and landscape scale.

ACKNOWLEDGEMENTS

We thank Director General, ICFRE, for help and entrusting us to conduct the study. We would also like to thank the Project Directors, of all the projects under SLEM-CCP projects for sharing the information with the TFO. We express our gratitude to World Bank for providing funding support for conducting the study.

REFERENCES

Aber, J.D., Magill, A., McNulty, S.G., Boone, R.D., Nadelhoffer, K.J., Downs, M., Hallett, R. 1995. Forest biogeochemistry and primary production altered by nitrogen saturation. *Water, Air, and Soil Pollution*, 85, 1665–1670.

Annual Report. 2013. SLEM project annual report 2012-13. SLEM-TFO, ICFRE, Dehradun (in press).

Barnett, T.R., Malone, R., Pennell, W., Stammer, D., Semtner, B., Washington, W. 2004. The effects of climate change on water resources in the West: Introduction and overview. *Climate Change*, 62 (1-3),1-11.

Beerling, D.J. 1996. Ecophysiological responses of woody plants to past CO_2 concentrations. *Tree Physiology,* 16, 389–396. doi:10.1093/treephys/16.4.389.

Brian, H.H., Callaway, M., Smith, J., Karshen, P. 2004. Climate change and US water resources: from modeled watershed impacts to national estimates. *J. Am. Water Resour. Assoc.,* 40, 129–148.

Dettinger, M.D., Cayan, D.R. 1995. Large-Scale Atmospheric Forcing of Recent Trends toward Early Snowmelt Runoff in California, *J. Climate*, 8, 606–623.

Gain, A.K., Immerzeel, W.W, Sperna-Weiland, F.C., Bierkens, M.F. P. 2011. Impact of climate change on the stream flow of lower Brahmaputra: trends in high and low flows based on discharge weighted ensemble modeling. *Hydrol. Earth Syst. Sci. Discuss*, 8, 365–390.

Gosain, A.K., Rao, S., Basuray, D. 2006. Climate change impact assessment on hydrology of Indian river basins. *Current Science*, 90(3), 346–353.

Hansen, A.J., Neilson, R.P., Dale, V.H., Flather, C.H., Iverson, L.R., Currie, D.J., Shafer, S., Cook, R., Bartlein, P.J. 2001. Global change in forests: Responses of species, communities, and biomes. *BioScience*, 51, 765–779.

ICFRE, 2013. Forest types of India: Revisited. Published by ICFRE, Government of India. Dehradun.

Immerzeel, W.W., Van Beek, L.P.H., Konz, M., Shrestha, A.B., Bierkens, M.F.P. 2012. Hydrological response to climate change in a glacierized catchment in the Himalayas. *Climate Change*, 110, 721–736.

IPCC. 2007. Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. In: *Core Writing Team, Climate Change 2007* (ed. by R.K. Pachauri and A. Reisinger). Synthesis Report, Geneva, Switzerland, p. 104.

Leith, R.M.M., Whitfield, P.H. 1998. Evidence of climate change effects on the hydrology of streams in south-central British Columbia. *Canadian Water Resource Journal*, 23(3), 219–230.

Moran, M.S., Peters, D.P. C., McClaran, M.P., Nichols, M.H., Adams, M.B. 2008. Long-term data collection at USDA experimental sites for studies of ecohydrology. *Ecohydrology,* 1, 377–393. doi:10.1002/eco.24.

Negi G.C.S, Joshi V. 1996: Geohydrology of springs in a mountain watershed: The need for problem solving research. *Current Science*, 1996, 71(10), 772–776.

Negi, G.C.S, Joshi, V. 2004: Rainfall and Spring Discharge Patterns in two Small Drainage Catchments in the Western Himalayan Mountains, India. *The Environmentalist*, 24, 19–28.

Prentice, I.C., Harrison, S.P. 2009. Ecosystem effects of CO_2 concentration: evidence from past climates. *Climate of the Past*, 5, 297–307. doi:10.5194/cp-5-297-2009.

Sahin, V., Hall, M.J. 1996. The Effects of Afforestation and Deforestation on Water Yields,' *J. Hydrol.*, 178, 293–309.

Singh, A.K., Rawat, D.S. 1985: Depletion of Oak Forests Threatening Springs: An Exploratory Study. *The National Geog. J. India*, 31(1), 44–48.

Singh, A.K., Pande, R.K. 1989: Changes in the Spring Activity: Experiences of Kumaun Himalaya, India, *The Environmentalist*, 9(1), 25–29.

Stoy, P., Katul, G., Siqueira, M., Juang, J., Novick, K., McCarthy, H.R., Oishi, A.C., Umbelherr, J., Kim, H., Oren, R. 2006. Separating the effects of climate and vegetation on evapotranspiration along a successional chronosequence in the southeastern US. *Global Change Biology* 12, 2115–2135.

Sun, G., McNulty, S.G., Moore-Myers, J.A., Cohen, E.C. 2008. Impacts of multiple stresses on water demand and supply across the Southeastern United States. *J. Am. Water Resour. Assoc.,* 44, 1441–1457.

Tambe, S., Kharel, G., Arrawatia, M.L., Kulkarni, H., Mahamuni, K., Ganeriwala. A.K. 2012. Reviving Dying Springs: Climate Change Adaptation Experiments from the Sikkim Himalaya. *Mountain Research and Development*, 32 (1): 62–72.

Vose, J.M., Ford, C.R., Laster, S., Dymond, S., Sun, G., Adams, M.B., Sebestyen, S., Campbell, J., Luce, C., Amathya, D., Elder, K., Scalley, T.H., 2012. Can forest watershed management mitigate climate change effects on water resources ?. Proceedings of a workshop during the XXV IUGG General Assembly in Melbourne. pp. 12–25.

10

Assessment of Water Resources under the Impact of Climate Change in the Central Highlands of Vietnam using a Multi-Model Ensemble Approach

Dao Nguyen Khoi

10.1 INTRODUCTION

The Intergovernmental Panel on Climate Change report reaffirmed that global warming is occurring (IPCC, 2007). Climate change is expected to affect water resources in terms of water quantity and quality. Therefore, future decisions on water resources planning and management should be taken keeping these changes in mind (Kim and Kaluarachchi, 2009). To quantify the climate change impacts on hydrology and water resources at the basin or watershed scale, a common approach is to use climate change scenarios in combination with hydrological models (Islam *et al.*, 2012; Kling *et al.*, 2012). General Circulation Models (GCMs) are the primary tools used to generate future climate conditions for a given greenhouse emission scenario (Li *et al.*, 2013). However, the spatial resolution of GCM is too coarse (1-2.5°) and it is difficult to directly apply the GCM outputs to hydrology and water resources studies at sub-grid scales. *Statistical downscaling methods have been proposed to transform the GCM outputs from a coarse resolution to a fine resolution for catchment modeling*. In addition, it is well known that different GCMs may produce different projections of future climate conditions (Deque*et al.*, 2007; Kling *et al.*, 2012). Therefore, multiple GCMs are usually used to provide ensemble scenarios for impact studies (Li *et al.*, 2013). In hydrological impact studies, the principal tool used to investigate the potential effects of climate change are hydrological models. A widely used hydrological model in Asia and Vietnam is the Soil and Water Assessment Tool (SWAT), e.g. Khoi and Suetsugi (2012), Raghavan *et al.* (2012), Narsimlu *et al.* (2013). The SWAT model is a spatial distributed hydrological model developed by the Agricultural Research Service (ARS) of the United States Department of Agriculture (USDA) in the 1990s and it has been used to evaluate the impacts of different scenarios including climate and land-use change on water availability and sediment production.

Vietnam is a developing country with the economy depending on agriculture, which is highly climate sensitive. Agriculture accounts for about 22 per cent of GDP and 60 per cent of employment. According to the report of the Ministry of Natural Resources and Environment (2009), the annual average temperature increased by 0.5-0.7°C and the annual rainfall decreased by approximately 2 per cent over the past 50 years (1958-2007). The regional climate change has altered regional hydrologic conditions and subsequently impacted regional water resources in Vietnam. In addition, Wang *et al.* (2013) emphasized that the local impacts of climate change on hydrology and water resources vary from place to place and need to be investigated on a regional scale.

The purpose of this study was to investigate the impacts of climate change on water resources in the Srepok watershed of the Central Highlands of Vietnam. Projections were based on the climate scenarios A1B and B1, developed from an ensemble of GCMs for the periods 2010-2039, 2040-2069, and 2070-2099 and these were compared with baseline data for the period 1980-2009. The results obtained in this study are expected to help water managers get a better insight into the climate change impacts on the availability of water resources.

10.2 METHODOLOGY

10.2.1 Study area

The Srepok watershed, a sub-basin of the Mekong River basin, is located in the Central Highlands of Vietnam, and lies between latitudes 11°45′–13°15′N and longitudes 107°15′–109°E (Figure 10.1).The Srepok River is formed by two main tributaries: the Krong No and Krong Ana rivers. The total area of this watershed is approximately 12,000 sq.km with a population of 2.2 million (2009). The average altitude of the watershed varies from 100m in the northwest to 2,400m in the southeast. The climate in the area is very humid (78–83 per cent annual average humidity) with annual rainfall varying from 1,700mm to 2,300mm and features a distinct wet and dry season. The wet season lasts from May to October (with peak floods often in September and October) and accounts for over 75–95 per cent of the annual precipitation. The mean annual temperature is 23°C.

In this watershed, there are two dominant soils: grey and red-brown basaltic. These soils are highly fertile consistent with agricultural development. Agriculture is the main economic activity in this watershed, of which coffee and rubber production are predominant.

10.2.2 SWAT hydrological model

The SWAT model is a physically based distributed model designed to predict the impact of land management practices on water, sediment, and agricultural chemical yields in large

<< Back to contents

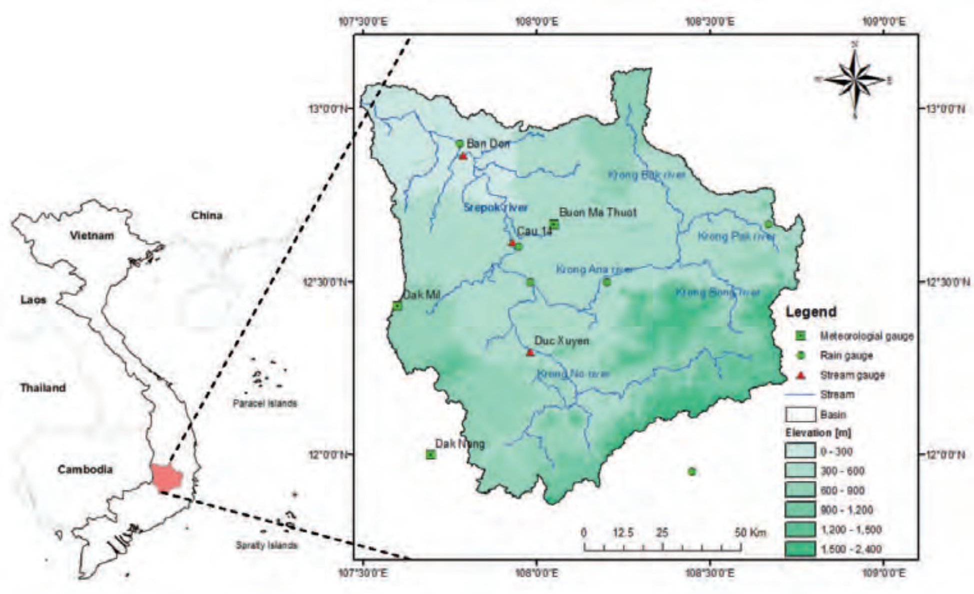


Figure 10.1: Location map of the Srepok watershed

complex watersheds with varying soil, land-use, and management conditions over long periods of time (Neitsch*et al.*, 2011). With this model, a catchment is divided into a number of sub-watersheds or sub-basins. Sub-basins are further partitioned into hydrological response units (HRUs) based on soil types, land use, and slope classes that allow a high level of spatial detail simulation. The model predicts the hydrology at each HRU using the water balance equation as follows:

$$SW_t = SW_0 + \sum_{i=1}^{t}\left(R_{day} - Q_{surf} - E_a - w_{seep} - Q_{gw}\right) \quad (11.1)$$

where SW_t is the final soil water content (mm H_2O), SW_0 is the initial soil water content on day i (mmH_2O), t is the time (days), R_{day} is the amount of precipitation on day i (mm H_2O), Q_{surf} is the amount of surface runoff on day i (mm H_2O), E_a is the amount of evapo transpiration on day i (mm H_2O), w_{seep} is the amount of water entering the vadose zone from the soil profile on day i (mm H_2O), and Q_{gw} is the amount water return flow on day i (mm H_2O). A detail description of the different model components can be found in the SWAT Theoretical Documentation (Neitsch *et al.*, 2011).

10.2.3 SWAT model setup

In this study, SWAT 2009 with an ArcGIS 9.3-supported interface has been used. The SWAT model requires a digital elevation map (DEM), soil map, land-use map, and climate data, for modelling a watershed. Table 10.1 summarizes the input data used in the study. After data preparation, the model setup then performed the following four main steps: (i) watershed delineation, (ii) hydrologic response unit (HRU) definition, (iii) model run, and (iv) calibration and validation of the model (Fiseha *et al.*, 2013).

During the watershed delineation, the 90m DEM was used for watershed configuration and topographical parameterization. The Srepok watershed was delineated and subdivided into 51 sub-watersheds with a threshold area of 10,000ha and the characteristics of the watersheds such as slope gradient, slope length and the streamflow network characteristics were also generated. In the second step, the HRU definition was performed through the 'HRU analysis' module. Based on unique land-use type, soil type and slope class, the sub-watersheds have been further divided into HRUs. In defining HRUs, threshold value of 10 per cent for land-use, slope, and soil were considered to ignore minor land-use, slope, and soil types in each sub-watershed. Overall, there were 430 HRUs defined in the entire watershed within the 51 sub-watersheds. The third step uses the necessary meteorological data inputs and the essential information from HRUs defined from the previous step. In this study, we used 9 stations for precipitation and 3 stations for temperature. These weather stations were assigned to each sub-watersheds based on their proximity to centroids of the sub-watersheds. The simulation was run first for the calibration period of 1980 to 1990 using the first year as a warm-up period to stabilize the model. In the last step in the modelling process, the SWAT model was calibrated with 10 years of discharge data (1981-1990) and validated from 1991 to 2000 at DucXuyen, Cau 14, and Ban Don Stations using the auto-calibrated tool that is currently available in the SWAT Interface. The discharge data were obtained from the Hydro-Meteorological Data Centre.

10.2.4 Performance evaluation of the SWAT model

The Nash-Sutcliffe efficiency (NSE) and percent bias (PBIAS) were used as statistical indices to assess the goodness of fit of the model. The NSE determines the relative magnitude of the residual variance compared with the measured data variance and the PBIAS measures the average tendency of the simulated value to be larger or smaller than their observed counterparts. The NSE value is defined by

<< Back to contents

$$NSE = 1 - \frac{\sum_{i=1}^{N}(O_i - S_i)^2}{\sum_{i=1}^{N}(O_i - \bar{O})^2} \qquad (11.2)$$

and the PBIAS value is defined by

$$PBIAS = \left[\frac{\sum_{i=1}^{N}(O_i - S_i) \times 100}{\sum_{i=1}^{N}(O_i)}\right] \qquad (11.3)$$

where O is the observed discharge, S is the simulated discharge, and N is the number of observed discharge data.According to Moriasi*et al.* (2007), the values of NSE greater than 0.5 and the PBIAS values less than 25 per cent indicate satisfactory model performance for flow simulation.

Table 10.1: Data sources for the Srepok watershed

Data type	Data description	Scale	Data sources
Topography	Elevation	90m	STRM
Land-use	Land-use classification such as agricultural land, forest, and urban	1km	GLCC
Soil	Soil types and physical properties	10km	FAO
Meteorology	Daily precipitation, minimum and maximum temperature	Daily	Hydro-Meteorological Data Centre (HMDC)

10.2.5 Climate change scenarios

Climate change scenarios were developed for three future periods (2010 to 2039, 2040 to 2069, and 2070 to 2099) using an ensemble of four GCM simulations (CGCM3.1(T63), CM2.0, CM2.1, and HadCM3) driven by the A1B and B1 emission scenarios obtained from IPCC-AR4 (2007). The four GCM simulations were chosen based on statistical evaluation of GCM performance in reproducing historical rainfall for the Be River Catchment that is close to the Srepok watershed (Khoi and Suetsugi, 2012). The detailed information about the 4 GCMs is listed in Table 10. 2.

The GCMs accurately represent climate on a global scale, but are inaccurate when simulating climate at a regional scale (Boyer *et al.*, 2010). In order to apply the GCMs on a regional scale and create future climate scenarios for local hydrological impact assessment, the delta change method was used to downscale GCM output to regional level. The delta change method has been widely used in previous climate change studies (Boyer *et al.*, 2010; Kienzle*et al.*, 2012). In essence, it modifies the observed historical time series by adding the difference between future and the baseline periods as simulated by a GCM. The differences are then added to the observed daily maximum and minimum temperature during the baseline period while the ratio is applied to precipitation

10.3 RESULTS AND DISCUSSION

10.3.1 SWAT calibration and validation

The SWAT hydrological parameters used for calibration and validation of the model were selected by referring the relevant study in the Be River Catchment (Khoi and Suetsugi, 2012). The selected parameters for the flow simulation were CN2, ESCO, GWQMN, ALPHA_BF, SOL_Z, SOL_AWC, CH_K2, GW_REVAP, CH_N2, and SOL_K. The calibration and validation of the SWAT model for the Srepok watershed were carried out by comparing

Table 10.2: List of 4 GCMs used in this study

Code	Centre, country	Centre abbreviation	Model identify	Model resolution (degree)
1	Canadian Centre for Climate Modelling and Analysis, Canada	CCCMA	CGCM3.1 (T63)	3.75x3.71
2	Geophysical Fluid Dynamics Laboratory, United States	GDFL	CM2.0	2.50x2.02
3			CM2.1	2.50x2.02
4	UK Met Office, United Kingdom	UKMO	HadCM3	3.75x2.50

Table 10.3: Model performance for the simulation of streamflow

Period	Time step	DucXuyen station		Cau 14 station		Ban Don station	
		NSE	PBIAS	NSE	PBIAS	NSE	PBIAS
Calibration 1991-1990	Daily	0.57	-3%	0.68	1%	0.72	-8%
	Monthly	0.70		0.78		0.82	
Validation 1991-2000	Daily	0.58	3%	0.70	3%	0.75	-3%
	Monthly	0.69		0.88		0.90	

<< Back to contents

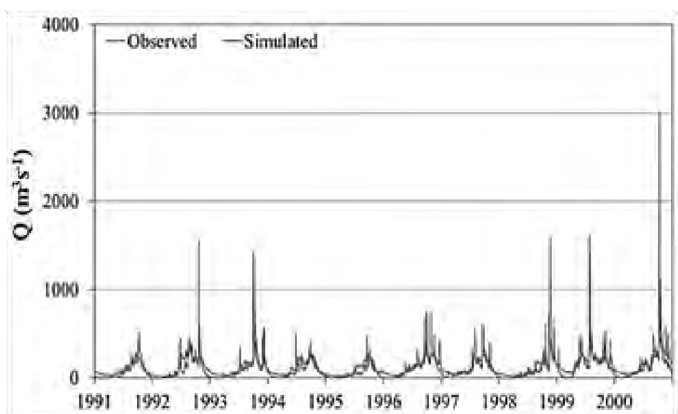
the simulated streamflow with the observed flow at main gauging stations (DucXuyen, Cau 14, and Ban Don stations).The plots of observed and simulated daily flow are presented in Figures 10.2, 10.3 and 10.4. It shows that the model could produce the similar trend between observed and simulated streamflow during the calibration and validation periods. Although the similar trend was achieved, the peak streamflow was not well matched. This may have resulted from uneven representation of spatial distribution of rainfall. The statistical indicators for evaluation of the model performance computed using daily and monthly streamflow in the calibration and validation periods are listed in Table 10.3.

The observed and simulated daily streamflow showed a good agreement with the NSE and PBIAS values varying in the range of 0.57 to 0.72 and -8 to 1 per cent, respectively, for the calibration period. For the validation period, the NSE and PBIAS values varied from 0.58 to 0.75 and -3 to 3 per cent, respectively. Using aggregated monthly average streamflow values based on daily streamflow values improved the fit between simulated and observed values. The fit was indicated by the NSE values varying in the range of 0.70 to 0.82 for the calibration period and 0.69 to 0.90 for the validation period. In general, the SWAT model could capture the hydrological characteristics of the watershed reasonably well and the calibrated model could be used to examine the impacts of climate change on water resources of the Srepok watershed.

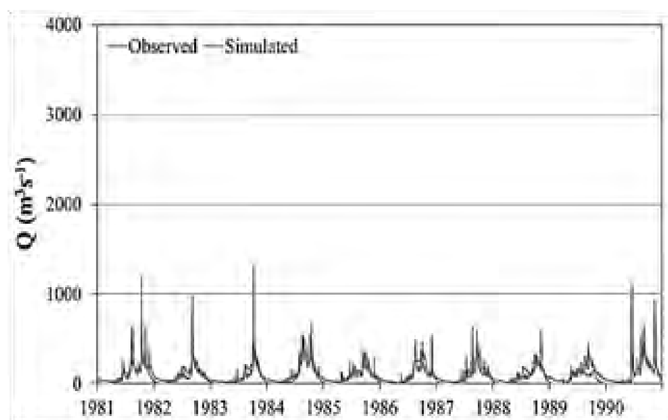
10.3.2 Climate change scenarios

Future climate conditions were determined using an ensemble of GCMs (CGCM3.1 (T63), CM2.0, CM2.1, and HadCM3) driven by the A1B and B1 emission scenarios. Figure 10.5 illustrates the shift in annual distribution of temperature and precipitation in the future compared with the baseline period. Analysis of temperature change indicates an obvious increase in future temperatures. The annual average temperature in the A1B scenario has a mean shift of 1°C for the 2020s, 1.7°C for the 2050s, and 2.5°C for the 2080s, while the B1 shift is 0.8ºC in the 2020s, 1.3ºC in the 2050s, and 1.8ºC in the 2080s. The ensemble averages for all time periods indicate more warming from the mid-dry season to the early wet season. Averaged over all GCMs, the annual precipitation

Figure 10.2: Observed and simulated hydrographs at the DucXuyen station for the (a) calibration and (b) validation periods

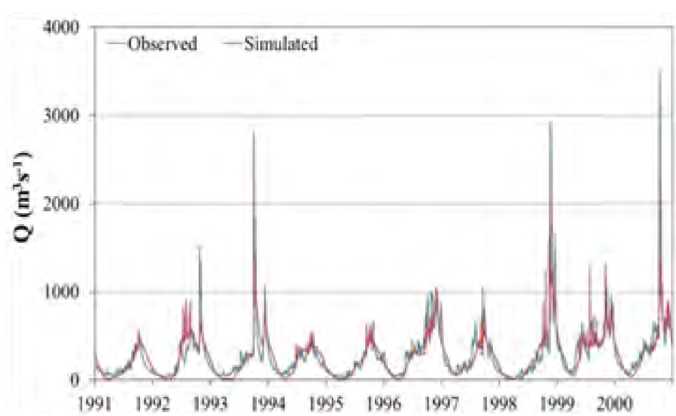


(a)

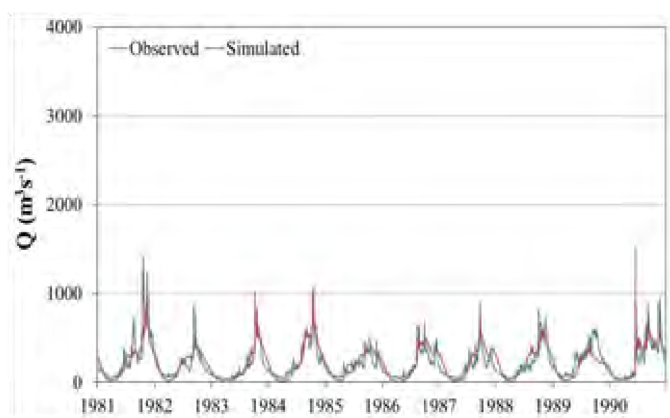


(b)

Figure 10.3: Observed and simulated hydrographs at the Cau 14station for the (a) calibration and (b) validation periods

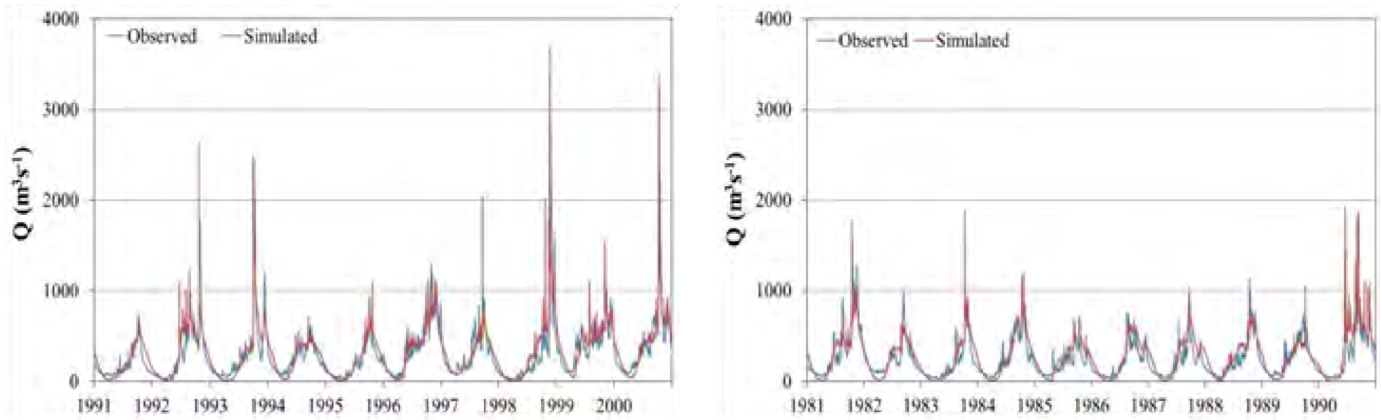


(a)



(b)

Figure 10.4: Observed and simulated hydrographs at the Ban Don station for the (a) calibration and (b) validation periods



(a) (b)

decreases 0.4 per cent in the 2020s and 2.5 per cent in the 2050s, and increases 0.7 per cent in the 2080s for the A1B scenario. By the B1 scenario, the precipitation decreases 4.7 per cent in the 2020s and 1.9 per cent in the 2050s, and increases 1.7 per cent in the 2080s. There are many possible reasons for a precipitation decrease in the 2020s and 2050s and an increase in the 2080s. However, they are most likely attributed to the GHG emission scenarios. In the dry season (November to April), precipitation significantly decreases within a range from 10.1 to 19.6 per cent for the 2020s, from 10.9 to 13.0 per cent for the 2050s, and from 5.8 to 12.2 per cent for the 2080s. In the wet season (May to October), the precipitation slightly changes, ranging from -1.4 to 1.9 per cent in the 2020s, from -0.7 to 0.6 per cent in the 2050s, and from 2.9 to 3.4 per cent in the 2080s. Changes in both temperature and precipitation are clear.

