Predicted Regional Hydrologic and Climatic Variables under Climate Change Scenarios using Statistical Downscaling Techniques for Future Water Resource Studies in Lombok, Indonesia

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Predicted Regional Hydrologic and Climatic Variables under Climate Change Scenarios using Statistical Downscaling Techniques for Future Water Resource Studies in Lombok, Indonesia

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Abstract

As water resources are directly dependent on climatic variables, they have the potential to be strongly impacted by climate change with wide-ranging consequences for human societies and ecosystems. Therefore, water resource studies should consider the possible effects of climate change.

In this paper, the development of predicted regional climatic variables under climate change scenarios using statistical downscaling techniques is described. Multiple linear regressions, nonlinear regressions, artificial neural networks, and a new proposed model are used to develop competitive models that can well simulate the following regional climatic variables based on the GCM outputs: humidity, rainfall, sunshine, temperature, and windspeed. The the Nash Sutcliffe Model Efficiency Coefficient (NSE), Akaike Information Criterion (AIC), and range of predicted variables are utilized to select the best model of each regional climatic variable from the competitive models. The Jangkok River, one of the first priority rivers in Lombok (a small island in Indonesia) has been chosen as a representative catchment for a case study. The GCM outputs from the second generation of the Canadian Centre for Climate Modeling and Analysis (CGCM2 - CCCMA) from 1971 to 2100 will be used in the downscaling exercise.

The results showed that the developed ANN model performed very well for simulating regional future climatic variables based on a single driving GCM; however for simulating regional future climatic variables based on multiple driving GCM, the new proposed HYAS model has a better performance than ANN for regional climate change studies in Lombok.

Keywords: Water Resource, Climate Change, Statistical Downscaling Techniques, Jangkok River Basin, Lombok, Indonesia.

Introduction

As reported in IPCC (2001), there have been many disasters around the world. Those disasters have destroyed residences, dams, roads, bridges, farms and many other facilities and have caused huge of financial losses around the world. These disasters have brought crucial questions as to what factors have triggered, and how to adapt to these disasters. It is believed that some of the recent disasters were related to climate change. Climate information plays an important role in answering questions such as: how large should agricultural land be developed in a particular basin; how many hours of wind are required to sustain a wind-driven generator; and what is the designed height of embankments to protect a town from floods.

In water resource studies, designs are directly dependent on the following climatic information: precipitation, temperature, humidity, wind, net radiation, groundwater, and stream-flows. These variables control water availability (Sudjarwadi, 1988; Dingman, 2002; Viessman, 2003; and Tallaksen and Van Lanen, 2004). However, it has been reported by IPCC (2007) that climate change will likely affect the change of precipitation including the annual average, intensities, and patterns during the 21st century. Information about global climate change based on emission scenarios has been simulated using General Circulation Models (GCMs); however, given the coarse resolutions, an enormous challenge is posed in utilizing these long-term outputs for any meaningful regional or local climate change studies. In light of this shortcoming, it becomes necessary to deploy downscaling models in order to simulate future climate change scenarios at finer spatial scales, which are more adaptable for useful regional climate change studies. Many researchers including Schnur and Lettenmaier (1996); Wilby et al., (2004); Cannon (2006); Lopes (2009); among others, have investigated and applied currently available approaches to GCM downscaling modelling such as dynamical and statistical methods. None of the current approaches has been found to be always best in all cases. Some of the disadvantages of current approaches include high cost of operations, inability to present changing variability in the future, inability to avoid producing some impossible variables, and difficulty in satisfying essential assumptions (Pfizenmayer and von Storch , 2001; Wilby et al, 2004). As such, one of the objectives of this proposal is therefore to examine the current downscaling approaches and if none of the currently existing approaches is appropriate for the region of interest, a new downscaling model will be developed for simulating regional hydrologic and climatic variables for the Jangkok River Basin.