10.3.3 Hydrological response to climate change

Figure 10.6 shows the changes in water balance components compared with the baseline periods. Under the climate change scenarios, actual evapotranspiration (ET) is predicted to increase from 0.9 to 2.8 per cent in the A1B scenario and change from -1.0 to 2.8 per cent in the B1 scenario, and potential evapotranspiration (PET) is predicted to increase by 3.1 to 8.3 per cent for the A1B scenario and by 2.8 to 5.7 per cent for the B1 scenario. This can be explained by increases in temperature and changes in precipitation in the future. Surface runoff (SURQ) is estimated to decrease from 0.6 to 7.6 per cent in the A1B scenarios. In the B1 scenario, SURQ decreases from 3.5 to 10 per cent in the 2020s and 2050s, and increases 3.5 per cent in the 2080s. In general, the pattern of change in SURQ is similar to changes in rainfall. In terms of all other water balance components, climate change in the A1B scenario causes a 3.9 to 12.5 per cent decrease in groundwater discharge (GW_Q), a 1.3 to 4.2 per cent decrease in lateral flow (LAT_Q), a 2 to 7.4 per cent in amount of water percolation (PERC), and a 5.6 to 8.0 per cent decrease in soil water content (SW). Under the B1 scenario, GW_Q, LAT_Q, PERC, and SW are predicted to decrease by 3.8 to 10.8 per cent, 0.4 to 5.6 per cent, 1.2 to 7.0 per cent, and 5.1 to 7.3 per cent, respectively.

Figure 10.5: Changes in monthly precipitation and temperature for the A1B (left) and B1 (right) scenarios for three time periods: 2010 to 2039, 2040 to 2069 and 2070 to 2099

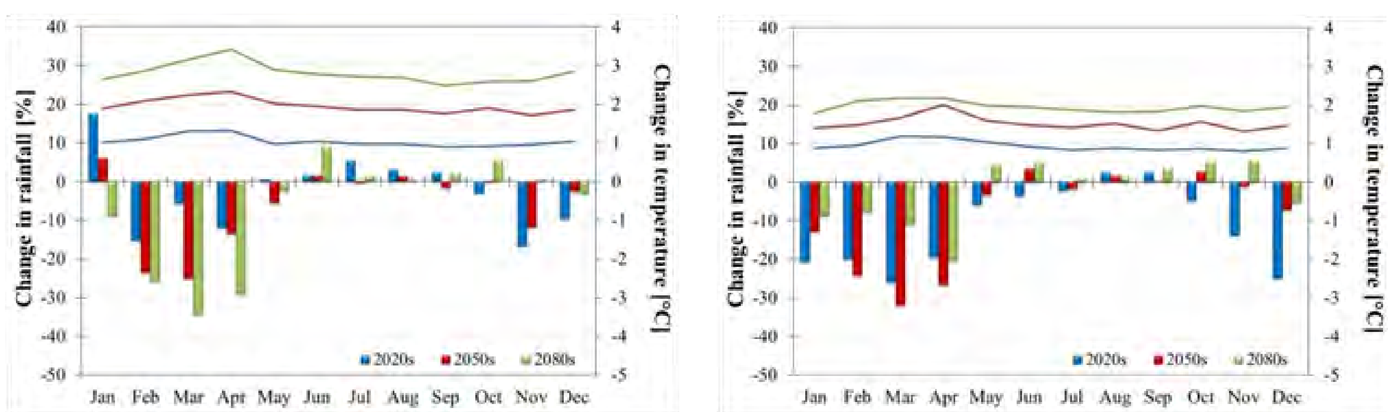


Figure 10.6: Changes in monthly precipitation and temperature for the A1B (left) and B1 (right) scenarios for three time periods: 2010 to 2039, 2040 to 2069 and 2070 to 2099

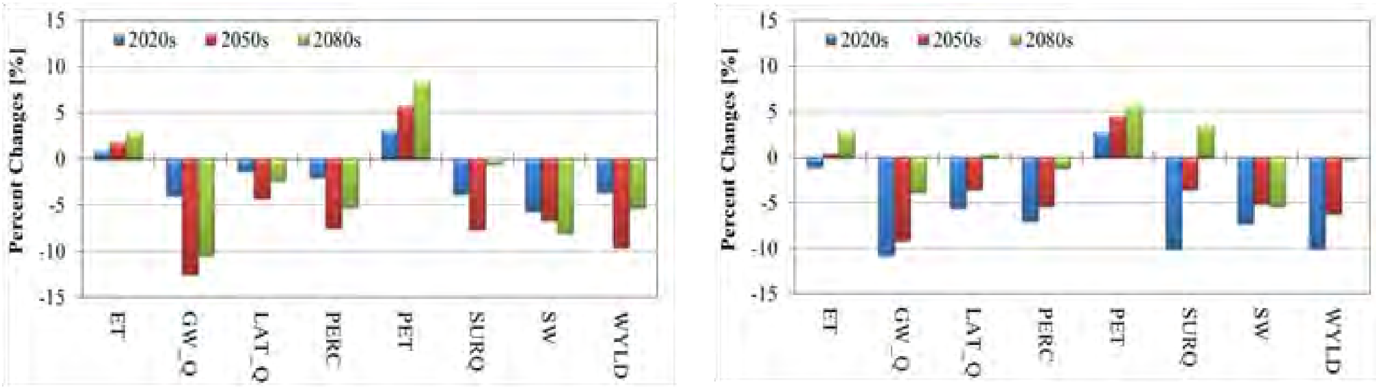
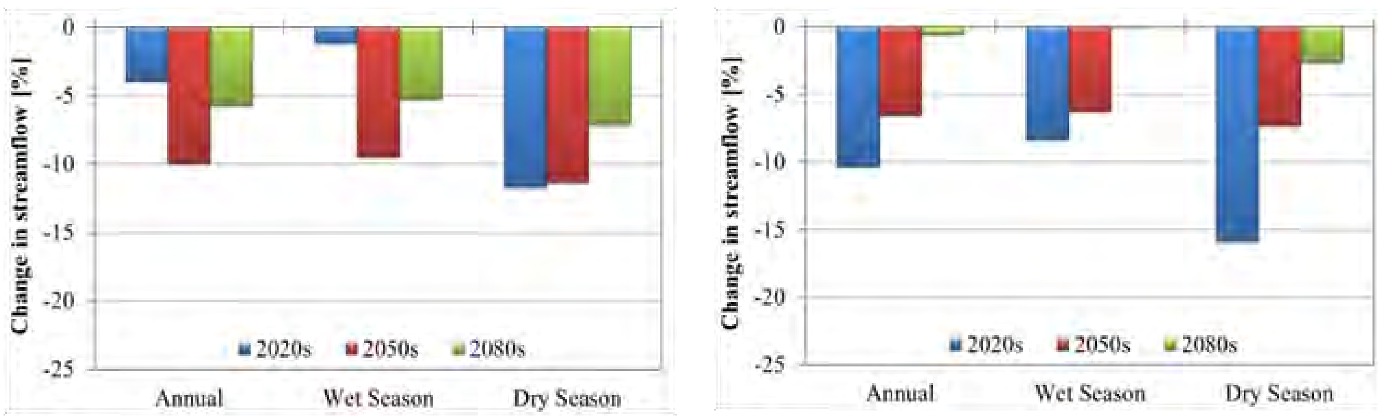


Figure 10.7: Changes in annual and seasonal streamflow for the A1B (left) and B1 (right) scenarios for three time periods: 2010 to 2039, 2040 to 2069 and 2070 to 2099



Under the impact of climate change scenarios, the annual streamflow is predicted to decrease during the three future periods (Figure 10.7). The decrease of annual discharge is 4.0, 10.0 and 5.7 per cent for the A1B scenario and 10.3, 6.6 and 0.6 per cent for the B1 scenario in the 2020s, 2050s and 2080s, respectively. The decreases in streamflow can be explained by increases in evapotranspiration caused by the increase in temperature and decreases in precipitation. In the case of seasonal streamflow, the predicted streamflow decreases in a range from 1.2 per cent to 8.3 per cent and 6.3 per cent to 9.5 per cent in the wet season for the 2020s and 2050s, respectively. By the 2080s, the wet-season streamflow changes from -5.2 to 0.2 per cent. In the dry season, the predicted streamflow decreases considerably varied from 11.7 per cent to 15.9 per cent, 7.3 to 11.3 per cent and 2.6 per cent to 7.1 per cent for the 2020s, 2050s and 2080s, respectively. In general, different seasons will present different streamflow change patterns. In addition, the seasonal streamflow change is not dramatic (less than ±20 per cent) in the future.

10.4 CONCLUSION

Assessment of climate change impacts on water resources is very important for river basin management and developing suitable adaptation strategies. In this study, the SWAT model was applied to simulate the responses of streamflow and water balance components to changes in climate in the Srepok watershed in the Central Highlands of Vietnam. The SWAT model was calibrated and validated against observed streamflow data and performed well during the calibration and validation periods for the study area. Therefore, the calibrated SWAT model could be used for investigating the impacts of climate change scenarios on water resources. The climate change scenarios for the Srepok watershed were generated from an ensemble of 4 GCMs using the simple downscaling method (delta change method) for the periods 2010-2039, 2040-2069, and 2070-2099. The climate change scenarios revealed that the climate in the study area would generally become warmer and drier in the future. Under the possible climate change, annual and wet-season streamflow would decrease slightly in the future while the dry-season streamflow would decrease rapidly. This would raise concerns regarding water shortages during the dry season in the future, which could be a problem for adequate irrigation purposes.

The results obtained in this study are not predictions, but are plausible changes in the streamflow. This initial work could be as a reference for the policy makers to provide them some idea of future changes to devise adaptation plans suitably. Further

<< Back to contents

research work is expected to focus on effect of land-use change and consideration of advanced downscaling methods such as SDSM and LARG-WS to arrive at more reliable estimation of changes in water resources in the watershed.

REFERENCES

Boyer, C., Chaumont, D., Chartier, I., Roy, A.G., 2010. Impact of climate change on the hydrology of St. Lawrence tributaries. *Journal of Hydrology,* 384, 65–83.

Deque, M., Rowell, D.P., Luthi, D., Giorgi, F., Christensen, J.H., Rockel, B., Jacob, D., Kjellstrom, E., de Castro, M., van den Hurk, B., 2007. An intercomparison of regional climate simulations for Europe: assessing uncertainties in model projections. *Climatic Change,* 81, 53–70.

Fiseha, B.M., Setegn, S.G., Melesse, A.M., Volpi, E., Fiori, A., 2013. Hydrological analysis of the Upper Tiber River Basin, Central Italy: a watershed modelling approach. *Hydrological Processes,* 27 (16), 2339–2351.

IPCC, 2007. The Physical Science Basis: Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, UK.

Islam, A., Sikka, A.K., Saha, B., Singh, A., 2012. Streamflow response to climate change in the Brahmani River Basin, India. *Water Resource Management,* 26, 1409–1424.

Khoi, D.N., Suetsugi, T., 2012. Hydrologic response to climate change: a case study for the Be River Catchment, Vietnam. *Journal of Water and Climate Change,* 3(3), 207–224.

Kienzle, S.W., Nemeth, M.W., Byrne, J.M., MacDonald, R.J., 2012. Simulating the hydrological impacts of climate change in the upper North Saskatchewan River Basin, Alberta, Canada. *Journal of Hydrology,* 412-413, 76–89.

Kim, U., Kaluarachchi, J.J., 2009. Climate change impacts on water resources in the upper Blue Nile River basin, Ethiopia. *Journal of the American Water Resources Association,* 45 (6), 1361–1378.

Kling, H., Fuchs, M., Paulin, M., 2012. Runoff conditions in the upper Danube basin under ensemble of climate change scenarios. *Journal of Hydrology,* 424-425, 264–277.

Li, F., Zhang, Y., Xu, Z., Jin, T., Liu, C., Liu, W., Mpelasoka, F., 2013. The impacts of climate change on runoff in the southeastern Tibetan Plateau. *Journal of Hydrology,* 505, 188–201.

MONRE - Ministry of Natural Resources and Environment, 2009. Climate Change, Sea Level Rise Scenarios for Vietnam.Vietnam Ministry of Natural Resources and Environment, Hanoi.

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. *Transactions of the ASABE,* 50, 885–900.

Narsimlu, B., Gosain, A.K., Chahar, B.R. 2013. Assessment of future climate change impacts on water resources of upper Sind River basin, India using SWAT model. *Water Resources Management,* 27, 3647–3662.

Neitsch, A.L., Arnold, J.G., Kiniry, J.R., Williams, J.R., 2011. Soil and Water Assessment Tool Theoretical Documentation Version 2009. Texas Water Resources Institute Technical Report No. 406. Texas A&M University, Texas.

Raghavan, S.V., Vu, M.T., Liong, S.Y., 2012. Assessment of future streamflow over the Sesan catchment of the Lower Mekong Basin in Vietnam. *Hydrological Processes,* 26(24), 3661–3668.

Wang, W., Shao, Q., Yang, T., Peng, S., Xing, W., Sun, F., Luo, Y., 2013. Quantitative assessment of the impact of climate variability and human activities on runoff changes: a case syudy in four catchments of the Haihe River basin, China. *Hydrological Processes,* 27 (8), 1158–1174.

11

Effect of Clear-cutting in the Forest Plantation Establishment in a Small Forested Catchment

S Siti Aisah , Z Yusopand S. Noguchi

11.1 INTRODUCTION

The effects of deforestation on catchment hydrology are dependent on the removal of dominant plant species and the climate (Newson, 1997). In catchments that receive high rainfall and have tall vegetation, streamflow is a useful indicator of hydrological responses to land-use change (Ward and Robinson, 2000). Increase in water yield would be expected following deforestation or removal of forest cover. The magnitude of increase varies with the annual rainfall and the proportion of cover removed (Newson, 1997).

In Malaysia, the main conversion of forest is from lowland forest to agriculture, especially rubber and oil palm plantations, which started in the early 1960s. The study on hydrological parameters by Abdul Rahim (1988) on the conversion of forest to cocoa and oil palm plantations revealed that the highest increases in water yield occurred in the second and fourth years after treatment with 157 per cent and 470 per cent of increments. The forested catchment had been subjected to timber logging, clear felled, burning of logs, road construction and tree plantings. Another study carried out by Abdul Rahim and Harding (1992) showed the effects of selective logging (commercial and supervised) on water yield and streamflow. They found significant water yield increases in both catchments, of which 70 per cent was from commercial logging and 37 per cent from supervised logging following the treatments, and the increases continued until the fourth year. Forest plantation will be the future source of timber to meet the forest resources demand and also because logging in upper hill forest will be more costly. However, there is no examination on the effect of establishment of forest plantation on runoff characteristics in Malaysia.

The aims of the study were; i) to quantify the yearly water yield changes before and after forest clear-cutting in C3; ii) the effect of forest clearance on peak discharges (Q_p) and regression analysis on dummy variables for logging effects on peak discharge (Q_p) and iv) water balance of the young *Hopea odorata* catchment.

11.2 METHODOLOGY

11.2.1 Study site

This study was conducted in catchment C1 (32.8 ha) and C3 (14.4 ha) at Bukit Tarek Experimental Watershed (3°31'30"N, 101°35'E, 48–213 m), Peninsular Malaysia. This forest is classified as a lowland rainforest and was first logged in 1963. The vegetation is dominated by *Koompassia malaccencis*, *Eugenia* spp., and *Canarium* spp. The period between June 1997 to October 1999 was taken as a calibration periods. The commercial timber trees in C3 were logged from November 1999 until August 2000. The remaining unmerchantable trees were clear-cut and the residual trees were burnt from December 2003 to January 2004 prior to forest planting. The *Hopea odorata* trees were planted in April 2004. The trees were about two years old when this study was initiated. The period of data observed from September 2000 to December 2003 was considered as period after forest logging.

This area is dominated by metamorphic rock from Arenaceous series with silt sediment formed in the Triassic Era (Roe, 1951). Some slope in these catchments can reach up to 40° as a result of metamorphic process in this area with strong forces from both W-SW directions (Saifuddin, 1991; 1994).

11.2.2 Hydrological observation

Runoff discharge was measured at the 120-degree V-notch wier at the stream outlet of catchment. Weir flow rate was continuously monitored using float-type water level instruments (C1: Steven's Frecorder; C3: W-021, Yokogawa, Japan) and capacitive water level sensor (C1 and C3: WT-HR, TruTrack, NZ). The discharge was calculated using a rating table for discharge-stage relationships. Rainfall was measured by a standard manual storage rain gauge and a tipping bucket rain gauge near the weirs.

11.2.3 Data analysis

The average daily discharges of years 1997, 1998, 1999, 2000, 2001, 2002, 2003, 2004, 2006, 2007 were used to determine the water yields based on the water years in Malaysia which starts from July of each year to June the following year. Water year, also known as hydrologic year, which is from 1 July to 30 June of the following year, is the period for the southern hemisphere. It is based on any twelve-month period, usually selected to begin and end during a relative dry season and used as basis for processing streamflow and other hydrological data.

The statistical analysis was conducted using Minitab. Minitab is a powerful software programme that provides a wide range of basic and advanced data analysis capabilities (Ryan and Joiner, 1994). The regression analysis of dummy variation was carried out to detect the changes in flows of the treated catchment (C3)

<< Back to contents

by using the peak discharge parameter. The method used to compare regressions by the approach of dummy variables follows the multi-step Chow test procedure. This technique was originally described by an economist (Gujarati, 1970) and then applied in hydrological research by Hewlett (1982), Hewlett and Ros (1984), Swindle and Douglass (1984) and Hsia (1987). Multiple linear regression with dummy variables was applied to explain the relationship between X and Y at difference phases. In general, the multiple linear regression model used for analyzing the data is as follows:

$$Y = \alpha_1 + \beta_1 X + \alpha_2 D_2 + \alpha_3 D_3 + \alpha_4 D_4 + \beta_2 D_2 X + \beta_3 D_3 X + \beta_4 D_4 X + e \qquad (11.1)$$

where,

Y is peak discharge of treated catchment (C3), X is peak discharge of control catchment (C1),

$$D_2 = \begin{cases} 1, & \text{for forest clear - cutting phase} \\ 0, & \text{for other phases} \end{cases}$$

$$D_3 = \begin{cases} 1, & \text{for recovery phase} \\ 0, & \text{for other phases} \end{cases}$$

$$D_4 = \begin{cases} 1, & \text{for after planting phase} \\ 0, & \text{for other phases} \end{cases}$$

α_i, and β_i areparameters of regression model.

Full model regression equation is as follows:

$$Y = \alpha_1 + \alpha_2 D_2 + \alpha_3 D_3 + \alpha_4 D_4 + (\beta_1 + \beta_2 D_2 + \beta_3 D_3 + \beta_4 D_4) X + e$$
$$= \alpha_1 + \alpha_2 D_2 + \alpha_3 D_3 + \alpha_4 D_4 + \beta_1 X + \beta_2 D_2 X + \beta_3 D_3 X + \beta_4 D_4 X + e \qquad (11.2)$$

where, α_1 is intercept before clear felling (Calibration), α_2, α_3 and α_4 are differential intercepts, β_1 is slope coefficient before clear felling, and β_2, β_3, and β_4 are differential slope coefficients.

11.3 RESULTS

11.3.1 Water yield changes

With annual rainfall ranging from 2,167 to 3,386 mm in the forested catchment (C1), the water balance analysis yielded ET values ranging from 1,153 to 1,621 mm and discharge from 632 to 1859 mm (Table 11.1). From these figures, about 43–70 per cent of the rainfall in the forested catchment formed a hydrologic loss showing the high evapotranspirative demands of humid tropical forest. This finding is compatible with other experimental catchment research by Low and Goh (1972) for five forested catchments in Selangor and Abdul Rahim (1988). The water yield of C1 was very low in year 1997-98 which coincided with the extreme weather that occurred in the same year. The rainfall received was also low compared with the long-term average (2,816 mm). Meanwhile, the water yield changes of C3 also had a similar pattern and it showed that the discharge amount before forest clearance in C3 was lower than in C1 (Table 11.1). This is related to the differences between the two catchments. C1 is of a bigger size and of a higher stream order than C3.

Table 11.1: Water yields of C1 based on water years from 1997 to 2003

	97/98	98/99	99/2000	2000/01	2001/02	2002/03
Q (mm)	631.7	1276.9	1725.6	1554.2	1051.8	1859.2
P (mm)	2167.2	2898.0	3177.0	2707.0	2507.0	3385.8
ET (mm)	1535.5	1621.1	1451.4	1152.8	1455.2	1526.6

11.3.2 Effect of forest clearance on peak discharges (Q_p) and regression analysis on dummy variables for logging effects on peak discharge (Q_p)

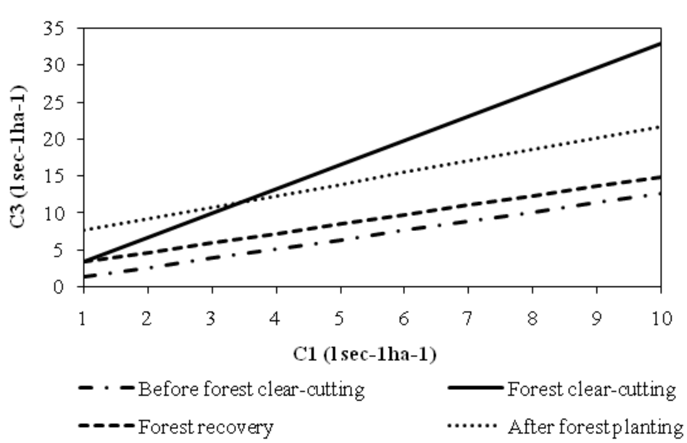
There are four regression equations from the four stages involved in the forest conversion that is calibration period, during forest clear-cut operation, forest recovery period and after forest planting. Figure 11.1 shows that peak discharges being higher in C3 compared with C1 before the forest was clear-cut could be due to the differences in forest density between the two catchments. The peak magnitudes were increased during the period of forest clearance and slowly decreased in the subsequent years. The peak magnitudes increased more with forest clearance again before tree planting and decreased in the subsequent years after the forest plantation was established which was from years 2004 to 2007.

11.3.3 Regression analysis on dummy variables for logging effects on peak discharge (Q_p)

Multiple linear regression with dummy variables was applied to explain the relationship between a peak discharge of control catchment (C1); X and a peak discharge of treated catchment (C3); Y at difference phases (Table 11.2). By using Minitab, the results of multiple linear regressions with dummy variables could be written as:

$$Y = 0.043 + 2.15\,D_2 + 2.21\,D_3 + 6.03\,D_4 + 1.37\,X + 1.40\,D_2X - 0.148\,D_3X + 0.182\,D_4X + e \qquad (11.3)$$

Figure 11.1: Linear regressions of Qp between treated catchment (C3) and control catchment (C1) for each phase



<< Back to contents

Table 11.2: Water yields of C3 based on water years from 1997 to 2003

	97/98	98/99	99/2000	2000/01	2001/02	2002/03
Q (mm)	418.7	1005.0	1490.0	1557.6	845.5	1352.3
P (mm)	2167.2	2898.0	3177.1	2707.0	2506.9	3385.8
ET (mm)	1748.5	1893.0	1687.1	1149.1	1661.4	2033.5

Note: Forest clearing took place in Nov 1999–Dec 2001

The results also show that not all of the parameters in the model are statistically significant at 5 per cent level of significance. D_3 ($p<0.05$), D_4($p<0.001$), X ($p<0.001$), and D_2X ($p<0.05$) are statistically significant but D_3X ($p=0.641$) and D_4X ($p=0.551$) are not statistically significant. These results also show that the estimation process of the multiple linear regression model can be continued until the final multiple linear regression was determined (i.e. model with all parameters are significant).

By using stepwise procedure, the results show that five predictors (independent variables) significantly influence the variable Y, i.e. variable X ($p<0.001$), D_4 ($p<0.001$), D_2X ($p<0.001$), D_4X ($p<0.05$), and D_3($p<0.05$) (in chronological order at stepwise results). In this final model, the constant (intercept) is not significant ($p=0.599$), so we eliminate the constant from the model and re-estimate the model without the constant. Therefore, the final multiple linear regression model could be written as follows:

$$Y = 2.11\,D_3 + 6.07\,D_4 + 1.26\,X + 2.02\,D_2X + 0.290\,D_4X + e \qquad (11.4)$$

This model shows that variable X was significant with reference to variable Y and the effects were different for each phase. The effect of X on Y at the forest clear-cutting phase is the largest compared with other phases (Table 11.3). The largest slope (b) occurs at forest clear-cutting phase, i.e. 3.28. It means that the increasing of X at this phase also yielded the largest increasing of Y compared with other phases, i.e. 1.55 at the after planting phase, and 1.26 at both calibration and recovery phases. The peak discharges increased higher in C3 than C1 after the removal of forest canopy as the hydrograph response also showed the faster response and shorter stormflow duration in C3 with sharp rising limb and recession compared with C1 with comparatively less steep rising limb and longer stormflow duration with the effect of forest canopy cover.

Additionally, the constant at the after planting phase was the largest compared with other phases, i.e. 6.07, 2.11, and 0 for the after planting phase, recovery phase, and both forest clear-cutting and calibration phases, respectively. This shows that forest clearance changed the hydrological condition of the forested catchment with the effect to the peak discharge still existing years after the forest was planted and it would take time to go back to its original state with the forest recovery or it would not.

Table 11.3: Constants and slope values for each phase

Phase	Coefficient model: Y = a + b X	
	a (constant)	b (slope)
Calibration phase	0	1.26
Forest clear-cutting phase	0	3.28
Recovery phase	2.11	1.26
After planting phase	6.07	1.55

11.3.4 Water balance of the young *Hopea odorata* catchment

Table 11.4 shows that water yield in C3 was higher than in the C1. The total discharges of about 61.4 per cent of rainfall in C3 and only 58.2 per cent of rainfall in C1 are compatible with the large amounts of rainfall received during this period and also after comparison with previous years' discharges. The ET was higher in C1 with the matured, dense forest canopy cover. The difference was only 188 mm which is small if compared with the yearly total and considering that the forest plantation was in the growing stage.

11.4 CONCLUSION

The site was clear-cut and the use of heavy machinery during site preparation damaged the soil surface and increased the surface runoff. The water yield in C3 was still higher than in the C1 after the two years of forest plantation establishment. The results from this study are consistent with the findings from small paired-watershed studies with the area of less than 100 sq.km. The annual runoff was found almost similar with the finding from other studies despite the different in forest species, forestry operation and climatic condition. This has been shown in the studies by Scott and Prinsloo (2008) and Alila *et al.* (2009). The effects also were found in earlier studies by Bruijnzeel (2004) and Waterloo *et al.* (2007). We can see that the significant effect on discharge was effective during forest clearance and the recovery period was taken for 2-3 years. The study of five small catchments by Webb *et al.* (2012) showed a significant increased in streamflow following forest disturbance. For the catchment which involved logging and burning, the annual runoff had returned to pre-treatment levels within 2.5 years. The annual water yield changes ranging from 120−319.6 mm.

The study case of impacts of forest harvesting on hydrology in a large watershed (>1000 sq.km) which was conducted by Zhang *et al.* (2012) at Yangtze River basin (2,528 sq.km) showed

Table11.4: Water balance at Bukit Tarek Experimental Watershed, water year 2006/07

Water year (July06/ June07)	Rainfall (mm)	Total discharge (mm)	Evapo-transpiration (mm)	Interception (mm)
Plantation catchment (C3)	3473.7	2133.9 (61.4%)	1339.8 (38.6%)	(12.7-19.5%)
Natural forested catchment (C1)	3473.7	2021.7 (58.2%)	1452.0 (41.8%)	(13.6%)

Note: Forest planting started in 2004

that the significant annual runoff change occurred about 10 years after the intensive harvesting with the average in annual runoff increment was 38 $mmyr^{-1}$.

The largest effect on the changes can be seen in the analysis of single peak storm events. The increase in peak flow following forest clearing was also observed by Guillemettea *et al.*(2005) in Montmorency Forest in Quebec, Canada. Further analysis of the dummy regression showed the effect of forest clearing in increasing the peak discharge in C3 in relation to C1. The equation derived from the regression analysis on dummy variables showed the relationships between the control and treated catchments. These relationships can be used to predict water yield (peak discharge) that would occur in the treated catchment, which can be applied to other treatment catchment at different sites.

The colonization by undergrowth and natural vegetation expedites the hydrological recovery in the plantation catchment. There will be additional water yield for a few years while the *Hopea odorata* stands are still young and this would possibly decrease as the trees attain their full growth potential.

The area involved in the actual forest plantation establishment is very large compared with the area in this study. Normally, the whole area of forest is clear-cut in the preparation of a forest plantation establishment and definitely the effects will not be the same as what have been obtained in this study. Thus, a large forest area that is to be converted to forest plantation should be divided into phases so that the forest clearance and planting can be done phase by phase so as to reduce the effect on hydrological parameters.

Forest plantation can be established with close supervision in order to reduce the impact on the environment as the degree of disturbance determines how long is taken for the forest to revert to its background level.

In conclusion, forest plantation establishment has positive influence on the water yield of the treated catchment in Bukit Tarek Tambahan forest reserve. The understanding on hydrological processes effected by clear-cutting activities is required for the stakeholders to take into account the forest plantation establishment for forest management plan development.

ACKNOWLEDGMENTS

The authors would like to thank the Forest Research Institute Malaysia (FRIM), from which this study was financially supported by the Ministry of Science, Technology and Innovation (MOSTI) from the Science Fund (MOA) through Grant No. 31300203003.

REFERENCES

Abdul Rahim, N. and Harding, D. 1992. Effect of selective logging methods on water yield and streamflow parameters in Peninsular Malaysia. *J. Trop. For. Sci.*, 5, 130–154.

Abdul Rahim, N. 1988. Water yield changes after forest conversion to agricultural landuse in Peninsular Malaysia. *J. Trop. For. Sci.*, 1, 67–84.

Alila, Y., Kuras, P.K., Schnorbus, M. and Hudson, R. 2009. Forests and floods: a new paradigm sheds light on age-old controversies. *Water Resour. Res.*, 45(8), W08416.

Bruijnzeel, L.A. 2004. Hydrological functions of tropical forests: not seeing the soil for the trees? *Agric. Ecos. Env.*, 104, 185–228.

Guillemettea *et al*. 2005. Rainfall generated stormflow response to clear-cutting a boreal forest: peak flow comparison with 50 world-wide basin studies. *J. Hydrol.*, 302, 137–153.

Gujarati, D. 1970. Use of dummy variable in testing for equality between sets of coefficients in two linear regression. A note in *The American Statisticia*, February, 50–52.

Hewlett, J.D. and Ross, R. 1984. Forest, flood and error: A watershed experimental in the southern Piedmont. *For. Sci.*, 30, 424–434.

Hewlett, J.D. 1982. Forest and Floods in the Light of Recent Investigation. Paper Presented at Canadian Hydrology Symposium Ass. Comm. On Hydrology and National Res. Council Can. Frederiction, New Brunswick, 14-16 June, 1982.

Hsia, Y.J. 1987. Changes in storm hydrographs after clear-cutting at a small hardwood-forested watershed in central Taiwan. *For. Ecol. Manage.*, 20, 117–133.

Low, K.S. and Goh, K.C. 1972. The Water Balance of Five Catchments in Selangor, West Malaysia. *Journal of Tropical Geography* 35, 60–66.

Newson, M.D. 1997. Land, water and development: Sustainable management of river basin system. Routledge, London. pp. 351.

Roe, F.W. 1951. The geology and mineral resources of the Fraser's hill area Selangor, Perak and Pahang, Federation Malaysia with an account of the mineral resources. Memoir No. 5. Geology Survey Dept. Federation of Malaya.

Ryan, B.F. and Joiner, B.L. 1994. Minitab Handbook (Third edition). Duxbury Press. An imprint wadworth publishing company, Belmont, California. pp. 448.

Saifuddin, S. 1994. Hubungkait kiantara ciri-ciri morfometri dan sebahagian parameter hidrologi di tadahan berhutan. Tesis Ijazah Sarjana Sastera, Universiti Kebangsaan Malaysia, Bangi. pp. 266.

Saifuddin, S., Abdul Rahim, N. and Muhammad, F.R. 1991. Establishment and physical characteristics of Bukit Tarek watershed. *FRIM Res. Pam.,*110, 1–51.

Scott, D.F. and Prinsloo, F. 2008. Longer-term effects of pine and eucalypt plantations on streamflow. *Water Resour. Res.*, 44(7). W00A08.

Swindel, B.F. and Douglas, J.F. 1984. Describing and testing nonlinear treatment effects in paired watershed experiments. *For. Sci.*, 30, 305–313.

Ward, R.C. and Robinson, M. 2000. Principles of Hydrology. McGraw Hill Publishing Company. London. pp. 265.

Waterloo, M.J., Schellekens, J., Bruijnzeel, L.A. and Raweqa, T.T. 2007. Changes in catchment runoff after harvesting and burning of a *Pinus caribaea* plantation in Viti Levu Fiji. *Forest Ecology and Management*, 251, 31–44.

Webb, A.A., Katheria, A. and Turner, L. 2012. Longer-term changes in streamflow following logging and mixed species eucalypt forest regeneration: the Karual experiment. *Journal of Hydrology*, 464-465, 412–422.

Zhang, M., Wei, X., Sun, P., and Shirong, M. 2012. The effect of forest harvesting and climatic variability on runoff in a large watershed: the case study in the upper Minjiang River of Yangtze River basin. *Journal of Hydrology*, 464-465, 1–11.

12

Hydrological Characteristic and its Response to Climate Change: A Case Study of Tropical Rainforest in Jianfengling, Hainan Island, South China

Qiu zhi-Jun, Zhou Guang-Yi and Li Yi-De

12.1 INTRODUCTION

Tropical rainforest is the most complex forest ecosystem, having the highest biodiversity, playing an important role in adjusting regional water recycle and water resources, and having been always taken seriously (Zang *et al.,* 2001; Hardesty *et al.*, 2002; Bunker *et al.,* 2005; Zheng *et al.,* 2006). Especially, climate change and its effect on hydrology has been a hot issue following global change (Gawith *et al.,* 2012; Zhang *et al.,* 2012). Tropical mountain rainforest in Jianfengling is one of the most intact tropical rainforest ecosystems in China (Jiang and Lu, 1991; Fang *et al.,* 2004). Based on the hydrological data (1989-2007) and meteorological data (1957-2007) at Jianfengling of Hainan Island, China, this paper analyzed characteristics of rain and runoff, water balance of tropical mountain rainforest, and impacts of climate change on runoff.

12.2 METHODOLOGY

12.2.1 Study area

Having the oldest national nature reserves of China, Jianfengling mountain is located at southwest of Hainan island, with the latitude of 18°20′-18°57′N, longitude of 108°41′-109°12′E. There existed a perfect vegetation series here, including spinose seashore shrub, savanna, tropical semi-deciduous monsoon forest, tropical evergreen monsoon rainforest, tropical mountain rainforest and mossy forest, which distribute from the foot to mountaintop, and the tropical rainforest of this region is one of the most intact in China (Jiang and Lu, 1991). On an average, there were about three typhoons (or tropical storms) which affected this region and brought more than 1,000 mm rainfall every year (Zhou *et al.,* 1996).

12.2.2 Field data collection

Meteorological data of 1957-1988 was recorded manually every day, and data of 1989-2007 was monitored by auto weather station for two sites, Tianchi (altitude of 820 m) and Shiyanzhan (68 m). A tropical mountain rainforest catchment of 3.01 ha has been selected for stream gauging since 1989. The altitude ranges from 826m to 1,010m, the domain tree species consists of *Castanopsis fissa, C. tonkinensis* and *Nephelium topengii.* The lateritic yellow soil derives from porphyritic granite in the catchment. Water level of the stream gauge station was recorded by daily auto-paper-recorder from 1989 to 1998 and by a water

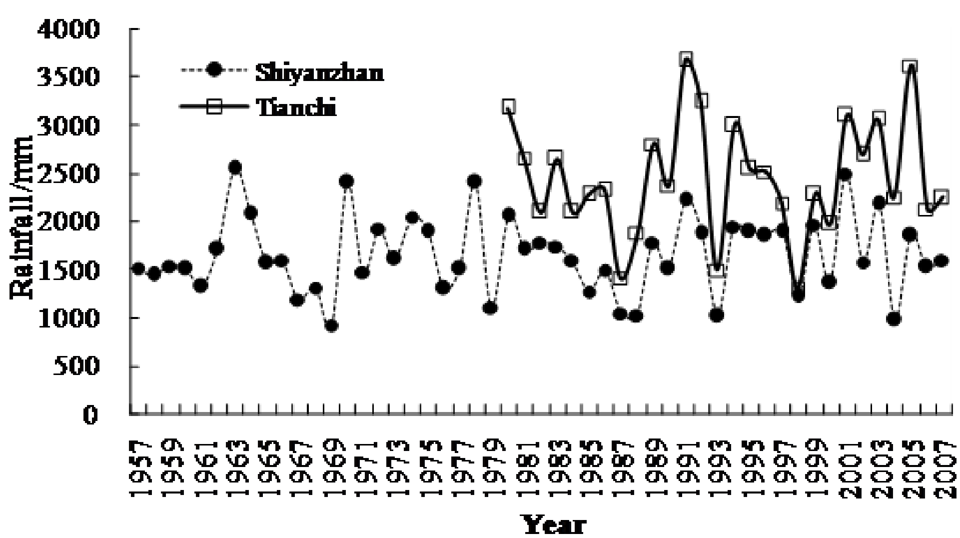


Figure 12.1: Annual rainfall of Jianfengling tropical rainforest region

<< Back to contents

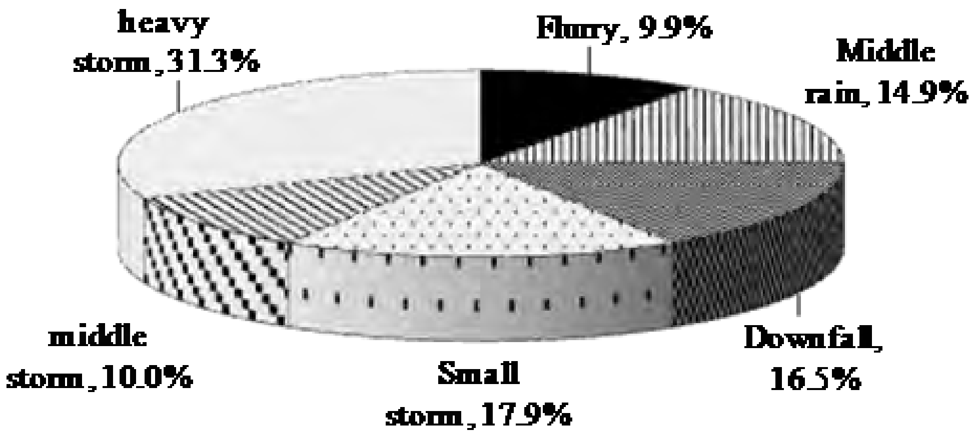


Figure 13.2: Rainfall amount percentage of different rain event in Tianchi (1980-2007) (Flurry: 0 mm≤R24<10 mm; Middle rain: 10 mm≤R24<25 mm; Downfall: 25 mm≤R24<50 mm; Small storm:50 mm≤R24<100 mm, middle storm: 100 mm≤R24<200 mm; heavy storm: 200 mm≤R24. R24 means the rainfall of one day)

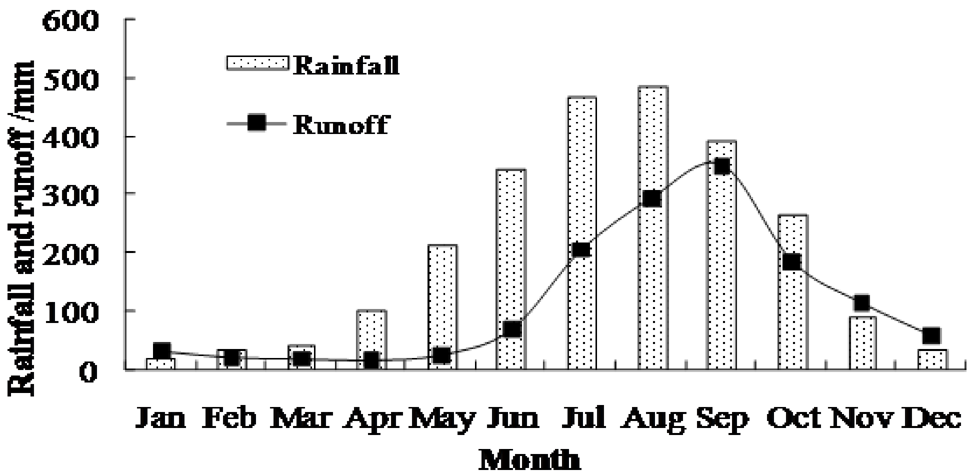


Figure 12.3: Monthly rainfall and runoff of Jianfengling tropical rainforest catchment (1989-2007)

level recorder with data logger from 1999 to 2007. Discharge and runoff were computed from water level.

12.3 RESULTS

12.3.1 Rainfall

Annual precipitation (P) ranges from 1,305.5 mm to 3,662.3 mm with the mean of 2,478.9 mm in Tianchi, from 914.3 mm to 2,539.1 mm (average 1,645.2 mm) in Shiyanzhan. And there is a rotation of 12-14 years in rainfall time series (Figure 12.1) which maybe influenced by sunspots activities. Rainfall from May to October accounts for 87.74 per cent of annual total. Storms where daily rainfall is more than 50 mm accounts for the main proportion (59.2 per cent) of P (Figure 12.1).

12.3.2 Runoff

Monthly runoff of the catchment has similar dynamics as monthly rainfall but flood detention. The lowest and the highest monthly runoff in a year appear in April and September, respectively (Figure 12.3). There were 6 abundant runoff years and 8 insufficient runoff years duing 1989-2007. Annual mean surface runoff was 17.1 mm, which accounted for only 0.6 per cent of annual rainfall. After dividing runoff into base flow and quick flow using digital filters method (Chapman, 1991), It was found that annual mean base flow (BF) and quick flow (QF) were 864.7 mm and 541.5 mm, respectively. Hydrological response (QF/P) differs from year to year and reflects a slightly increasing trend (Figure 12.4).

12.3.3 Water balance

Canopy water balance of the tropical mountain rainforest indicated that 78.7 per cent, 7.1 per cent and 14.2 per cent of gross rainfall were partitioned into throughfall, stem flow and canopy interception loss, respectively, based on the observed data from 1989 to 1994 (Table 12.1). For water balance on small catchment scale, annual mean rainfall (P), runoff (R) and evapotranspiration (ET) from 1989 to 2007 is 2,542.9 mm, 1,406.2 mm and 1,136.7 mm, respectively (Table 12.2).

12.4.4 Climate change and its impacts on runoff

There was a warming trend in annual air temperature time series of Shiyanzhan (Figure 12.5). The 1960s-1970s was a cold period. In the 1980s, the annual air temperature increased

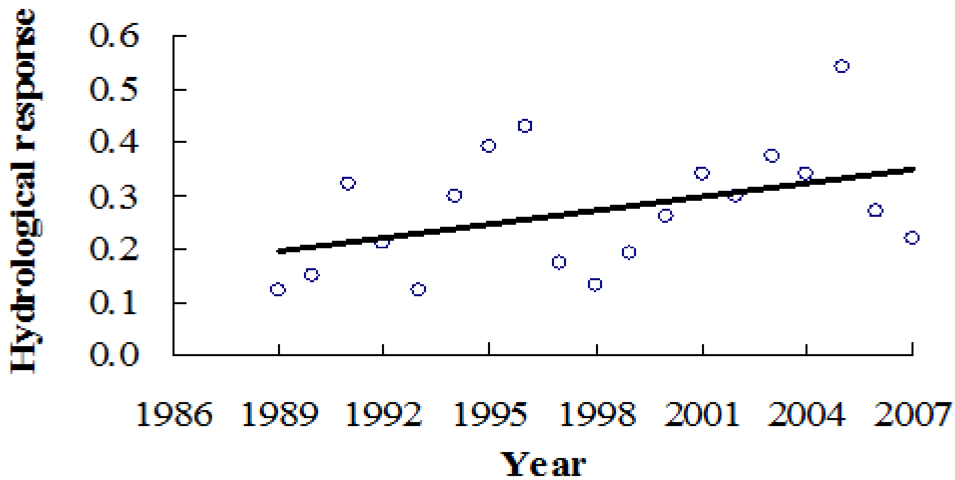


Figure 12.4: Annual hydrological response (1989-2007)

continually, with the increasing rate of 0.15°C/10 a. In the 21st centuries, annual temperature increased more significantly, and annual mean air temperature in 2001-2006 was 0.4°C higher than that of the 1990s. The year 1979 was a jump point of the time series, and the mean annual air temperature in 1957-1978 was 24.4°C, but that of 1979-2007 was 25°C. Air temperature of Tianchi has the same trend as Shiyanzhan, but the annual mean is 4.9°C lower than that of Shiyanzhan (Figure 12.5).

In traditional theory, when air temperature increases, evapotranspiration increases and runoff decrease. A Turc (1961) method was adopted to compute the evapotranspiration of tropical rainforest, and the simulation of impacts of annual temperature on runoff showed that when annual temperature increased 0.1°C, annual runoff decreased 6.3 mm to 6.7 mm.

However, the observed annual runoff has a similar trend as air temperature (Figure 12.6). The mean rainfall of 1989-1997 and 1999-2007 was almost the same, but the mean total runoff of 1999-2007 was 356.4 mm per year more than that of 1989-1997 (Table 12.2). The annual mean air temperature of 1999-2007 is 0.5°C higher than that of 1989-1997. It is indicated that there existed an incredible positive relation between runoff and temperature when other factors were not considered in Jianfengling of Hainan Island. Nevertheless, it can be seen in Table 12.2 that the measured wind velocity (V) and water evaporation (Ew) decreased, and relative humidity (RH) increased simultaneously when air temperature increased, and also the rain event changed. These changes impliedly explained well the difference of water balance during 1989-1997 and during 1999-2007. And it was suggested that multi-factors of climate change affected synthetically on water balance and runoff.