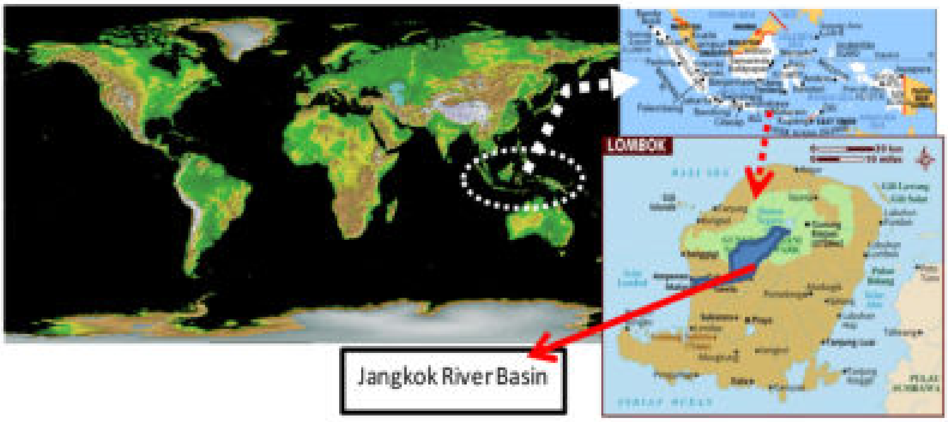


Fig. 1 Location Map of the Study

Methodology

Existing Downscaling Models include (Pfizenmayer and von Storch, 2001; Wilby et al., 2004; Timbal et al., 2009): Change Factor method, Dynamical models, and Statistical models, incl: weather classification (typing) models, regression approach (linear, non linear, neural networks), and weather generator (stochastic) models. Given the disadvantages of existing downscaling models, a new downscaling model will be developed in this proposal. This new model will consider more than one GCM variable (at least two GCM variables) to gain more information. Although according to Wilby et al. (2004), the most important GCM variable in the development of regional downscaling model is temperature either Screen (2m) Temperature (°C) or Skin (surface) Temperature (°C). In this proposal some other GCM variables as shown in Table 1 will be selected in a screening process using sensitivity analysis, before being involved in the development of downscaling model as they might give some other important information such as their trends and variations. In this proposal, the GCM variables are denoted as in Table 1. Pursuant to the objectives of this study, the schematic diagram shown in Figure 1 is presented to give a better understanding of the links among the various proposed procedures.