Table 12.1: Annual distribution of canopy interception of Jianfengling tropical mountain rainforest

Period	Rainfall	Throughfall		Stemflow		Canopy interception	
	/mm	/mm	/ %	/mm	/ %	/mm	/ %
1989.05~1990.04	2 915.5	2 284.9	78.3	124.7	4.3	505.9	17.4
1990.05~1991.04	2 224.4	1 687.9	75.9	143.9	6.5	392.6	17.6
1991.05~1992.04	3 502.6	2 797.4	79.9	299.1	8.5	406.1	11.6
1992.05~1993.04	3 000.9	2 410.7	80.3	258.9	8.6	331.3	11.0
1993.05~1994.04	1 698.0	1 342.1	79.0	125.3	7.4	230.6	13.6
Mean	2 668.3	2 104.6	78.7	190.4	7.1	373.3	14.2

Table 12.2: Main climate factors and water balance in Jianfengling tropical mountain rainforest

Year	Climate factor					Water balance				
	T	RH	V	Ew	Rain	P	R	BF	QF	ET
	(°C)	(%)	(m/s)	(mm)	(day)	(mm)	(mm)	(mm)	(mm)	(mm)
1989-1997	19.7	88.36	1.4	1233.8	130.4	2639.2	1283.0	735.4	547.6	1356.3
1999-2007	20.2	89.66	0.9	1194.3	137.9	2584.0	1639.4	1043.8	595.6	944.6
changes	0.5	1.3	-0.5	-39.5	7.5	-55.2	356.4	308.4	48.0	-411.7
1989-2007	20.0	89.0	1.2	1214.1	134.2	2542.9	1406.2	864.7	541.5	1136.7

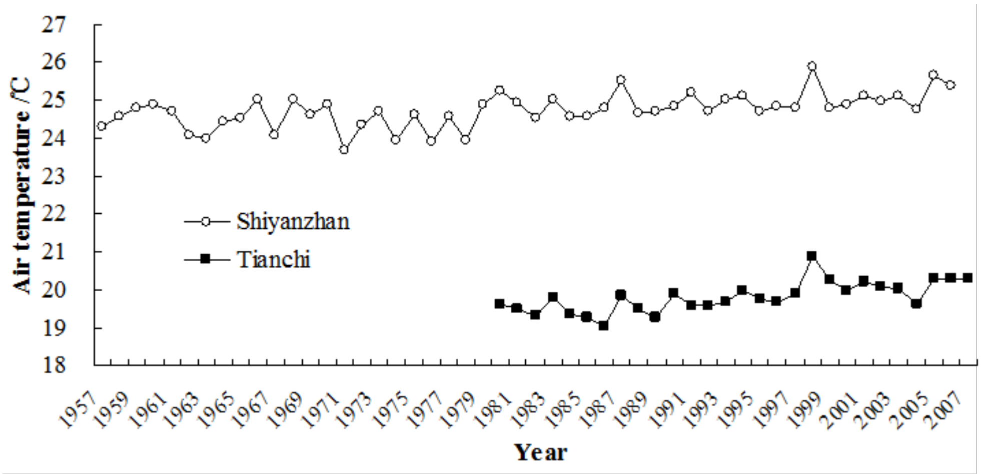


Figure 12.5: Annual air temperature of Shiyanzhan and Tianchi

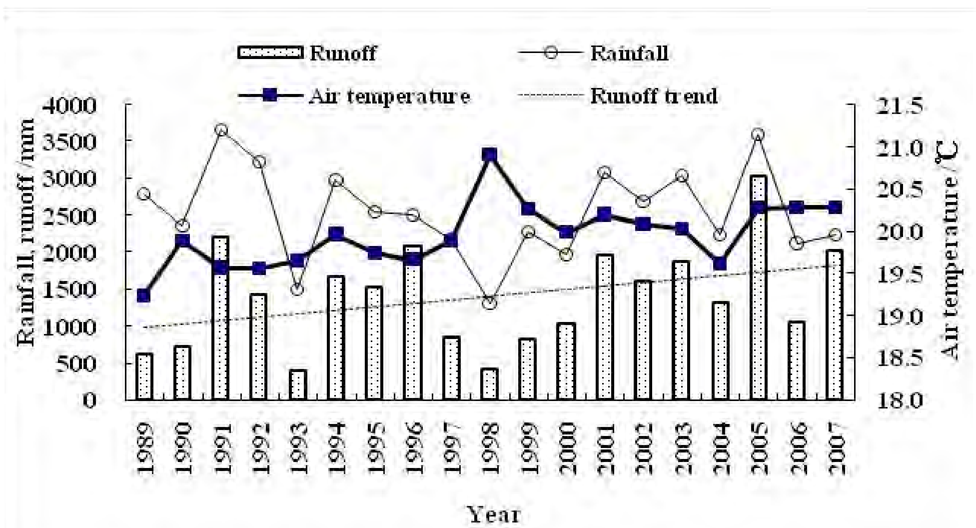


Figure 12.6: Annual runoff, rainfall and air temperature of Jianfengling tropical rainforest catchment (1989-2007)

12.5 DISCUSSION

The increasing trend in air temperature and runoff seems to be unreasonable and unbelievable because when air temperature increases, evaporation should increase too if other factors are ignored. However, it was found that there was a decreasing trend in wind speed and solar radiation of Jianfengling (Zhou *et al.,* 2009). Wind speed and solar radiation, as same as air temperature, have a positive effect on evapotranspiration. It is the function of decreasing wind speed and solar radiation, and the increasing air temperature that result in the fact of decreasing of evapotranspiration. Xiao *et al* (2008) had the same result when he analyzed the evaporation of South China.

Generally, there exists a trade-off between rainfall and air temperature, Figure 12.6 illustrated this trade-off relation during 1989 to 1999 but did not during 1999 to 2007. That maybe implies that most rainfall in the later duration (1999-2007) occurred in the night.

The effect of climate change on runoff is dependent on many factors such as rainfall, especially rainstorm, air temperature, wind speed, solar radiation, but their trend is different. Therefore, the effect of climate change on runoff and water balance is complex. Since typhoon storms affect runoff greatly (Zhou *et al.,* 1996), it is necessary to quantify the role of typhoons in increasing runoff of Jianfengling region. Further research is needed to mark and discriminate the effect of varied climate factors on runoff.

ACKNOWLEDGEMENTS

The data was obtained from Jianfengling National Forest Research Station. This study was financially supported by Special Research Programme for Public-Welfare Forestry (Grant No.201104009-06), and Natural Science Foundation of China (Grant No. 31170418). Special appreciation is given to those technicians who collect the data; among them Qiu Jian-riu spent almost his whole life for collecting meteorological data.

REFERENCES

Bunker, D.E., Declerck, F., Bradford, J.C., Colwell, R.K., Perfecto, I., Phillips, O.L., Sankaran, M., Naeem, S. 2005. Species loss and aboveground carbon storage in a tropical forest. *Science*, 310, 1029–1031.

Chapman T., 1991. Comment on “Evaluation of automated techniques for baseflow and recession analysis” by R.J. Nathan and T.A. McMahon. *Water Resources Research,* 27(7), 1783–1784.

Fang Jing-yun, Li Yi-de, Zhou Biao, LI Guo-hua, Zhou Gunag-yi. 2004. Community structures and species richness in the montane rainforest of Jianfengling, Hainan Island, China. *Biodiversity Science*. 12 (1), 29–43. (In Chinese)

Gawith, David, Kingston, Daniel G., McMillan, Hilary. 2012. The effects of climate change on runoff in the Lindis and Matukituki catchments, Otago, New Zealand. *Journal of Hydrology,* 51(2), 121–135.

Hardesty, B.D., Parker, V.T., 2002. Community seed rain patterns and a comparison to adult community structure in a West African tropical forest. *Plant Ecology,* 164, 49–64.

Jiang, Y.X. and Lu J.P., 1991.Tropical Forest Ecosystems in Jianfengling, Hainan Island, China Science Press, Beijing. (In Chinese)

Turc, L., 1961. “Evaluation des besoins en eau d’irrigation, evapotranspiration potentielle, formule climatique simplifiee et mise a jour.” *Ann. Agron*., 12(1), 13–49.

Xiao Wei-Jun, Jian Mao-qiu, Ye Ai-fen, Ji Zhong-ping, Wu Nai-geng. 2008. Spatial and temporal variations of evaporateion over southern China in autumn. *Journal of Tropical Meteorology,* 24(4), 385–390.

Zang Run-Guo, Yang Yan-Cheng and Jiang You-Xu. 2001. Community structure and tree species diversity characteristics in a tropical montane rain forest in Bawangling nature reserve, Hainan island. *Acta Phytoecologica Sinica,* 25(3), 270–275. (In Chinese)

Zhang Yongyong, Shifeng Zhang, Xiaoyan Zhai, Jun Xia. 2012. Runoff variation and its response to climate change in the Three Rivers Source Region. *Journal of Geographical Sciences*, 22(5), 781–794.

Zhou Guangyi, Chen Bufeng, Zeng Qingbo, Wu Zhongmin, Li Yide, Lin mingxian. 1996. Hydrological effects of typhoon and severe tropical storm on regenerative tropical mountain forest at Jianfengling. *Acta Ecologica Sinica*, 16(5), 555–558. (In Chinese).

Zhou Zhang, Li Yi-de, Lin Ming-xian, Chen De-xian, Xu Han, Luo Tushou, Qiu Jian-li. 2009. Climate changes characteristics over tropicalmountain rainforest in Jianfengling during the recent 26 years: radiation,moisture, and wind factors. *Acta Ecologica Sinica*, 29(3), 1112–1120. (In Chinese)

Zheng Zheng, Zhili Feng, Min Cao, Zhongfei Li, Jianhou Zhang, 2006. Forest structure and biomass of a tropical seasonal rainforest in Xishuangbanna, Southwest China. *Biotropica,* 38(3), 318–327.

13

Study on Hydrological Parameters of Forest Cycle with special reference to Dieback of Dalbergia Sissoo in Uttar Pradesh under Changed Climate Scenario

Anindita Bhattacharyya, Pankaj Kumar Roy and Asis Mazumdar

13.1 INTRODUCTION

Sissoo (*Dalbergia sissoo* Roxb.) an important multipurpose tree species distributed between latitude 21.17 N to 32.60 N, longitude 74.80 E to 93.43 E and altitude up to 900 m, is extensively used for timber, shelterbelts and fuel wood in the sub-humid and drier areas (Dhakal, 2001). The depleting quantities of *sissoo* can be attributed to overexploitation, absence of proper production management strategies (Dhakal, 2001) and climate change effect (Sah *et al*., 2003). The livelihood of the artisans in Saharanpur, those who earn through carving wood, is under threat as the alternative species of *sissoo* (like *Mangifera indica*) could not be carved due to its soft texture. Thus the traditional skills of carving are disappearing. The demand in the export market has also shifted to modular furniture (without carving) and low cost raw material. This results in earning much less foreign exchange, loss of livelihood opportunities for artisans and loss of our traditional art and culture.

Many other climate studies under different climate models conducted by people like Ravindranath *et al.* (2006), Sukumar (1999), IPCC (2001b), Ravindranath *et al.* (2003), Solomon *et.al.* (1996), Sukumar (2000), in the Indian subcontinent laid stress on the potential dieback effect of timber species regionally. The disease was first observed by Bakshi (1954) both in the natural forests and plantations in Taungyas, in Dehradun and Saharanpur districts, Uttar Pradesh. Bakshi *et al.* (1959), Parajuli *et al.* (1999) and Negi *et al.* (1999) studied the heavy mortality of *sissoo* and stated that the decline is due to occurrence of fungi such as *Fusarium sp.* in the roots and stem of diseased trees. Studies further reported that pathogens are only the secondary cause of decline, not the primary one (Manion, 1981). The Proceedings of the Sub-Regional Seminar "Dieback of sissoo (*Dalbergia sissoo*)" at Kathmandu, Nepal, 25-28 April 2000 by FAO compiled the result of all studies on dieback of *Dalbergia sissoo* and concluded that the three major causal factors of the *sissoo* decline is water stress, soil texture change and high water table which in turn creates conducive conditions for fungal growth that affects the *sissoo* tree.

Sah *et al.* (2003) throws light on the recent rise in mean annual maximum temperatures indicating climate change as one of the factors contributing to *sissoo* decline in Nepal and Indian subcontinent as a whole. Thus, it is suggested by various authors that long-term climate studies related to change in temperature, rainfall, hydrology, soil structure and other abiotic factors be undertaken in order to attribute climate change or global temperature rise as one of the reasons for *sissoo* decline in Nepal and the Indian subcontinent. This paper analyzes time series data of temperature, precipitation, soil texture (sand, silt and clay percentages), occurrence of flood and total soil moisture in baseline and two different scenarios (A_2 and B_2) to study the potential impact of climate variability on hydrological parameters, in reference to extent of dieback disease of *sissoo* in Saharanpur forest areas.

13.2 METHODOLOGY

Time series data of temperature, precipitation and total soil moisture in baseline (1961 to 1990) and two different scenarios (A_2 1970 to 2100 and B_2 1970 to 2100) were collected from the Indian Institute of Tropical Meteorology, Pune, generated using Hadley regional climate model PRECIS. The time series data of soil texture and extent of dieback was collected from the technical reports of Saharanpur forest divisions during field visits. The time series data on occurrence of flood in Uttarpradesh (with special reference to Saharanpur district) was extracted from Emergency Events Database (EM-DAT), Centre for Research on the Epidemiology of Disasters (CRED), Disaster Database. High resolution thematic grid map was used from Bhuvan, to extract gridded data. Table 13.1 shows the latitude and longitude values of the selected grid and the data extracted for Figure 13.1

However recent data on extent of dieback disease in *sissoo* and soil quality was collected during field visit. Started in September 2009, a random sampling of 345 sites (according to FMU described in working plan of Shivalik and Saharanpur social forestry division) was carried out. The quadrate of 10*10 m grid was set up and the soil from the sites was collected from top (0-5 cm) layers by a soil auger. All the soil samples were taken to the laboratory of the School of Water Resources Engineering, Jadavpur University, Kolkata in an air-tight plastic packet for soil analysis. Further data was interpreted using statistical analysis like correlation, regression, paired T test, factor analysis and least mean square method.

13.3 RESULTS

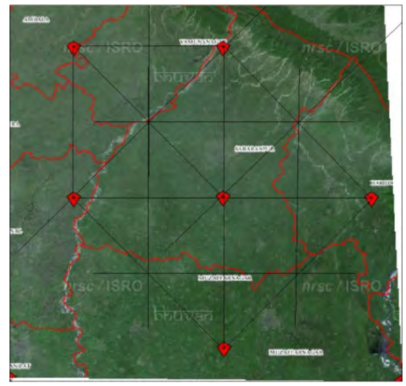
Analyzing the time series temperature data in baseline and two different changed climate scenarios (A_2 and B_2) projects rise

<< Back to contents

Table 13.1: Saharanpur Grid Points and Weightage.

Sl.No	Saharanpur		
	Longitude-East	Latitude-North	Weightage
1	77.125	29.8275	16.35%
2	77.5675	29.8275	51.93%
3	77.5675	30.27	31.71%

Figure 13.1 Thiessen Polygon drawn over Saharanpur image downloaded from Bhuvan



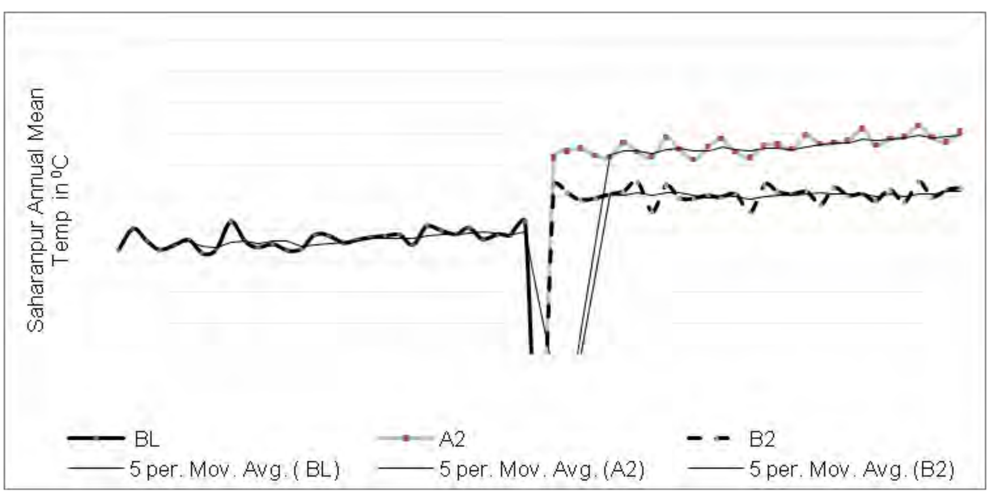
of temperature by 2^{0}C approximately. This escalating temperature is attributed to climate change (IPCC, 2006) which may be one of the reasons for the increase of dieback disease among *sissoo* trees (Sah *et. al.*, 2002). When compared to the baseline data, the annual mean temperature is predicted to increase by 5.74^{0}C in A_2 scenario and 2.18^{0}C in B_2 scenario by the year 2100. Figure 13.2 shows the annual mean temperature of Saharanpur in baseline, A_2 and B_2 scenarios. Figures 13.3 and 13.4 show the annual mean minimum and maximum temperature of Saharanpur in baseline, A_2 and B_2 scenarios.

Kausar *et al*. (2009) established that *Furasium solani* (*F. solani*) fungi, responsible for dieback disease in *sissoo* grows well at 21^{o}C to 40^{o}C. The colonization of the mycelium is reduced after 35^{o}C and diminishes after 40^{o}C. The growth of the mycelium below 21^{o}C is minimal. The present increased temperature (annual mean temperature- 23- 24^{o}C) is highly conducive for the growth of the fungus and thus increased instance of *sissoo* dieback can be predicted. The plant directly responds to the temperature rise from 21^{0}C to 35^{0}C. With a rise of 21+1^{0}C, 21+2^{0}C, 21+3^{0}C, 21+5^{0}C, 21+7^{0}C in annual mean temperature, the extent of dieback would increase by 3.29 per cent, 26.88 per cent, 55.52 per cent, 63.53 per cent and 68.62 per cent (Figure 13.5) from the base (21^{0}C – 29.98 per cent dieback) in Saharanpur, respectively. This is been calculated using least mean square method.

Time series rainfall data shows decreasing trend in baseline (392.38 mm) and A_2 (184.81 mm) scenario but increases by 458.82 mm in B_2 scenario. The amount of precipitation almost increases by 150-200 mm in monsoon months (July and August) over both A_2 and B_2 scenarios. The rainfall is more scattered and erratic in later decades of baseline scenario and in A_2, B_2 scenarios. Figure 13.6 represents the annual rainfall of Saharanpur and Figures 13.7, 13.8 and 13.9 show the monsoon and non-monsoon rainfall trends of Saharanpur in baseline, A_2 and B_2 scenarios, respectively.

The runoff volume is abstracted from the hydrologic budget formula for the catchment and evapotranspiration is calculated by using the empirical formulae of Blaney criddle and Thornthwaite. Analyzing the hydrograph drawn from runoff versus flood instance

Figure 13.2: Saharanpur-Annual Mean Temperature



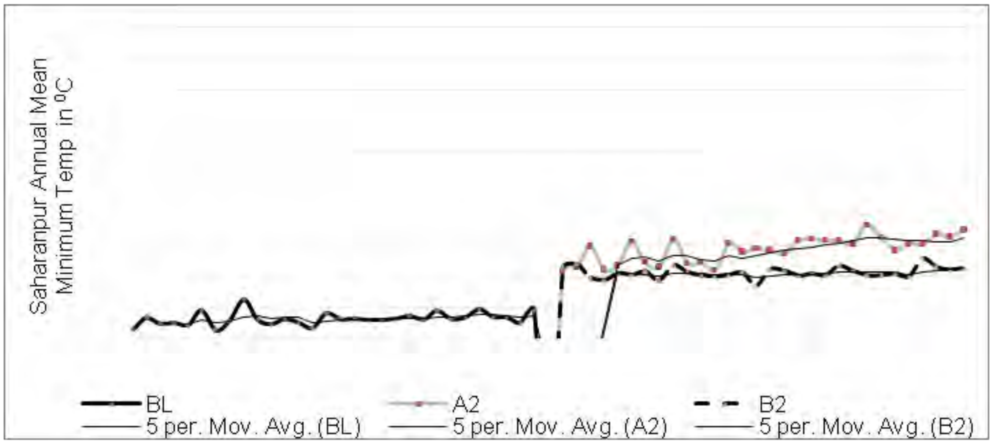


Figure 13.3: Saharanpur-Annual Mean Minimum Temperature

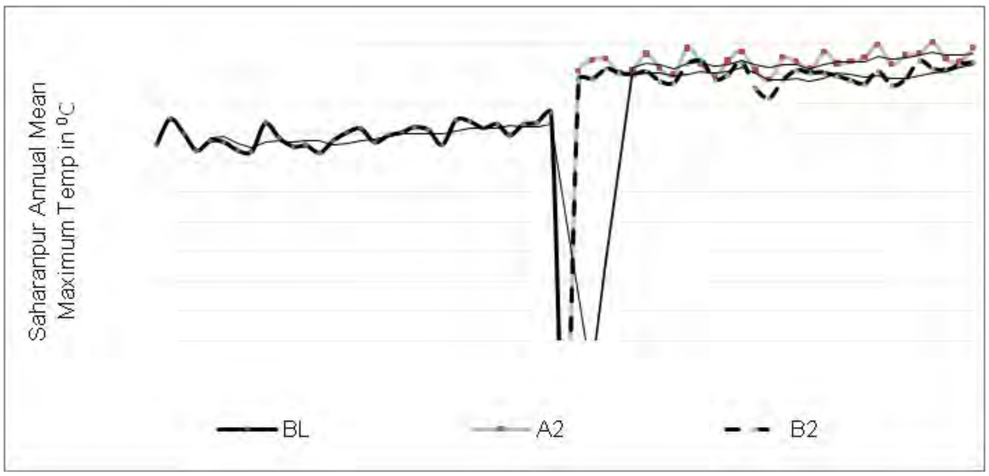


Figure 13.4: Saharanpur-Annual Mean Maximum Temperature

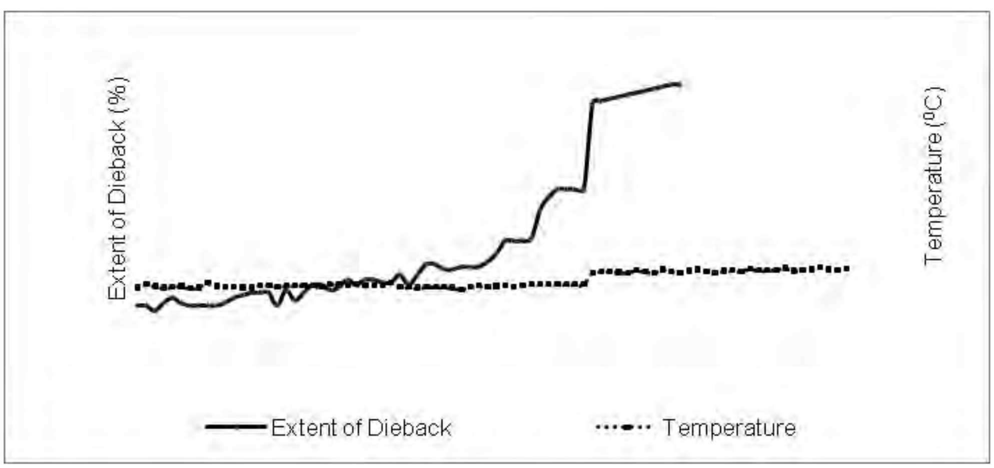


Figure 13.5: Temperature vs. Extent of Dieback in Saharanpur

of Saharanpur clearly indicates that instance of flood occurs after a shooting peak in the hydrograph representing high rainfall and high runoff (Figure 13.10). Saharanpur being geographically situated below the foothills of Shivalik ranges of mountains, it is prone to frequent floods from the upper catchments of River Ganges every year or else flood is caused by precipitation in its own catchment area. This remains one of the major reasons for deposition of clay rich alluvial soil in this district. Figure 13.11 shows the decadal growth of flood instances in Saharanpur since 1961. It is observed that flood occurs almost twice in a year in the recent decade. There is a high correlation (r =0.957, calculated) between annual rainfall and flood instance but it is to be clearly noted that rainfall is not the only parameter that is responsible for flood in this region. There may be many other factors that are responsible for flood. Studies on those parameters are to be considered for further research and are out of scope of this paper. Table 13.2 summarizes the climate data analysis.

Nathan *et al.* (2012) have discussed that higher instance

<< Back to contents

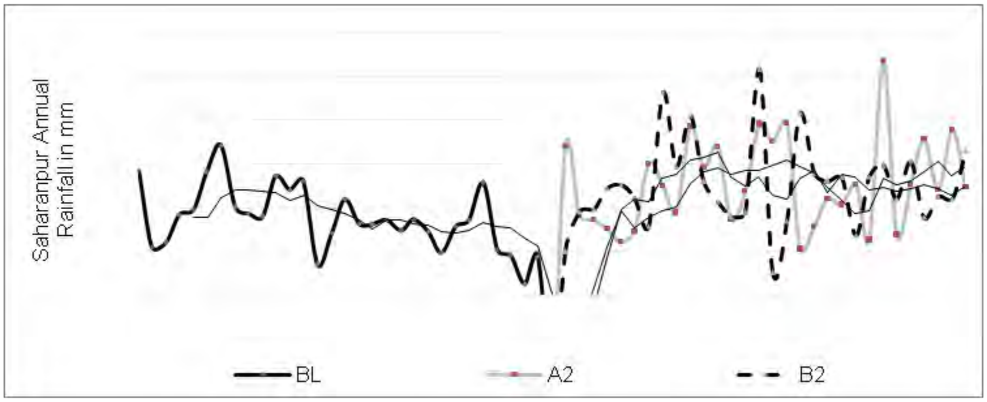


Figure 13.6: Saharanpur-Annual Rainfall in Baseline, A2 and B2 Scenarios

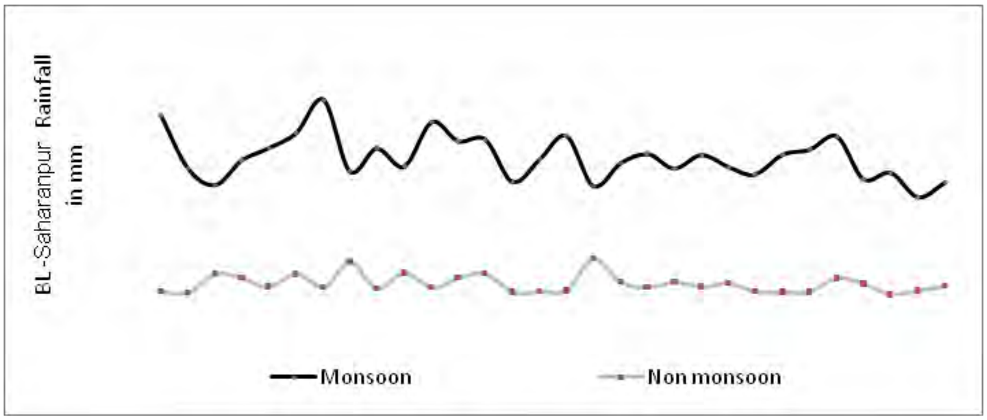


Figure 13.7: Saharanpur-Baseline, Monsoon and Non-monsoon Rainfall Trend

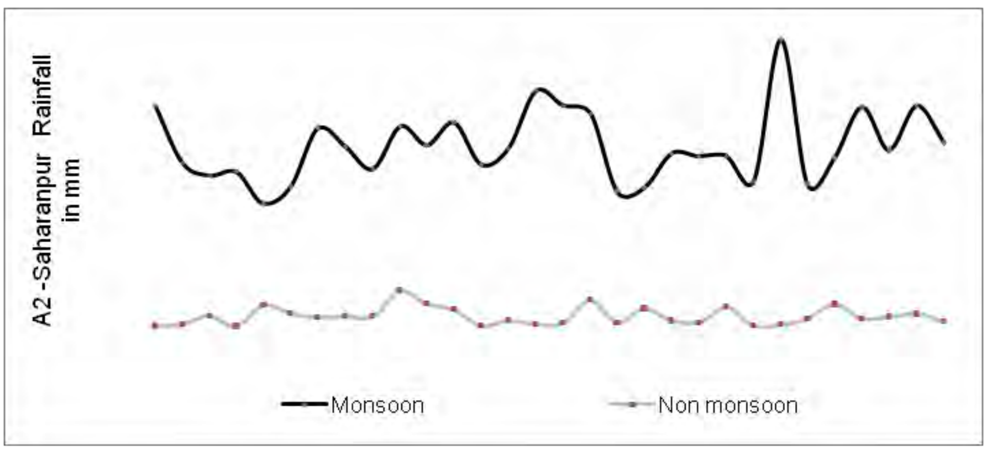


Figure 13.8: Saharanpur-A2, Monsoon and Non-monsoon Rainfall Trend

of flood lead to both water logging conditions in the area increasing the soil moisture content and simultaneously alters the soil texture of the area affecting the soil permeability. The increasing instance of flood in Saharanpur district leads to both water logging conditions in the area increasing the soil moisture content and simultaneously alters the soil texture of the area affecting the soil permeability. Figure 13.12 shows the soil texture changes recorded over last 50 years in Saharanpur. It is important to note that with the increase of clay content from 19 per cent to 29 per cent since 1961, the sand portion has decreased by more than 15 per cent, affecting the drainage system of the soil. Observations by Bakshi *et al. (*1957) showed that the soil texture had a significant correlation with the disease incidence The disease was not reported in sandy and sandy loam soils but began to manifest with increasing clay content. The stiff and clayey soils lead to asphyxiation of the feeding roots, and were subsequently colonized by wilt fungus *Fusarium solani* causing the death of the plant. This creates conducive environment for *F. solani* to grow rapidly resulting in increased instance of *sissoo* dieback disease.

All the factors–temperature, precipitation/ rainfall, soil texture (soil, sand and clay), occurrence of flood, runoff and total soil moisture–are analyzed statistically to establish the impact

<< Back to contents

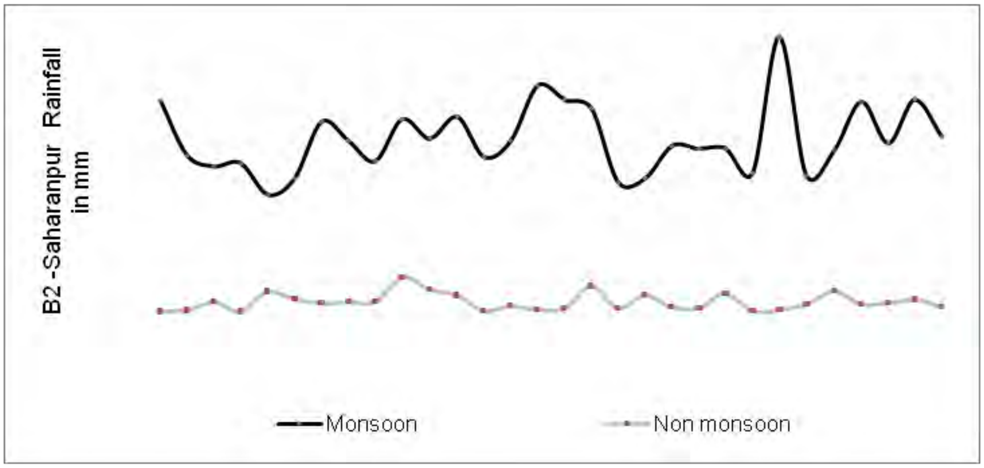


Figure 13.9: Saharanpur-B2, Monsoon and Non-monsoon Rainfall Trend

Table 13.2: Climate Data Analysis – Summarized

	Saharanpur					
	Baseline (BL)		A_2 Scenario		B_2 Scenario	
	1961	1990	2071	2100	2071	2100
Annual Mean temp C⁰	21.65	23.45	27.52	29.19	25.79	25.63
Annual Mean Min Temp in C⁰	15.64	16.9	19.36	22	19.56	19.59
Annual Mean Max Temp C⁰	28.21	30.41	33.16	34.78	32.66	33.81
Annual Rainfall in mm	1171.	779.0	1281	1096.1	801.48	1260.3
Monsoon Average Rainfall %	91.82		93.74		90.35	
Non Monsoon Average Rainfall %	8.18		6.26		9.65	
Monsoon Rainfall %	97.57	91.85	99.08	96.40	90.09	
Non Monsoon Rainfall%	2.43	8.15	0.92	3.60	9.91	
TSM	71.51	52.76	76.87	73.14	NA	

of climate change on hydrological parameters with reference to dieback disease of *sissoo*. Pearson correlation coefficient matrix was calculated for all the factors in Saharanpur. The paired t- test of Saharanpur was carried out with 51 degrees of freedom. Extent of dieback of *sissoo* shows high significance with Clay (P<=.001) and Total Soil Moisture content (P<.072) in the soil and Annual Mean Temperature (p<.005). Table 13.3 summarizes the Pearson correlation coefficients (r) and Paired T test (P) values with respect to extent of dieback of *sissoo* in Saharanpur.

The mean and standard deviation were 23.46 ±0.56°C for annual mean temperature, 983.49±191.74 mm for annual precipitation, 68.10±10.04 mm for total soil moisture, 0.56±0.56 for occurrence of flood and sand- 59.11±14.0 per cent, silt- 32.90± 6.56 per cent and clay- 37.20±8.69 per cent for soil texture and for 27.65±13.28 per cent extent of dieback in Saharanpur. However extent of dieback was highly variable (60.0±13.28). Among the variables, occurrence of flood and extent of dieback has the highest coefficient of variation (Table 13.4).

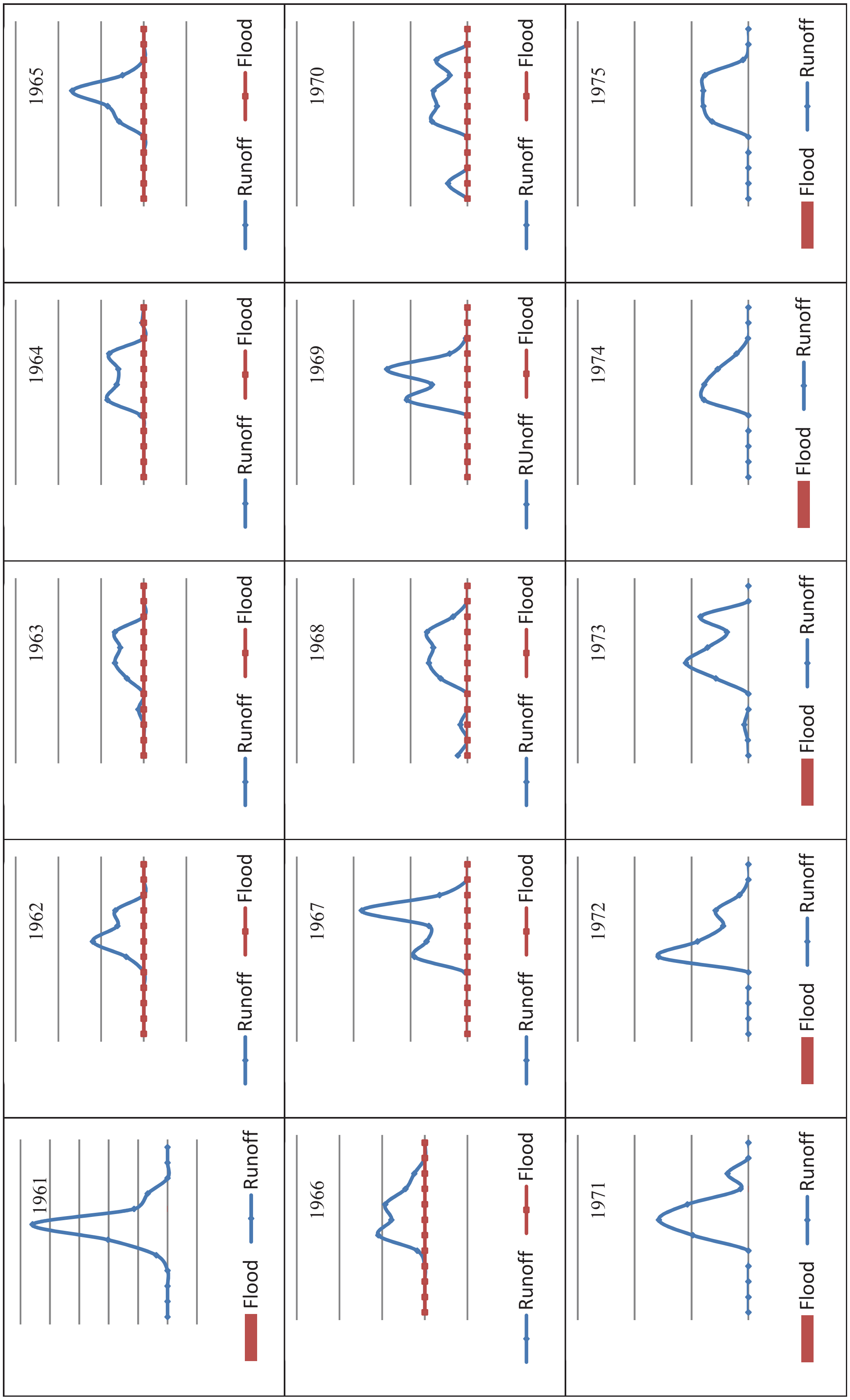
The change in the soil texture can be directly attributed to the occurrence of flood both literally (according to the experiments performed by Nathan (2012) and various others) and statistically conducted during the study. Extent of dieback was positively correlated to total soil moisture, annual mean temperature and the soil structure (silt and clay per cent). The regression curve analysis reveals that it is highly related to sand percentage (R^2= 0.90), clay content (R^2= 0.88) and TSM (R^2= 0.676) in Saharanpur. As plotted against all the above factors described, the best fit model for describing extent of dieback patterns across

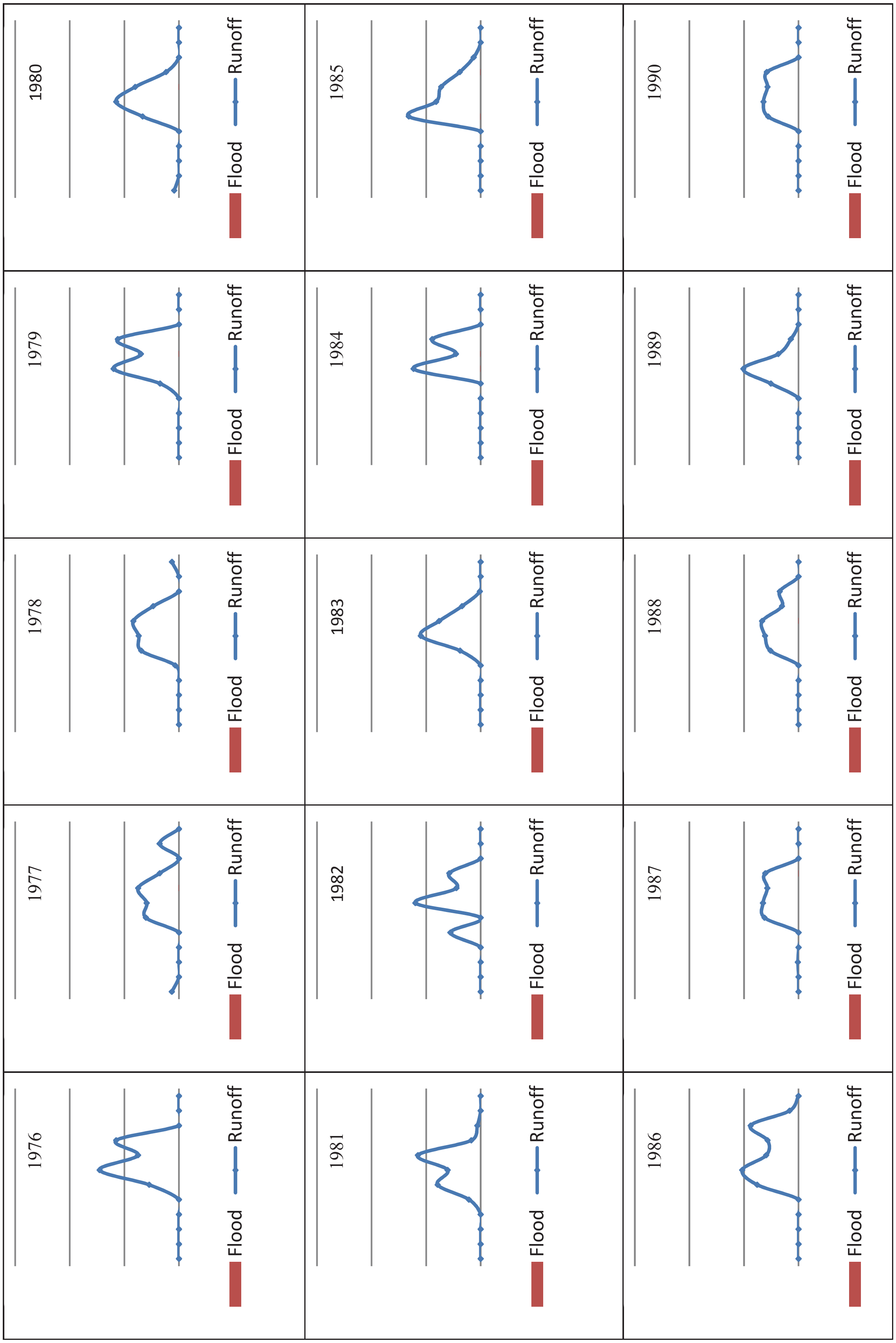
Table 13.3: Pearson correlation coefficients (r) and Paired T test (P) values with respect to extent of dieback of *sissoo* in Saharanpur

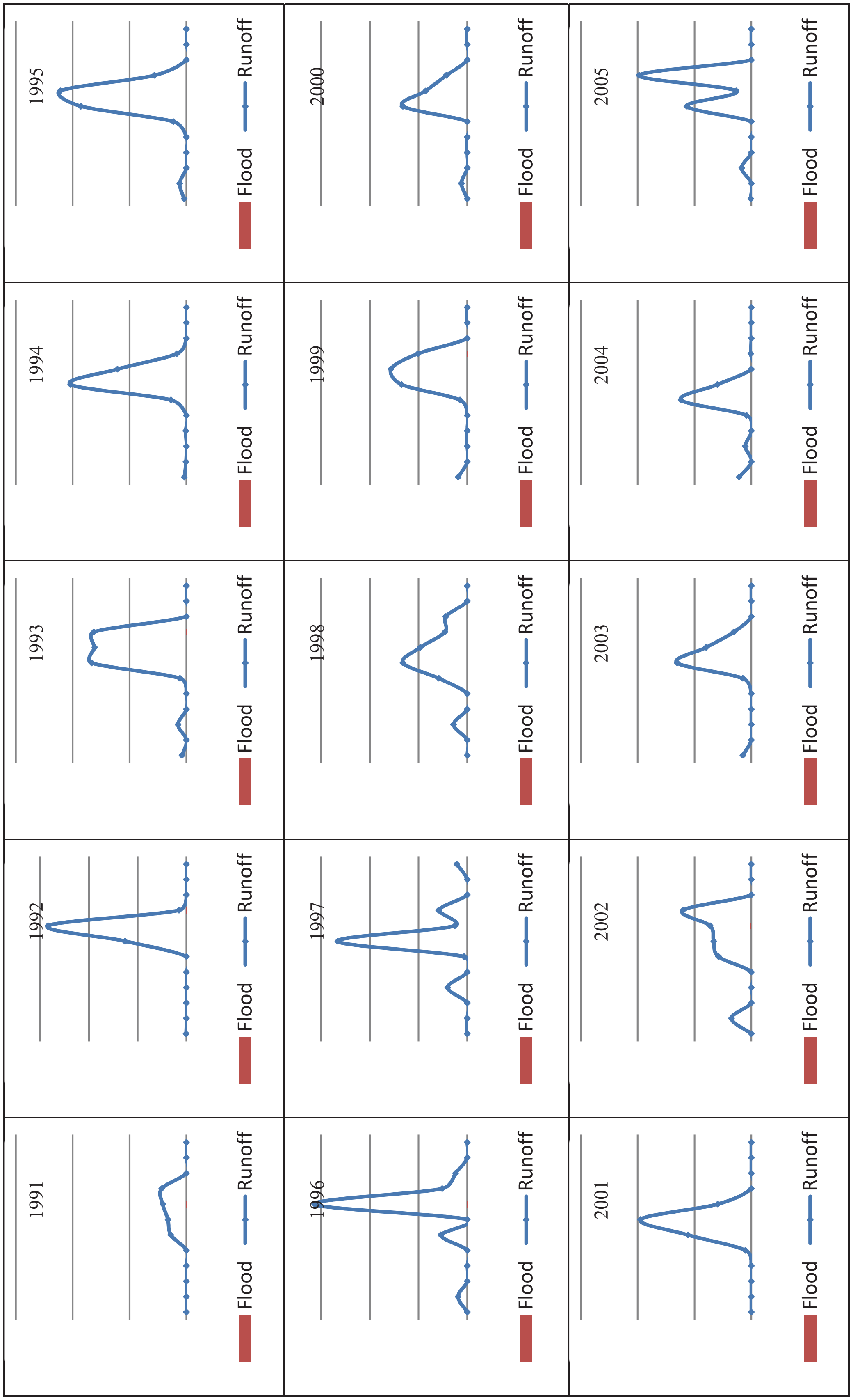
Value	Extent of dieback in Saharanpur	Sand	Silt	Clay	Annual Rainfall	Mean Temperature	Occurrence of flood	Runoff	TSM
r	1	-0.927	0.850	0.859	-0.042	0.360	0.402	0.064	0.752
P	NA	0.00	0.00	0.001	0.00	0.00	0.00	0.00	0.072

<< Back to contents

Figure 13.10: Saharanpur- Hydrograph vs Flood Occurrence




1976
1977
1978
1979
1980
1981
1982
1983
1984
1985
1986
1987
1988
1989
1990
Flood
Runoff


1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
Flood
Runoff

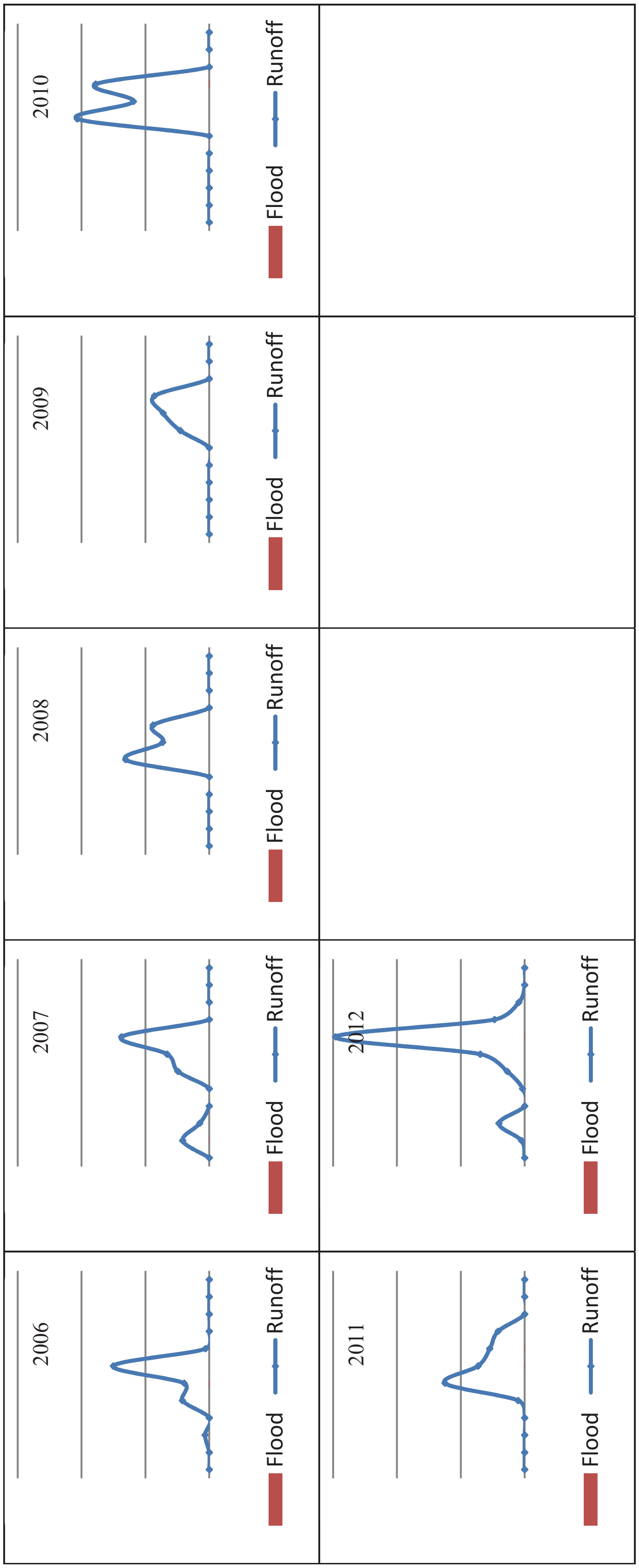


Figure13.11: Decadal Growth of Flood Instance in Saharanpur

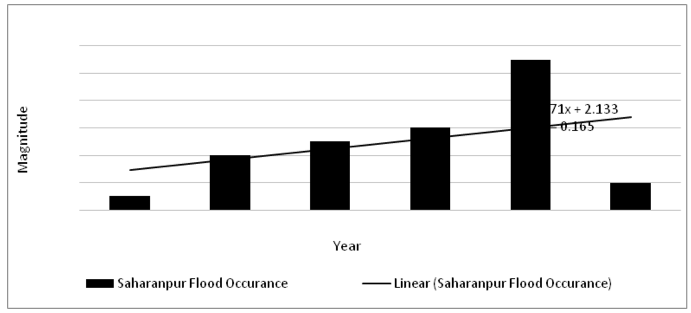
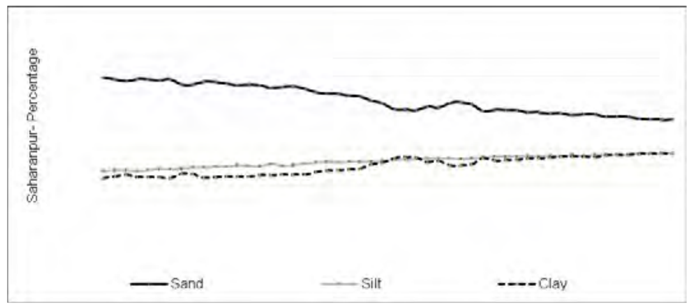


Figure 13.12: Soil texture Change in Saharanpur



the time of 52 years is quadratic except for the clay which shows a cubic curve. Table 13.5 shows the regression curve and the R^2 value of the factors described above.