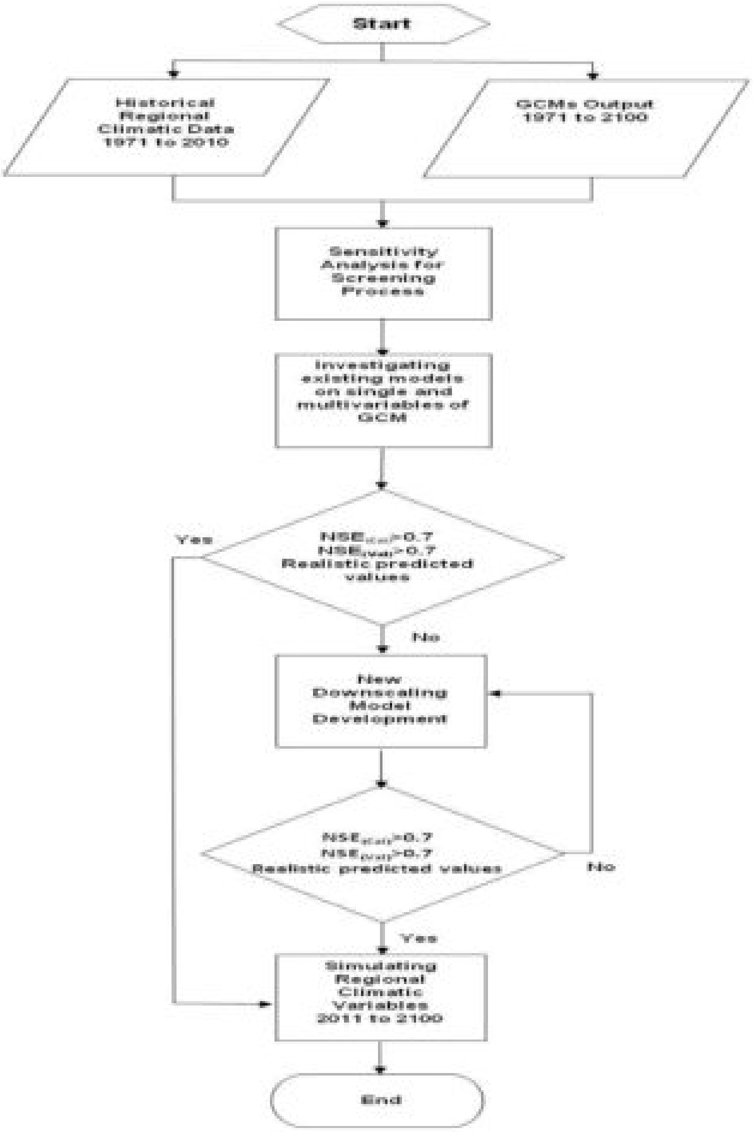


Fig. 2 Location Map of the Study

Table 1 GCM Variables involved in the new proposed model

Notation	Description	Units
X1	Mean 2m Wind Speed	m/s
X2	Evaporation	mm/day
X3	Precipitation	mm/day
X4	Screen (2m) Temperature	°C
X5	Screen Spec. Humidity	kg/kg
X6	Sea Level Pressure	hPa
X7	Skin (surface) Temperature	°C
X8	solar flux at surface	W/m^2
X9	Surface Pressure	hPa

3 (three) methods of sensitivity analysis: Neural Networks, Standardized Regression Coefficients, and Correlation Coefficients will be used in a screening process to select sensitive GCM variables that will be involved in the development of a new downscaling model. The description of neural networks, standardized regression coefficients, and correlation coefficients has been explained in detail in many text books. Their applications can also be found in many journals including in McCuen (1993), Stergiou and Siganos (1996), and Ji (2004); therefore they are not described in this proposal. The new proposed downscaling model, based upon a hybrid of algebraic and stochastic approaches and named the HYAS model, is expressed as

$$\hat{Y}_i = Y_i + sign[r] * K * \frac{\sum_{j=1}^{n} (X_{j(t)} - X_{j(m)})}{n} + C * \varepsilon_{(i)} \text{ ....} (1)$$

$$\text{If } \frac{\sum_{j=1}^{n} (X_{j(t)} - X_{j(m)})}{n} = G_i \text{, then}$$

$$\hat{Y}_i = Y_i + sign[r] * K * G_i + C * \varepsilon_{(i)} \text{ ....} (2)$$

Where:

$\hat{Y}_i$ = downscaled regional variable,

C = coefficient of rescaling prediction,

Y_i = baseline regional variable,

r = sign of correlation between the baseline of GCM and regional variables,

K = rescaling coefficient,

$X_{k(i)}$ = standardized GCM variable of i in the next k year (future period),

$X_{k0(i)}$ = standardized GCM variable of i in the baseline period,

ε_i = generated residuals with changing variance

The purpose of the coefficient of rescaling prediction (C) is to adjust the range of predicted regional variables ($\hat{Y}_i$) so that it will not cross beyond the limit of possible variables. If none of the predicted regional variables ($\hat{Y}_i$) lies beyond the boundary, C = 1 (one); if at least 1 (one) of predicted regional variables ($\hat{Y}_i$) lies beyond the boundary, the value of C will be between 0 (zero) and 1 (one) and can be obtained from calibration. The boundary is based on characteristic of regional variables, for example: the lower boundary of regional rainfall is 0 (zero) as the amount of rainfall cannot be smaller than 0 (zero).