Factor analysis is used in this study to define the main underlying factors that affects the extent of dieback disease of *sissoo* in Saharanpur. Correlation matrix based extraction method is used to identify the number of underlying factors. The factors that have yield initial Eigen value more than one are considered for the varimax rotation and Kaiser Normalization. According to the Eigen values, clay and sand are the most correlated factors which would have an impact on the extent of dieback disease of *sissoo* in Saharanpur. The Eigen value of clay and sand are 3.109 and 1.006, respectively.

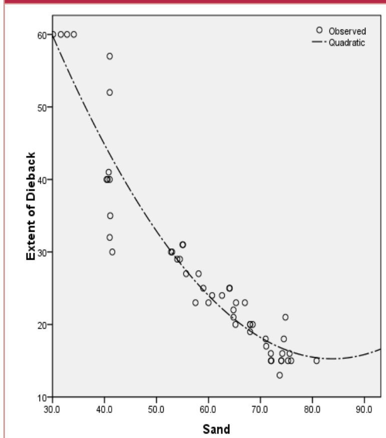
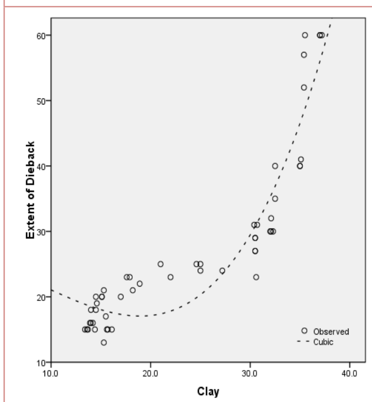
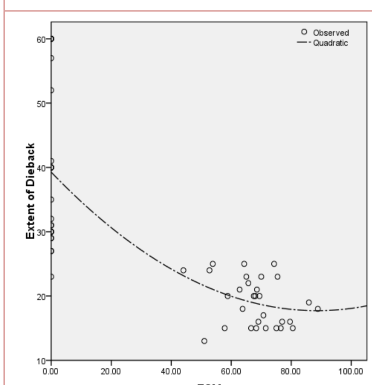
13.4 CONCLUSION

Recently *Fusarium solani* has been isolated as a facultative parasite residing in *sissoo* and is responsible for causing dieback disease. This new form of the disease has reached epidemic proportion in India, Nepal, Bangladesh and other South Asian countries. The disease has already become a threat affecting the availability of the species for commercial purposes. Several researchers have been working on this issue since 1954 and reported that increasing temperature, soil texture change and water-logging conditions are the main reasons of spread of this disease. The threshold temperature at which the fungi *F.solani* shows high rate of colonization ranges from 25^{0}C to 35^{0}C, water logging conditions and poor soil drainage.

Environmental factors like sand, clay and silt percentages (representative of soil texture) of the area, occurrence of flood, total soil moisture and annual mean temperature are correlated

Table 13.4: Saharanpur data distribution analysis

Variable	Extent of Dieback %	Sand	Silt	Clay	Annual Rainfall	Mean temperature	Occurrence of flood	Runoff	TSM
Mean	27.65	59.11	16.99	23.90	983.49	22.36	0.56	887.31	68.10
SD	13.28	14.07	6.56	8.69	191.74	0.56	0.56	191.96	10.04
CV	0.48	0.24	0.39	0.36	0.19	0.03	1.00	0.22	0.15
Max Value	60.00	80.80	32.90	37.20	1429.70	23.46	2.00	1373.33	88.87
Min Value	13.00	30.10	3.70	13.40	555.00	20.98	0.00	513.84	44.06
Skewness	1.35	-0.55	0.82	0.15	0.19	0.00	0.80	0.39	-0.18
Kurtosis	1.01	-0.90	-0.05	-1.71	-0.17	-0.60	-0.42	-0.03	-1.87

Regression Curve	R^2 Value
	Linear- 0.860 Logarithmic- 0.895 Inverse- 0.808 Quadradic-0.901 Cubic- 0.901 Growth- 0.818 Exponential- 0.818
	Linear- 0.738 Logarithmic- 0.680 Inverse- 0.623 Quadradic-0.864 Cubic- 0.888 Growth- 0.844 Exponential- 0.844
	Linear- 0.566 Logarithmic- 0.0 Inverse- 0.0 Quadradic-0.676 Cubic- 0.676 Growth- 0.659 Exponential- 0.659

with the extent of dieback disease of *sissoo* in Saharanpur. The sand percentage in the soil is negatively correlated to extent of dieback disease. The plant directly responds to the temperature rise from 21⁰C to 35⁰C. With a rise of 21+1⁰C, 21+2⁰C, 21+3⁰C, 21+5⁰C, 21+7⁰C in annual mean temperature, the extent of dieback would increase by 3.29 per cent, 26.88 per cent, 55.52 per cent, 63.53 per cent and 68.62 per cent from the base (21⁰C – 29.98 per cent dieback) in Saharanpur, respectively.

Water logging conditions and poor soil drainage are the next major factors responsible for causing dieback disease in *sissoo,* as the fungi *F. solani* thrives well in highly humid and warm conditions. It colonizes and clogs the roots of the tree, preventing it from absorbing nutrients thus leading to undernourishment and finally death. Frequent occurrence of flood (6 floods during 1991-2000, 11 floods during 2001-2010) in Saharanpur, and the upper catchment areas of Ganges river might have led to alluvial deposition resulting in increase of clay percentages in the soil over years. This has influenced the soil structure leading to poor drainage conditions and thus creating a conducive environment for growth of *F. solani*. Precipitation being one of the major factors for causing flood is analyzed over 82 years. The rainfall increases from the values of 1990 in both A_2 and B_2 scenarios but shows a very erratic and scattered distribution. However precipitation does not show any significant correlation with either extent of dieback or soil texture but with occurrence of flood, it is very high. Thus it is noted that flood is not only a function of precipitation but many other factors too. The moisture condition (total soil moisture -TSM) of the soil shows an overall increasing trend of water-logging conditions.

Pearson correlation coefficient, paired T test, factor analyses were used to statistically prove that soil texture (clay percentage in the soil) and temperature were the most important factors that influenced the extent of dieback disease in *sissoo* in the changed climate scenarios. The analysis of data in three different scenarios explains the effect of climate change (raising temperature and soil texture change due to increased flash floods) on hydrological parameters which in turn affects the health of *sissoo* trees. This is in line with the results produced by various other researchers. Increase in extent of dieback disease in *sissoo* as a result of climate change and anthropogenic activates has resulted in decline of the species drastically and the livelihood of the wood-based SMEs of Saharanpur is already at stake.

REFERENCES

Bakshi, B.K. and Singh, S.L. 1959. Root disease of shisham *(Dalbergia sissoo)*. VIII Inoculation studies on wilt. *Indian Forester,* 85(7), 415–421.

Bakshi, B.K. 1954. Wilt of shisham *(Dalbergia sissoo* Roxb.) due to *Fusarium solani* Sensu Snyder and Hansen. *Nature,* 174-4423, 278–91.

Bakshi, B.K. 1957. Wilt of shisham IV: The effect of soil moisture on the growth and survival of *Fusarium solani* in laboratory. *Indian Forest.*, 83, 505–512.

Dhakal, L. 2001. *Sisso*o dieback: Is tree improvement a probable solution? In Proc., Workshop on *Sisso*o Dieback, Kathmandu, Nepal (1991). Reprint available from HMG/DANIDA. Tree Improvement and Silviculture Component / Natural Resources Managements Sectors Assistant Program, Hattisar, Naxal, Kathmandu, Nepal.

IPCC, 2001b. 2001: Climate Change: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Third Assessment Report of the Intergovernmental Panel on Climate Change (IPCC). Cambridge University Press, Cambridge.

Manion, P.D. 1981. Tree disease concepts. Prentice-Hall, Inc. Englewood Cliffs, New Jersey. 399.

Nathan R.D.J., Thomsen M., Yin, Y., 2012. Threshold effects of flood duration on the vegetation and soils of the Upper Mississippi river floodplain. *Forest Ecology and Management,* 270(2012), 135–146.

Negi, J.D.S., Pokhriyal, T.C., Sharma, S.D. and Bhandari, R.S. 1999. Shisham mortality in India – A case study. *Indian Forester* (Communicated).

Parajuli, A.V., Bhatta, B., Adhikari, M.K., Tuladhar, J. and Thapa, H.B. 1999. Causal agents responsible for the die-back of *Dalbergia sissoo* in Nepal's eastern Terai. *Banko Janakari,* 9(1).

Kausar, P., Chohan, P. and Parveen, R. 2009. Physiological studies on Lasiodiplodia theobromae and Fusarium solani, the cause of Shesham decline. *Mycopath,* 7(1), 35–38.

Ravindranath, N.H., Joshi, N.V., Sukumar, R., Saxena, A. 2006. Impact of climate change on forest in India. *Current Science,* 90(3), 354–361.

Ravindranath, N.H., Murthy, I.K., Sudha, P., Geetha, K.N., Sangeetha, G. 2003. Assessment of Afforestation and Agroforestry as Potential CDM Activities in Semi-arid Tumkur District, India. *Journal of Environmental Studies and Policy*, JESP 6(1).

Sah, S.P., Sharma, C.K. and Sehsted, F. 2003. Possible role of Soils in the Sissoo decline in Nepal Terai. *Plant, Soil Environ.*, 49(8), 378–385.

Sah, S.P., Jha, P.K. and Lamersdorf, N. 2002. Nutrient status of a natural and healthy sissoo forest and a declining plantation sissoo forest in Nepal. *J. For. Sci*, 48(10), 185–201.

Sah, S.P., Upadhyay, S.K., Pandit, P. and Lilles, J.B. 2004. Effects of soils on sissoo growth in a plantation forest of Nepal. *The Indian Forester*, 129(9), 1059–68.

Sharma, C.K., Sehested, F. 2003. Possible role of the soil in the *sisso*o forest Dalbergia *sisso*o Roxb.) decline in the Nepal Terai. *Plant Soil*, 49, 378–385.

Sharma, M.K., Singhal, R.M. and Pokhriyal, T.C. 2000. Dalbergia *sisso*o in India. Proc. Seminar on "Dalbergia *sisso* die-back". April 25-28, Kathmandu, Nepal.

Solomon, A.M., Ravindranath, N.H., Stewart, R.B., Weber, M., Nilsson, S., Duinker, P.N., Fearnside, P.M., Hall, P.J., Ismail, R., Joyce, L.A., Kojima, S., Makundi, W.R., Pollard, D.F.W., Shvidenko, A., Skinner, W., Stocks, B.J., Sukumar, R., and Deying, X. 1996. Wood production under changing climate and land use. pp. 487-510 In: Watson, R.T., Zinyowera, M.C. and Moss, R.H., (eds.) Climate Change 1995—Impacts, Adaptations, and Mitigation of Climate Change: Scientific-Technical Analyses– Contributions of Working Group II to the Second Assessment Report. Cambridge University Press, New York. pp. 878.

Sukumar, R. 2000. Climate and Ecosystem Change: what does it for biodiversity conservation in India?. *Journal of the Indian Institution of Science,* Nov- Dec, 80, 609–618.

14

Climate Change, Water Resources and Forests: A Global Perspective

Srishti Singh

14.1 INTRODUCTION

The distribution of water on the Earth's surface, particularly in forests, plays a central role in governing temperature and precipitation patterns. The hydrologic cycle is the pathway of water movement on Earth and in the atmosphere and is strongly coupled to the climate system. Increasing climate change has generated awareness of the adverse impacts it has caused on the availability and quality of water in many regions of the world, specially forest lands. This growing body of science has demonstrated that the Earth's climate has warmed rapidly during the 20th century, leading to significant changes in the hydrologic cycle. Sixty-six million people rely on a national forest as their water source (USDA, 2008). It is this water that fills our rivers, lakes and streams; sustains fish, plants and wildlife; supports food, energy and industrial production; enables navigation; and pours from the faucets of our homes and businesses. Climate change is likely to have significant impacts on the availability of fresh water. Already in short supply throughout many parts of the world, water for human consumption, agriculture, and industry will be a major factor in economic growth, ecological sustainability, and global conflict. Climate change may also reintroduce water security challenges in countries that for a hundred years have enjoyed reliable water supplies and few, if any, water shocks. Much of the developing world will have to cope with droughts and/or the growing risk of flooding. Currently, 1.6 billion people live in countries and regions with absolute water scarcity and the number is expected to rise to 2.8 billion people by 2025 (World Bank, 2013).

Forests are a significant part of the global carbon cycle. Forest ecosystems make an important contribution to the global carbon budget. It should be thus emphasized that forests can only take up carbon if they take up water at the same time. In addition, and very important in this context, forests have a great potential to reduce impacts of climate change on water resources. Forests capture and store water and can play an important role in providing drinking water for millions of people in the world's mega-cities. Given this fact, the members of the Collaborative Partnership on Forests (CPF), international organizations involved in forests, call upon countries to pay more attention to forest protection and management for the provision of clean water. Thus forests play a crucial role in the hydrological cycle. Forests influence the amount of water available and regulate surface and groundwater flows while maintaining high water quality. Forests and trees contribute to the reduction of water-related risks such as landslides, local floods and droughts and help prevent desertification and salinization. Forested watersheds supply a high proportion of the world's accessible fresh water for domestic, agricultural, industrial and ecological needs in both upstream and downstream areas.

However, water supplies stored as snow cover in high-elevation forests are particularly vulnerable to climate change and are projected to decline over the course of the century. Earlier spring runoff and reductions in low flows will reduce water availability downstream during the summer and fall months. Higher water temperatures, flooding, and droughts would further affect water quality and exacerbate water pollution. This research paper summarizes these changes and expected impacts, based on the work of leading authorities such as the Intergovernmental Panel on Climate Change (IPCC) as well as many other individual scientists and institutions around the world.

14.1.1 Climate change is hydrologic change

According to IPCC Report 2007, temperature changes are one of the more obvious and easily measured changes in climate, but atmospheric moisture, precipitation and atmospheric circulation also change, as the whole system is affected. Further, increase in temperature leads to increase in the moisture-holding capacity of the atmosphere at a rate of about 7 per cent per °C (Table 14.1). Together these effects alter the hydrological cycle, especially characteristics of precipitation (amount, frequency, intensity, duration, type) and extremes (Trenberth *et al.*, 2003). The assessment report of the IPCC has concluded that there is increasing evidence that the earth's climate is changing and at an unprecedented rate (IPCC, 2007). One of the important aftermaths of this change is the acceleration of the hydrological cycle which implies increasing frequency and magnitude of extreme events (flood and drought), with embedded acceleration of glacial melt and sea level rise threatening humans and ecosystems.

The hydrologic cycle is the pathway of water movement on Earth and in the atmosphere is strongly coupled to the climate system. The distribution of water on the earth's surface plays a central role in governing temperature and precipitation patterns. It is also controlled by those patterns. As a result, hydrologic changes, particularly the changes in snow-packs and runoff patterns, are among the most prominent and important consequences of climate change. A significant amount of the energy of Earth is received from the Sun which is redistributed

<< Back to contents

around the world by the hydrological cycle in the form of latent heat flux. Changes in the hydrological cycle have a direct impact on droughts, floods, water resources and ecosystem services. Thus, climate change is said to be a hydrologic change.

14.2 METHODOLOGY

The details pertaining to this study were compiled from published literatures and also from reports of various worldwide organizations. The idea behind the paper is to overview the interaction between climate change and forests with its impacts on water quality and its availability. However, a focus has also been kept on the changes in forest water resources and hydrological cycle due to changing climate.

14.3 RESULT

Climate is a major driver of forest species distribution and growth rate as well as structure of forests. Thus, climate change has significant effects on forest hydrology, particularly the amount of water available. Higher water temperatures, flooding, and droughts affect water quality and exacerbate water pollution. The availability and quality of water in many regions of the world are even more threatened by overuse, misuse and pollution, and it is increasingly recognized that both are strongly influenced by forests. Moreover, climate change is altering forest's role in regulating water flows and influencing the availability of water resources (Bergkamp *et al.*, 2003). Hydrological services are one of the main ecosystem functions provided by forests and they

Table 14.1: Trends of precipitation and its projected impacts on different sectors

Phenomenon and direction of trends of changes in precipitation patterns due to climate change	Major projected impacts on different sectors		
	Agriculture, forestry and ecosystems	**Water resources**	**Human health**
Heavy precipitation events: frequency increases over most areas	Damage to crops; soil erosion; inability to cultivate land due to water logging of soils.	Adverse effects on quality of surface and groundwater; contamination of water supply; water scarcity may be relieved	Increased risk of deaths, injuries and infectious, respiratory and skin diseases.
Area affected by drought increases	Land degradation, lower yields/ crop damage and failure; increased livestock deaths; increased risk of wildfire.	More widespread water stress	Increased risk of food & water shortage; increased risk of malnutrition; increased risk of water- and food-borne diseases.
Intense tropical cyclone activity increases	Damage to crops; Wind throw (uprooting) of trees; damage to coral reefs	Power outages causing disruption of public water supply.	Increased risk of deaths, injuries, water- & food-borne diseases; post-traumatic-stress disorders.

(Source: IPCC Fourth Assessment report, working group 1)

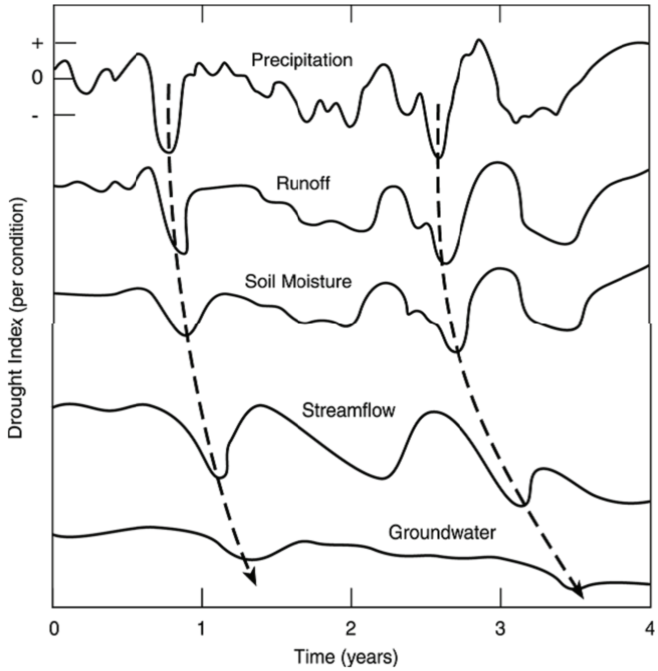
Table 14.2: Effects of climate change and its impacts on water services

Observed effects of climate change	Potential impacts on water
Increase in atmospheric temperature	Reduction in water availability in basins fed by glaciers that are shrinking, as observed in some cities along the Andes in South America (Ames, 1998; Kaser and Osmaston, 2002).
Increase in surface water temperature	Reductions in dissolved oxygen content, mixing patterns, and self purification capacity. Increase in algal blooms
Sea-level rise	Salinization of coastal aquifers
Shifts in precipitation Patterns	Changes in water availability due to changes in precipitation and other related phenomena (e.g., groundwater recharge, evapo-transpiration)
Increase in inter-annual precipitation variability	Increases the difficulty of flood control and reservoir utilization during the flooding season
Increased Evapo-transpiration	Water availability reduction, Salinization of water resources & Lower groundwater levels
More frequent and Intense extreme events	Floods affect water quality and water infrastructure integrity, and increase fluvial erosion, which introduce different kinds of pollutants to water resources. Droughts affects water availability and water quality

(Source: IPCC AR4, WGII Chapter 3)

<< Back to contents

Figure 14.1: Precipitation deficiencies during a hypothetical 4-year period are translated through other physical components of the water cycle



(Source: Winstanley et al., 2006)

are greatly influenced by climate change and thus impact water resources as a whole.

All the elements of the hydrological cycle react in a different way to climate change, sometimes amplifying each other's action, sometimes giving rise to negative feedbacks. In addition, variations in the hydrological cycle often take place at regional or even local scale (such as variations in ecosystem composition or runoff processes) but they trigger modifications that have an upscale effect possibly leading to regional or even global changes in the water cycle. Global climate models indicate the possibility of global precipitation changes before the end of the current century, with an intensity and pattern that depend on the specific climate scenario (Table 14.2).

Figure 14.1 shows the effects of hypothetical fluctuations in precipitation over a four-year period on runoff, soil moisture, stream flow and groundwater levels. In general, it takes about a month before shallow groundwater levels start to reflect precipitation or the lack thereof (Changnon, 1987).

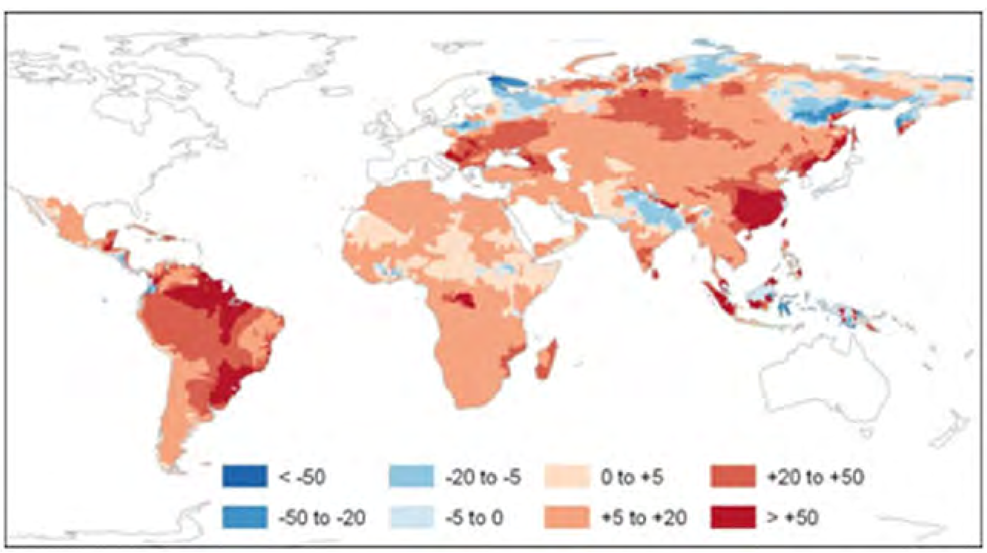
The figure clearly shows how the extent of precipitation can have inline effects with the various components of the water cycle and can overall lead to deficiency in water quantity and its availability at ground as well as below-ground levels. The fluctuation in the precipitation pattern affecting soil moisture will lead to detrimental effects on forest growth and agricultural crops as well.

It has also been observed that, through the regulation of microclimates, the provision of products substituting fossil energy and through carbon storage and sequestration, forests play a crucial role in climate change mitigation. But since part of the price of carbon sequestration is paid in water; in particular, the trade-offs between the water consumption of forests and the ecosystem services (including climate change mitigation) they provide, it is clearly reflected that changes in the hydrological cycle have a significant impact on forest water resources, and hence people's lives. Hydrological changes, particularly the changes in snow-packs and runoff patterns, are among the most prominent and important consequences of climate change as show in Figure 14.2. In some areas, increases in runoff, flooding, or sea level rise are a concern. These effects have reduced the quality of water and damaged the infrastructure used for treatment, transport and deliver water. Warmer air temperatures have raised stream and lake temperatures, which have harmed aquatic organisms that live in cold-water habitats, such as trout and salmon. These changes are expected to intensify in the future and have large impacts on forests and the watershed services they provide.

Climate change could profoundly alter future patterns of

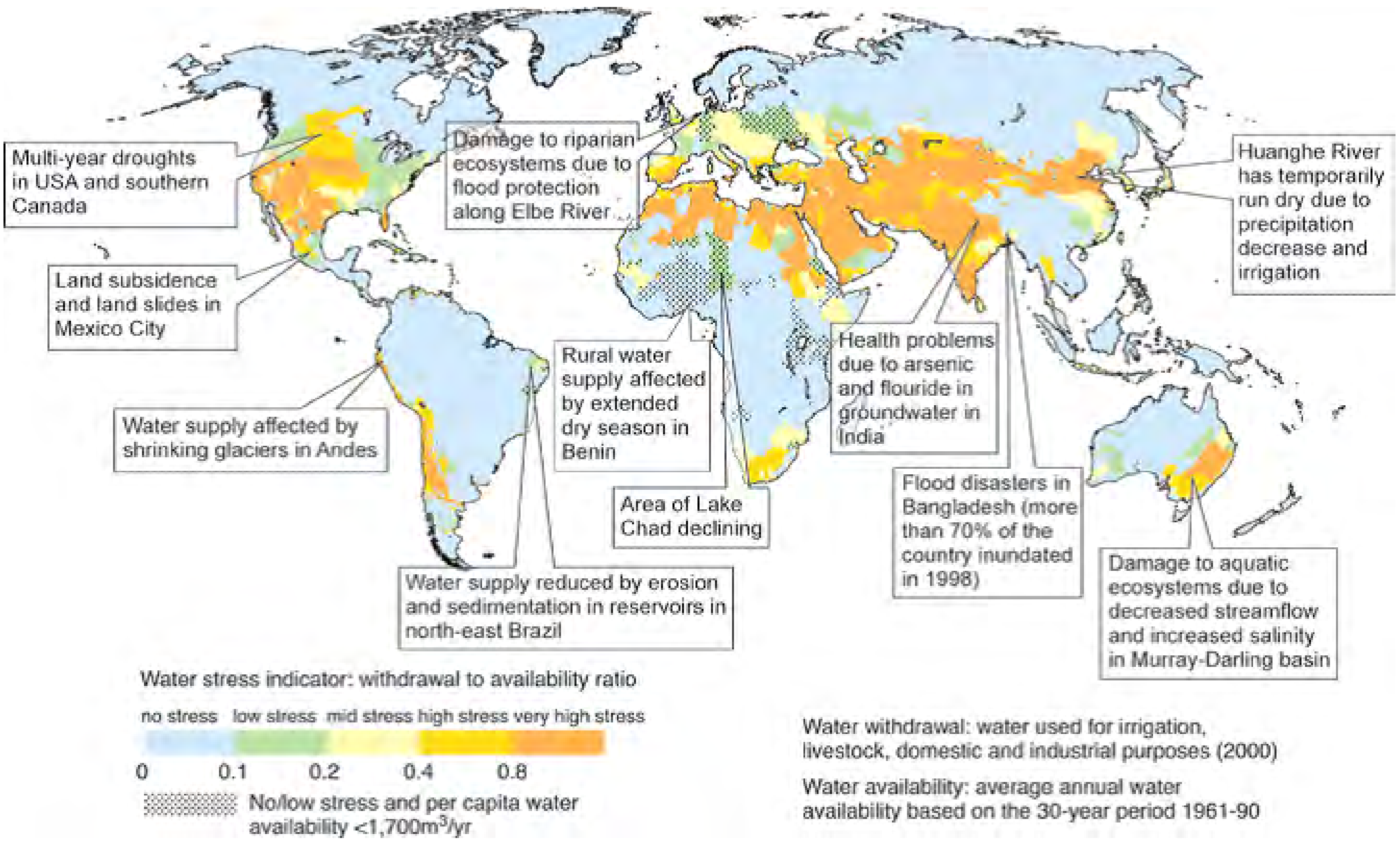
Figure14.2: Projected percent change in water deficit index for 2030

(Source: World Bank 2013)



<< Back to contents

Figure 14.3: World scenario of current vulnerability of freshwater resources and their management; in the background, a water stress map based on Water GAP



(Alcamo *et al*., 2003a)

both water availability and use, thereby increasing water stress globally. Future water availability, use, and investments will also depend on non-climatic drivers, including financial and sector conditions. Water investments are particularly vulnerable to impacts of climate change. The extent to which water investments are impacted by climate change will have ramifications that could extend to the economy and society at large (World Bank, 2009). This agenda on climate change has more specifically, informed about the water sector on climate issues and climate-smart adaptation options. Using the existing knowledge and additional analysis commissioned, the reporting of impacts on climate change on water resources illustrates that it is affecting the hydrologic cycle and the projected future hydrology would have a direct impact on the water resources base availability, usage, and management(Figure 14.3).

14.4 CONCLUSION

A key challenge faced by land, forest and water managers is to maximize the wide range of forest benefits without detriment to water resources and ecosystem function. This is particularly relevant in the context of adaptation to climate change, which increasingly reinforces the importance of sustainable forest management. In addition, growing problems of water scarcity, environmental degradation, food insecurity and poor livelihood conditions and human health all require urgent policy and management measures, pointing attention to interrelationships between forest and water. Sustainable management of forests can not only mitigate global climate change but also improve the structure of the hydrological cycle as well as maintain the availability and quality of water.

ACKNOWLEDGEMENT

I am grateful to Forest Research Institute, Dehradun for expanding my knowledge and providing support as well as assistance. I also thank Mr. Parth Tailor for his innovative ideas and suggestions for the paper.

REFERENCES

Andreassian, V. 2004. Water and forests: from an historical controversy to scientific debate. *Journal of Hydrology,* 291, 1–27.

Bates, B.C., Kundzewicz, Z.W., Wu, S., Palutikof, J.P. (eds). 2008. Climate change and water. Technical Paper. Geneva: Intergovernmental Panel on Climate Change (IPCC) Secretariat. p. 210.

Bergkamp, G., Orlando, B. and Burton, I. 2003. Change: Adaptation of Water Resources Management to Climate Change. Gland,

<< Back to contents

Switzerland and Cambridge, UK, International Union for Conservation of Nature (IUCN).

Calder, I., Hofer, T., Vermont, S. and Warren, P. 2007. Towards a new understanding of forests and water. Unasylva, 58(229) . FAO: Rome. www.fao.org/docrep/010/a1598e/a1598e02.htm

Chang, M. 2003. Forest hydrology: an introduction to water and forests. Boca Raton, FL: CRC Press. 488 p.

IPCC, 2007a, Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B.M.Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 996 pp.

IPCC, 2007b, Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Parry, M.L., O.F. Canziani, J.P. Palutikof, P.J. van der Linden, C.E. Hanson (eds)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Nabuurs, G.J. *et al.*, 2007, Forestry. In Climate Change 2007: Mitigation. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [B. Metz, O.R. Davidson, P.R. Bosch, R. Dave, L.A. Meyer (eds)], Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Ravindranath, N.H., Murthy, I. K., Sudha, P., Ramprasad, V., Nagendra, M.D.V., Sahana, C.A., Srivathsa, K.G., and Khan, H. 2007. Methodological issues in forestry mitigation projects: A case study of Kolar district. *Mitigation and Adaptation Strategies for Global Change,* 12(6), 1077–1098.

Robledo, Carmenza and Claudio Forner. 2005. Adaptation of Forest Ecosystems and the Forest Sector to Climate Change. Forest and Climate Change Working Paper 2. Rome: Food and Agriculture Organization of the United Nations, pp. 49.

Winstanley, D., Angel, J.A., Changnon, S.A., Knapp, H.V., Kunkel, K.E., Palecki, M.A., Scott, R.W. and Wehrmann, H.A. 2006. The Water Cycle and Water Budgets in Illinois: A Framework for Drought and Water-supply Planning, I/EM 2006-02, 114 p. Illinois State Water Survey, Champaign, IL.

World Bank. 2009. Water and Climate Change: Understanding the risks and making Climate-smart investment decisions. Retrieved from http://siteresources.worldbank.org/EXTNTFPSI/Resources/DPWaterClimateChangeweblarge.pdf. Cited on 9 December 2013.

15

Use of Uc-Dhr Model to Identify Sediment Recovery Following Tropical Selective Logging Given the Effect of Climate Dynamics and Data Gaps

Siti Nurhidayu Abu Bakar, Nick A. Chappell and WlodekTych

15.1 INTRODUCTION

Hydrological cycles in tropical forest areas consist of the balanced process of rainfall, throughfall or interception on the trees, or infiltration to the soil, evapotranspiration by the soil or trees, subsurface flow and surface water and stream water flow. Stream water flow from forested catchment contributes at least 60 per cent of the clean water source for domestic, agricultural, and industrial usage, and power generation. The understanding of the control of rainfall, evapotranspiration and other climate parameters in runoff and stream water generation from forested areas is crucial to ensure the sustainability of important clean water resources.

Issues of concern regarding water quality and quantity from the forested areas are high sedimentation and water pollution from logging activities. The consequences of sedimentation on forest activities contribute much to water quality degradation. The resultant contribution of sediment into streams also leads to damage to fish populations (Martin-Smith, 1998), ecological disturbance, reductions in channel capacity affecting flood risk and boat traffic and the inundation of offshore corals. Natural hydrological cycles such as annual cycles, seasonal cycles (wet or dry), and extreme events, potentially affect and change the way the catchments respond to rainfall and other climate parameters.

Rainfall is critical to the understanding of temporal variability in tropical erosion and sediment delivery, with extreme rainfall events often being responsible for most of the sediment flow (Douglas *et al.*, 1999). Extreme events generate new mass movement throughout the channels, slopes and mobilised surficial erosion and channel-bed sediment. However, the rare and episodic nature of extreme events increases the difficulties in investigating their recurring interval. Therefore, the understanding of hydrological cycles in transporting sedimentation to the river is essential whether it is caused by natural process, or human activities (i.e. land use conversion, logging).

Sediment delivery under natural conditions is normally influenced by rainfall, surface water, wind and topography. Selective logging operations (access road construction, tree-felling and removal), as with any other land cover, fundamentally alters the detail of forest geomorphology. The impact of forestry practices, particularly harvesting, on flooding and site hydrology is a recurrent scientific, social and political theme in watershed management (Andreassian, 2004). Uncontrolled logging influences a significant increment of sediment delivery into the stream. The immediate effects of logging in increasing storm discharge, reducing the lag time between peak rainfall and peak discharge, and in creating suspended sediment loads up to 20 times those in undisturbed areas at Danum, Malaysia were reported previously (Douglas *et al.*, 1999).

There are numerous existing research focused on the immediate erosional and hydrological impacts of rainforest logging (Douglas *et al.*, 1992; Lai, 1993; Yusop and Suki, 1994; Chappell *et al.*, 1998b; Chappell *et al.*, 2006). The erosional impact of selective logging can be reduced significantly by avoiding aligning logging roads across the middle of slopes, selective destruction of bridges and culverts (sites of potential landslides), at the end of logging operations, and avoiding the creation of steep road drain sections down road embankments (Walsh *et al.*, 2006). Although there is an attempt to minimise it with the introduction of Selective Management System (SMS) which was the logging method in Malaysia during 1987, sediment loss still occurs and has not decreased. Understanding the sediment recovery process in logged forested catchment is very important, because forest trees need soil for nutrients. Too much sediment delivery into the river reduces the soil and its nutrients needed by trees for growth and for regeneration (Bruijnzeel, 2001).

The understanding of the natural cycles of hydrological parameters from forested areas is necessary as it may have significant effect on the purely natural dynamics of the hydrological components in generating sedimentation. The rainfall cycles in tropical areas normally consist of very little annual seasonality (Chappell *et al.*, 2001), unclear annual trends (Nienwolt, 2001), El-Niño Southern Oscillation (ENSO) (Glynn, 1990), inter-annual cycles, Quasi-biennial oscillation (QBO)and diurnal cycles (Solera-Garcia *et al.*, 2006). Several methods have been utilised to understand the cycles of the hydrological process or human factors (forest operations), such as linear regression, Mann-Kendal, modelling techniques (i.e. Young *et al.*, 1999) and mathematical equations, to extract the trends and cycles from the data series. Hydrological modelling is the most powerful technique in the planning and development of an integrated approach to forest hydrology research. There are three types of models commonly used for hydrological modelling research which are; (i) a physically based model, (ii) a conceptual model, (iii) black box models and (iv) DBM models.

Physically based models of catchment hydrology also solve many geophysical equations for the component water paths within catchments, while conceptual models make assumptions and then use simplified equations to capture the hydrological dynamics. Conceptual, semi-distributed models have a much simpler model structure in comparison to physics-based models. Black box models are invariability statistical models, which are used to obtain the most efficient hydrological predictions (outputs) from one or more inputs, notably rainfall or upstream flow. DBM models are obviously different from physically based and conceptual models as they make no *a priori* assumption about the nature of hydrological systems, because the most important understanding is that natural environment systems are not normally manmade.

The DBM modelling philosophy deems that the modelling of environmental systems should be 'objective oriented and data based' (Young, 1993a). Essentially, DBM modelling involves four stages that exploit advanced methods of time series analysis: data based identification of the model structure based on the assumed generic model form; estimation of the parameters that characterise this identified model in physically meaningful terms; validation of the estimated model on rainfall-flow data that is different from the calibration data used in the identification and estimation analysis.

The DHR model was successfully applied by Ampadu (2007) to identify cycles in rainfall and runoff across the Ghanaian latitudinal gradient. Solera-Garcia *et al.* (2006) identified the hydroclimate cycle in tropical areas. Bidin (2001) utilised DHR to study the water yield and riverflow responsiveness in the Danum Valley, Borneo. Lin & Beck (2001) reported the advantages of the application of DHR in understanding the dynamics of algal photosynthesis and respiration. Chappell *et al.* (2001) applied DHR modelling to investigate the temporal variability of rainfall and canopy controls in Borneo while Boochabun *et al.* (2002) applied DHR to study the rainfall and river flow trends and cycles in Thailand.

Other than hydrological cycle, the DHR model also has been applied in investigating and forecasting other cycles, i.e. economic (Young *et al.*, 1989). The advantages of DHR modelling are that it can be used for forecasting and back-casting, and has the ability to handle missing data, which is a common problem when working with longer-term data series.

There is an increasing awareness that natural climate cycles, notably in rainfall, have an impact on runoff and sediment delivery (e.g., Mo, 2010; Liu *et al.*, 2011). These cycles may, therefore, mask or reinforce the effects of commercial timber logging on runoff or sediment delivery (Chappell *et al.*, 2004; Chappell and Tych, 2012). Consequently, understanding of decadal changes in sediment delivery from catchments disturbed by commercial logging requires an analysis

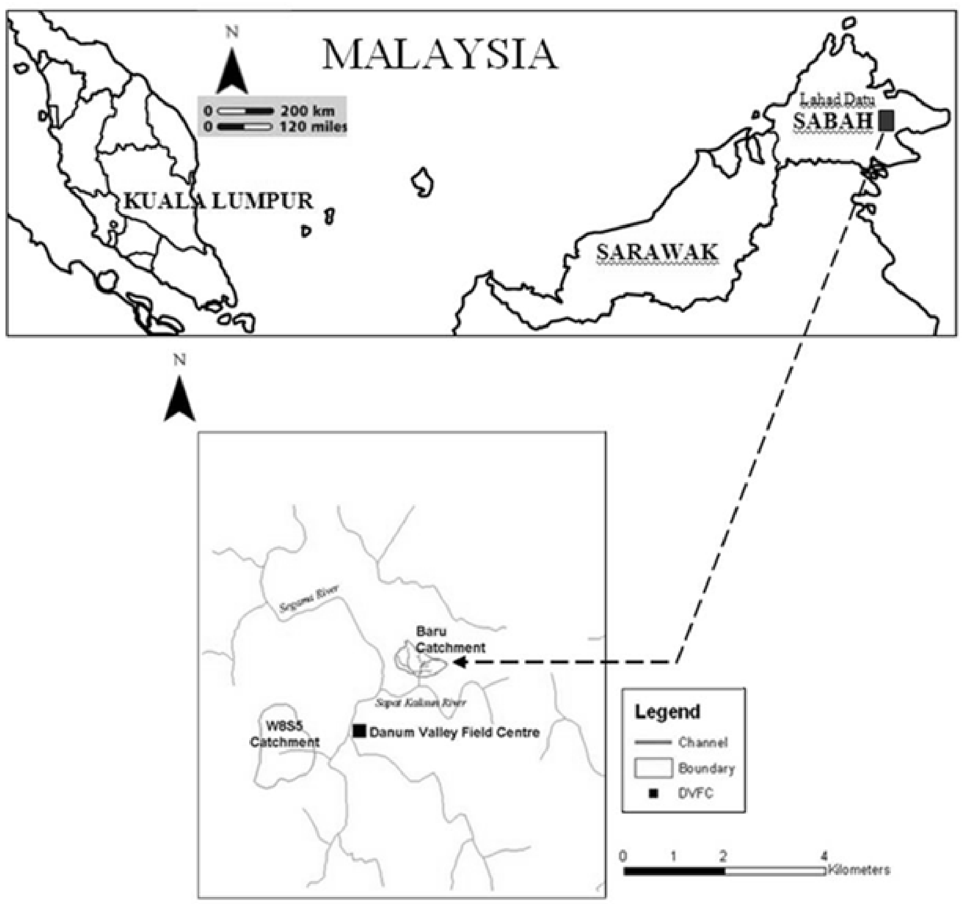


Figure 15.1: Location of the studied catchment, 0.44 km2 the Baru catchment (5°010' N and 117°48.75' E) near the Danum Valley Field Centre, Sabah, Borneo Island in Southeast Asia. The location of 1.7 km2 W8S5 (undisturbed) catchment is shown.

Figure 15.2: The 120º thin plate V-notch weir constructed at the Baru catchment outlet in January 1996. The original stilling well for the rated natural section monitored from 1988-1995 is shown on the right of the photograph.

of the spectral properties of the rainfall and runoff, which also controls suspended sediment delivery, and all using longer term data. This paper aimed to identify sediment recovery following selective logging in the Baru catchment, Malaysian Borneo, using the Unobserved Components-Dynamic Harmonic Regression (UC-DHR) model given the effect of climate dynamics and data gaps.

15.2 METHODOLOGY

15.2.1 Experimental region

The Baru catchment is 0.44 sq.km in area and lies 2 km northeast of the Danum Valley Field Centre (DVFC), Sabah (Figure 15.1). The catchment is finely dissected with a drainage density of 20-22 km per sq.km. The local climate is equatorial, with modest annual seasonality and some influence of the El-Niño Southern Oscillation (ENSO) (Chappell *et al*., 2001). Over the twenty-four year period of 1986-2009 inclusive, a mean annual rainfall of 2,862 mm has been recorded. The Baru catchment is located on Kuamut geology which is a melange comprising mostly of mudstone and sandstone (Leong, 1974). The soils belong to the Malaysian Bang Association (Wright, 1975), and are classified as Ultisols in the USDA system, and of the Acrisol-Alisol group in the FAO classification. The Baru catchment is covered by Lowland Dipterocarp Forest, which is the most extensive forest type found in Borneo (Newbery *et al*., 1992). Forest and terrain disturbance in the Baru catchment started in August 1988 when secondary and feeder roads were established (Walsh *et al*., 2006). The skidder yarding was continued until June 1989, and from July 1989, the forest and terrain was left to recover (Chappell *et al*., 2006).

15.2.2 Instrumental and field data monitoring

The time-series data from the Baru gauging station were collected from 1988 prior to the first and only phase of commercial forestry operations. The data processed are observed stream-level, suspended sediment concentration (SSC) and turbidity data from 1988 to 2008 and were monitored at the main Baru gauging station, and these were supplemented by daily rainfall data recorded at the DVFC meteorological station. From June 1988 to 1991, an OTT Hydromet GmbH chart recorder connected to a pulley, float, and counter-weight, was used for the level recording. These data once digitised were then rated to stream discharge, using numerous current metering exercises. In 1991, the chart recorder system was replaced with a Technolog Ltd floatand shaft encoder based system. In January 1996, a 120º thin plate V-notch weir was constructed at the gauging section. At the same time, other V-notch weirs were built throughout the catchment. In 2003, the shaft-encoder was replaced with a pressure transducer (Keller PDCR1830). By 2007, the central section of the zinc V-notch had deteriorated, so a stainless steel V-notch section was added to the existing zinc structure.

From 1988, a North Hants Ltd Automatic Liquid Sampler was used to collect water samples at 7.5 minute intervals through storms to obtain the SSC data. In 1991, this unit was replaced with a Buhler Montec Group Ltd 'Epic' Automatic Water Sampler, and then in 2003 by a Teledyne ISCO Inc Automatic Water Sampler. The SSC in these samples was determined in the DVFC hydrology laboratory using the gravimetric method. From 1995, spot water samples subsequently analyzed by the gravimetric method, were used to calibrate continuously measured turbidity measurements. Strictly, these turbidity measurements (initially with a Partech Ltd IR15C probe) were taken every 10 seconds, and stored if they were

<< Back to contents

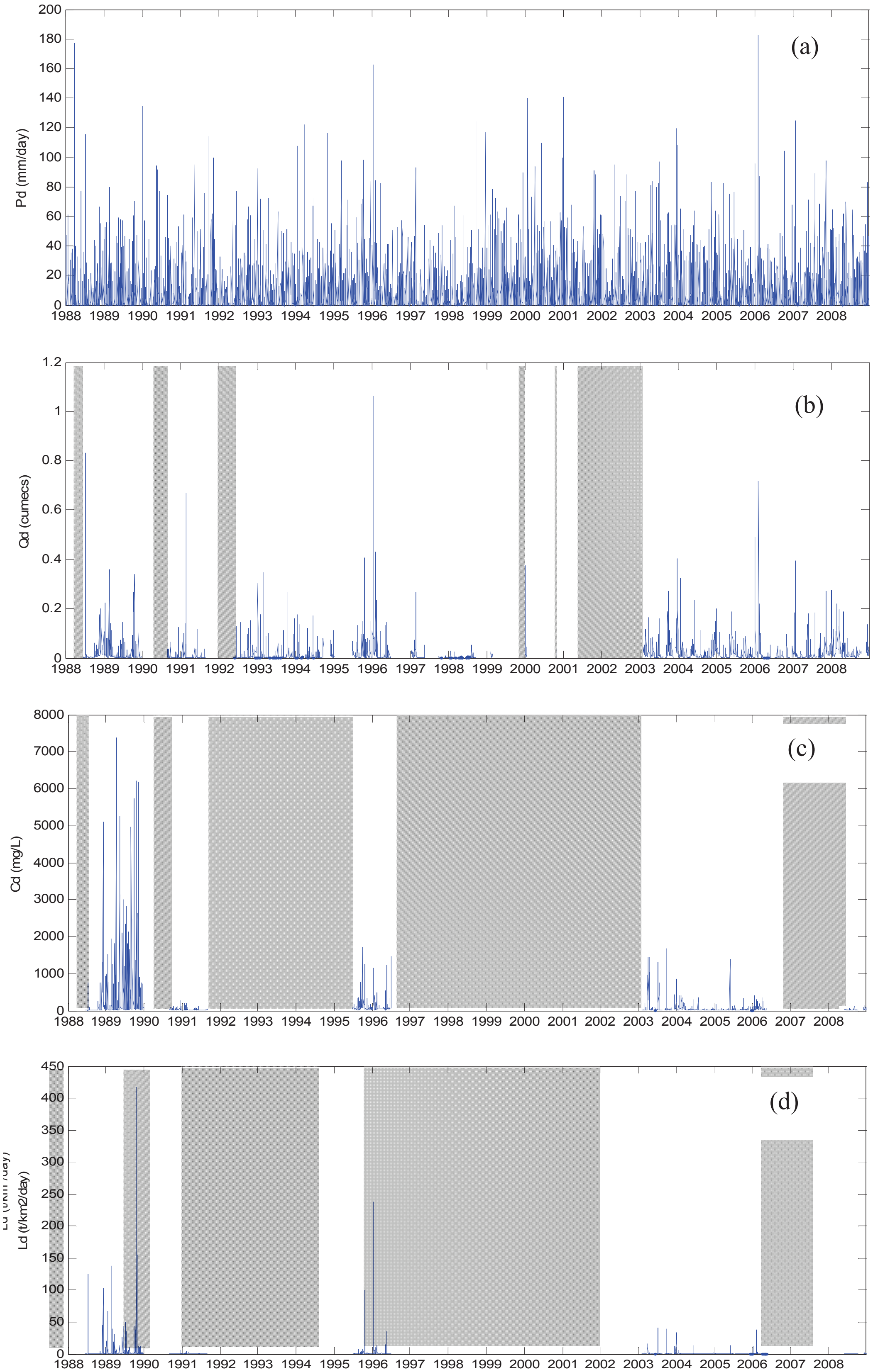


Figure15.3: Quality assured time-series integrated at a daily resolution for (a) rainfall (mm day-1), (b) discharge (m3 s-1), (c) suspended sediment concentration (mg L-1) and (d) suspended sediment load (t km-2 day-1) over the period 1988-2008. Long periods without high quality data are shown with by stippling.

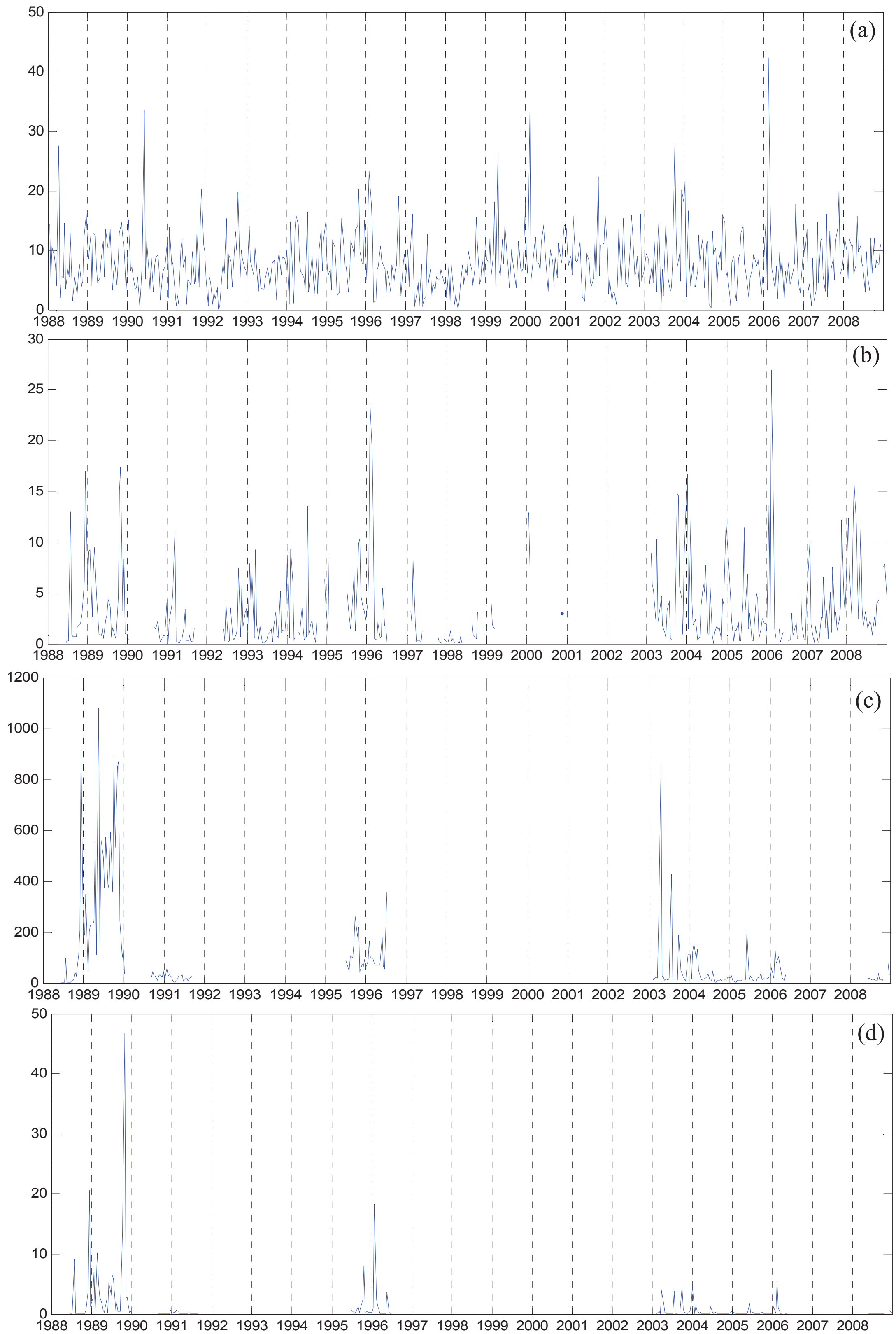


Figure 15.4: Data integrated over 14 days periods of: (a) rainfall (mm day-1), (b) runoff (mm day-1), (c) suspended sediment concentration (mg L-1) and (d) suspended sediment load (t km-2 day-1) for the period 1988-2008.

different from the previous monitored values. In 2003, the IR15C turbidity probe was replaced with a McVan Instruments Pty Ltd Analite-195 turbidity probe, and then by an Analite16NEP9500 unit. Given the known presence of breaks in the monitoring of the Baru catchment, and the changes to the types of sensors deployed, the quality assurance procedure was applied to the available time-series data of rainfall, discharge, and SSC (and the associated variables of water-level and turbidity) from 1988 to 2008. All data concatenation, errors identification, calibration and integration were carried out in Matlab programme.

15.2.3 Data series used in analysis

The time-series used for this study were collected at the main gauging station of Baru catchment, Malaysian Borneo, from 1988 (just prior to the first and only phase of commercial forestry operations) to 2008, and supplemented by daily rainfall data recorded at the DVFC meteorological station.

The monitoring equipment used changed over the 21-year period of monitoring, and therefore produced different resolution data (1-min to 1-day) with gaps, step changes and different calibration equations, which require quality checking and data processing. Via quality assurance procedures, the data were calibrated and integrated to daily resolution to ensure only high quality data used for analysis (see e.g., Mosley and McMillan, 1994). Each discharge value was normalized by the area of the Baru catchment to give a runoff value (mm day^{-1}) and hence the same units as the rainfall (mm day^{-1}). The quality assured daily data were then integrated over 14-day periods prior to analyze for the accurate identification of cycles with a periodicity of several months to several years (Young *et al.*, 1999) (Figures 15.3 and 15.4).

15.2.4 Unobserved Component-Dynamic Harmonic Regression (UC-DHR) Model

The model identification routine used in this study is the UC-DHR model (Young *et al.*, 1999). The DHR model is part of the CAPTAIN toolbox developed at Lancaster University (Taylor *et al.*, 2007) that is utilised within Matlab programming environment. The DHR model is a recursive interpolation, extrapolation and smoothing algorithm for non-stationary time-series analysis. The model is particularly useful for adaptive seasonal adjustment, signal extraction and interpolation over gaps, as well as forecasting and back-casting (Young *et al.*, 1999).The general form of Unobserved Component (UC) models of a scalar time series is as given by Young (2011):

$$y_t = T_t + S_t + e_t \qquad (16.1)$$

where y_t refers to a time series, T_t is the trend, which in this case includes the inter-annual cycles and longer-term trend lines, known here as 'drift'; e_t is white noise component, and S_t is known as the 'seasonal component' that describes the cycles with a periodicity of one year or less. This S_t term is further defined by:

$$S_t = \sum_{i=1}^{R_s} \{a_{i,t}\cos(\omega_i t) + b_{i,t}\sin(\omega_i t)\} \qquad (16.2)$$

where $a_{i,t}$ and $b_{i,t}$ are Time-Variable-Parameters (TVPs; i.e., stochastic parameters that vary with time), R_s refers to the number of annual and sub-annual frequencies in the data series, ω_i are the sets of frequencies chosen by reference to the spectral properties of the time series.

15.2.5 Modelling procedure

Application of the DHR model to time-series data began with the optimization of the Time Variable Parameters (TVPs). The optimization was achieved by first estimating the Noise Variance Ratio (NVR) of the TVPs. In the CAPTAIN Toolbox, the 'NVR hyper-parameters' that control the 'volatility' (i.e., temporal variability) of the model parameters, T_t, $a_{i,t}$, and $b_{i,t}$, are optimized via a Maximum Likelihood (ML) routine based on 'prediction error decomposition'. NVR is defined as:

$$NVR = \frac{\sigma_i^2}{\sigma_e^2} \qquad (16.3)$$

where σ_i^2 is the variance of the noise in parameter i, and σ_e^2 is the variance of the 'data observation disturbance', e_t. To estimate the NVR of the TVPs, the logarithmic pseudo-spectrum of the DHR model needs to be fitted to the estimated logarithmic autoregressive (AR) spectrum of the observed time series (i.e., rainfall, runoff, and SS concentration and load). The optimal order of the AR model was identified via the Akaike Information Criterion (AIC; Akaike, 1974) after the AR (n) spectrum and the accompanying frequencies and harmonics are determined. Once the NVR parameters were optimized, a single run of two recursive algorithms (Kalman Filter and Fixed-Interval-Smoothing) provided estimates of the seasonal and trend components. The performance of the model is assessed using the simplified Nash-Sutcliffe efficiency measure, R_T^2:

$$A_{e(t)} = \sqrt{\sum_{i=1}^{R_s} a_{i,t}^2 + a_{i,t}^2} \qquad (16.4)$$

where σ^2_r is the variance of the model residuals (i.e. model fit-observations) and σ^2_o is the variance of the observed time series. R^2_T varies between minus infinity and 1, which is a perfect fit. However, the model cannot be evaluated just based on the R_T^2 as each data series has different variability depending on climate and land use changes. In fact, it is easy to overfit a DHR model by maximising its model fit (R_T^2) whereby the model would be producing meaningless results which are hard to interpret. The evolution of the signal was shown by plotting the effective amplitude of the DHR-estimated frequencies, calculated from:

$$A_{e(t)} = \sqrt{\sum_{i=1}^{R_s} a_{i,t}^2 + a_{i,t}^2} \qquad (16.5)$$

Figure 15.5: Flow chart of DHR modelling procedure and interpretation processes.

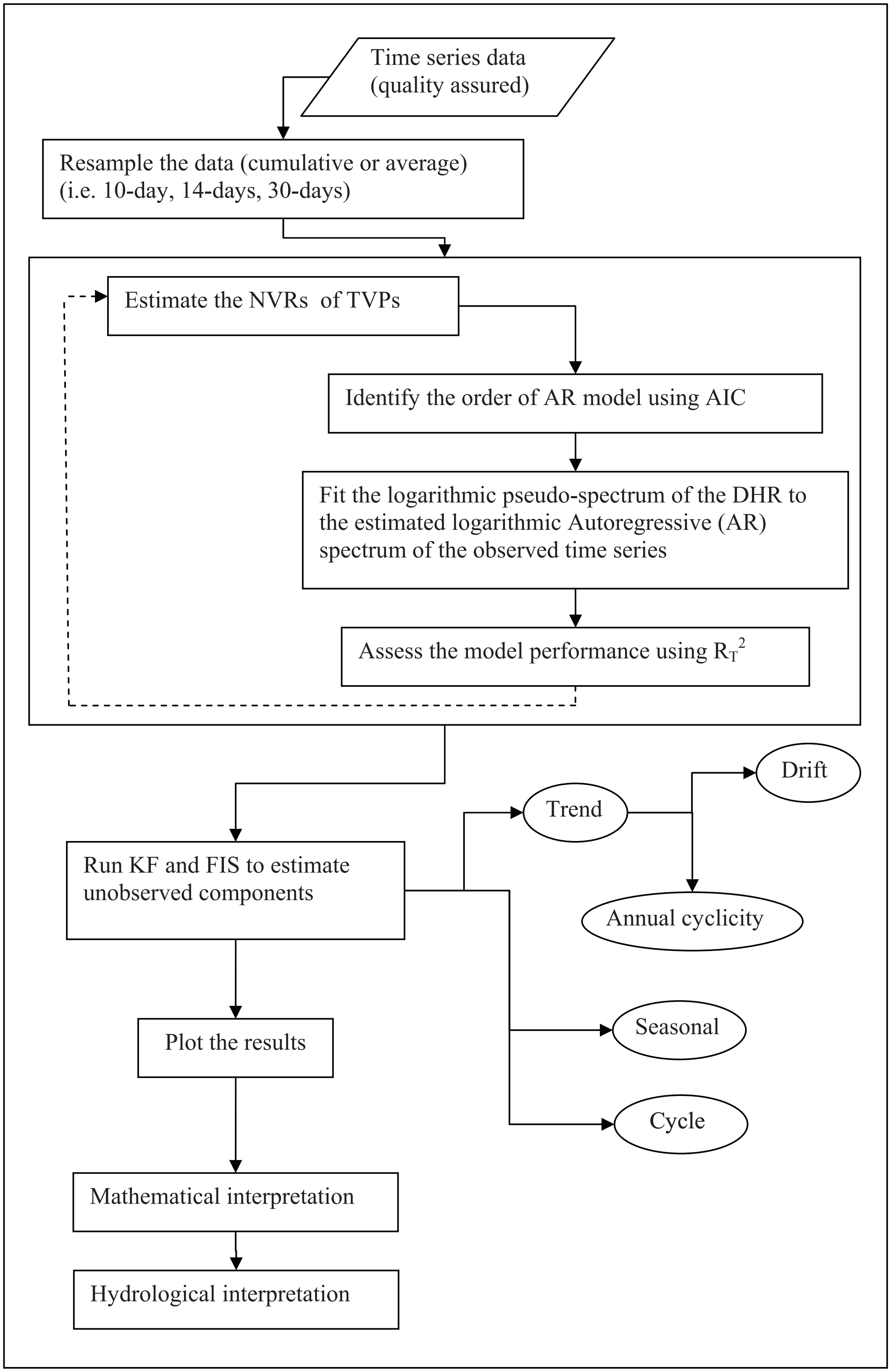
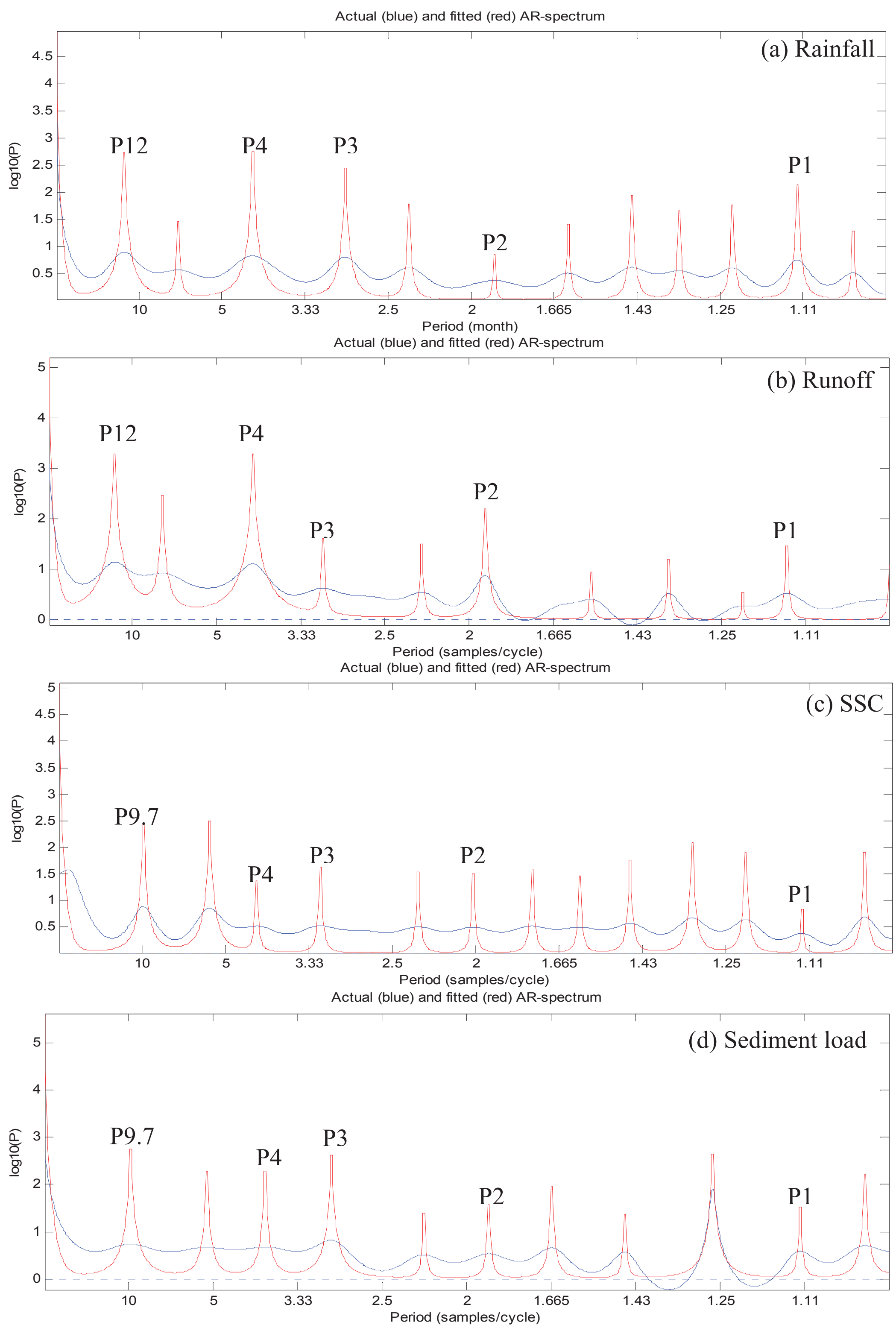


Figure 15.6: Fitted DHR spectrum (red line) and actual AR spectrum (blue line) of rainfall, runoff and suspended sediment concentration or load time-series. Certain periodicities (months) are highlighted. Model peaks clearer because the model does not include the observation noise. P is the power of pseudo-spectra of the time series: (a) rainfall, (b) runoff, (c) suspended sediment concentration and (d) load.



where A_e is the effective amplitude and the subscript i indicates the harmonic index. More detailed discussion of the DHR recursive techniques can be found within Young (1998) and Young *et al.* (1999). The DHR modelling procedure applied for rainfall, runoff, SSC and sediment load data for this study is simplified in flow chart in Figure 15.5.

15.3 RESULTS

The DHR model successfully interpolated the cycles and trends over data gaps that were rejected by customary quality assurance (Figure 15.6). The climatic vs forestry-related effects were obvious within the trend and drift of DHR simulated data. Modest seasonality with strong inter-annual cycles was observed in rainfall and runoff series whereas there was a strong seasonality with weak inter-annual cycles in SS concentration. The combination of quality assurance and UC-DHR modelling demonstrated the degree to which a recovery in the sediment system can be interpreted given data gaps and strong inter-annual and seasonal cycles in climate.

ACKNOWLEDGEMENT

The authors thank DVFC staff for their help in fieldwork, plus the Danum Valley Management Committee, the Economic Planning Unit of the Prime Minister's Department of Malaysia, the Sabah Chief Minister's Department of Malaysia and the Sabah Chief Minister's Department for permission to carry out research at Danum Valley.

REFERENCES

Akaike, H. 1974. A new look at the statistical model identification. *IEEE Trans. Auto. Cont.,* 19, 716–723.

Ampadu, B. 2007. Simulating rainfall and riverflow dynamics in Ghana. Unpublished PhD thesis, Lancaster University, UK.

Bruijnzeel, L.A. 2001. Hydrology of tropical montane cloud forests: a re-assessment. *Land use and water resources research*, *1*(1), 1.

Bidin, K. 2001. Spatio-temporal variability in rainfall and wet-canopy evaporation within a small catchment recovering from selective tropical forestry. Unpublished PhD thesis, Lancaster University, Lancaster, UK.

Boochabun, K., Tych, W., Chappell, N.A., Carling, P.A., Lorsirirat, K. and Pa-Obsaeng, S. 2004. Statistical modelling of rainfall and river flow in Thailand. *Journal of the Geological Society of India,* 64, 503–515.

Chappell, N.A., Bidin, K. and Tych, W. 2001. Modelling rainfall and canopy control on net-precipitation beneath selectively-logged tropical forest. *Plant Ecology,* 153, 215–229.

Chappell, N.A., Tych, W., Yusop, Z., Rahim, N.A., Kasran, B. 2004. Spatially-significant effects of selective tropical forestry on water, nutrient and sediment flows: a modelling supported review, in: Bonell, M., Bruijnzeel, L.A., (eds), Forest, Water and People in the Humid Tropics, Cambridge University Press, Cambridge, pp. 513-532.

Chappell, N.A., Tych, W., 2012. Identifying step changes in single streamflow and evaporation records due to forest cover change. *Hydrol. Process*. 26, 100–116.

Chappell, N.A., McKenna, P., Bidin, K., Douglas, I., and Walsh, R.P. D. 1998b. Upscaling suspended-sediment flows in disturbed rainforest terrain: Role of localised new sources. In Proceedings of 3rd International Conference on GeoComputation, University of Bristol, United Kingdom, 17-19 September.

Chappell, N.A., Vongtanaboon, S., Jiang, Y. and Tangtham, N. 2006. Return-flow prediction and buffer designation in two rainforest headwaters. *Forest Ecology and Management,* 224, 131–146.

Douglas, I., Bidin, K., Balamurugan, G., Chappell, N.A., Walsh, R.P.D., Greer, T. and Sinun, W. 1999. The role of extreme events in the impacts of selective tropical forestry on erosion during harvesting and recovery phases at Danum Valley, Sabah. *Phil. Trans. R. Soc. Lond.* 354, 1749–1761.

Glynn, P.W. 1990. Coral mortality and disturbances to coral reefs in the tropical eastern Pacific. In: Global ecological consequences of the 1982-83 El Nino-Southern Oscillation Glynn, P.W. (ed.) Amsterdam: Elsevier Oceanography Series, pp. 55-126.

Lai, F.S., Lee, M.J. and Mohd, R. 1995. Changes in sediment discharge resulting from commercial logging in the Sg. Lawing basin, Selangor, Malaysia. In: Effects of scale on interpretation and management of water quality, Osterkamp, W.R. (ed.), IAHS Publ. No. 226: 55–62.

Liu, J., Wang, B., Wang, H., Kuang, N., Ti, R., 2011. Forced response of the East Asian summer rainfall over the past millennium: results from a coupled model simulation. *Clim. Dyn.* 36, 323–336.

Mo, K.C., 2010. Interdecadal modulation of the impact of ENSO on precipitation and temperature over the United States. *J. Climate.* 23, 3639–3656.

Mosley, M.P., and McMillan, D.A., 1994. Quality assurance for hydrological data. *WMO Bull.* 43(1), 29–35.

Martin-Smith K. 1998. Biodiversity patterns of tropical freshwater fish following selective timber extraction: a case study from Sabah, Malaysia. *Italian Journal of Zoology (Suppl. S),* 65, 363–368.

Nienwolt, S. 1975. Tropical Climatology: An Introduction to the Climates of the low Latitudes. Unwim Brothers Limited, The Gresham Press, Oid Working, Surrey. Nairobi.

Solera-Garcia, M.A., Chappell, N.A. and Tych, W. 2006. Identification of the distribution of hydroclimatic cycles of field observations in Southeast Asia. Climate Variability and Change–Hydrological Impacts. Proceedings of the Fifth FRIEND World Conference held at Havana, Cuba, November 2006) IAHS Publ. 308.

Walsh, R.P. D., Clarke, M.A., Bidin, K., Blake, W.H., Chappell, N.A., Douglas, I., Ramli, N., Sayer, A.M., Sinun, W., Larenus, J. and Hanapi, J. 2006. Changes in the spatial distribution of erosion with a selectively logged rainforest catchment in Borneo 1988-2003. In: Soil erosion and sediment redistribution in river catchments: Measurement, modelling and management. Owens, P.N., and Collins, A.J. (eds). Wallingford, CABI Publishing. pp. 239–253.

Young, P.C., 2001. Model validation: perspectives in hydrological science. Anderson, M.G., Bates, P.D. (eds), Chichester: Wiley, 117–161.

Young, P.C., 2011. Recursive Estimation and Time-Series Analysis. An Introduction to Student and Practitioner. Second Edition. Springer. London, New York. pp. 504.

Young, P.C., Pedregal, D.J., Tych, W. 1999. Dynamic harmonic regression. J. Forecasting 18: 369–394.

Yusop, Z. and Suki A. 1994. Effects of selective logging methods on suspended solids concentration and turbidity level in stream water. *Journal of Tropical Forest Science,* 7, 199–219.

Young, P.C. 1993. Time variable and state dependent modelling of non-stationary and nonlinear time series. In: Developments in Time Series Analysis, Subbarop, T. (ed). Chapman & Hall. 374–413.

Young, P.C., Pedregal, D. and Tych, W. 1999. Dynamic Harmonic Regression. *Journal of Forecasting,* 18, 369–394.