Model acceptance criteria are used to judge whether the new model can satisfactorily replace currently used models. A new model will be accepted only if it satisfies the criteria proposed in Table 2.

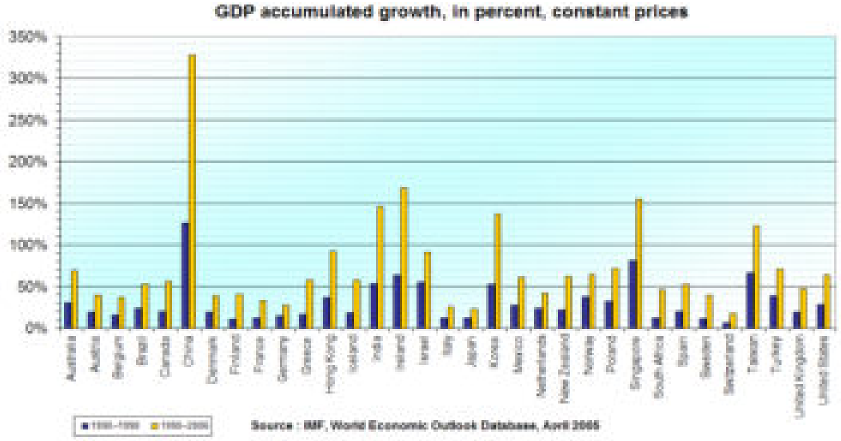
Table 2 Model Acceptance Criteria

No	Criteria	Range of Acceptance
1	Goodness of fit model validation	NSE > 0.7
2	Realistic range of simulated results	Regional Humidity (%) = 0 ~ 100 Rainfall (mm) = 0 ~ + infinity Sunshine (%) = 0 ~ 100 Air Temperature (°C) = – infinity ~ + infinity Wind Speed (knots) = 0 ~ + infinity
3	Statistical characteristics	Presence of changing future mean and variability.

In the development of a model, model goodness of fit tests is an important step both in calibration and in validation processes. Model goodness of fit tests in this proposal refers to the analysis to describe how well a model fits a set of observations. Measures of goodness of fit will summarize the discrepancy between observed variables and the variables expected from the model (Sorooshian and Gupta, 1995). The goodness of fit test that will be used in this study is the Nash Sutcliffe Model Efficiency Coefficient (NSE) (Nash and Sutcliffe, 1970).

RESULTS

It has been reported in Central Bureau of Statistics (2008), that the population of Indonesia has the growth rate of 1.34 % per year. Moreover, in the report of UN 2004 (Basu et al., 2004), the prediction of world's population to 2050 will reach 8.9 billion. Moreover, world's economic growth is not the same for every country and region as pictured in Figure 3.



Source : IMF, World Economic Outlook Database, April 2005

Figure 3 Global Economic Growths from 1990 until 2006

As characteristics of population, economic, and technology growths in the world meet the assumptions of the A2 emission scenario, this study will employ the A2 emission scenario to simulate the possible change of regional hydrologic and climatic variables and to study the impacts of global climate change.

Table 3 Investigation of Downscaling Models

	Downscaling Models	Humidity cal/val/AIC	Rainfall cal/val/AIC	Sunshine cal/val/AIC	Temperature cal/val/AIC	Wind Speed cal/val/AIC
Simple	ANN	**0.86/0.6/-459**	**0.99/0.78/1448**	**0.98/0.66/64**	**0.99/0.81/-86**	**0.52/-0.24/-526**
	CF	1/0.37/	1/0.16/	1/0.5/	1/0.75/	0.87/-0.85/
	LR	0.66/0.27/181	0.67/0.5/2867	0.5/0.44/1454	0.6/0.58/-50	0.01/-0.07/-326
	NLR	0.66/0.22/190	0.69/-0.12/2864	0.49/0.44/1457	0.62/0.57/-54	0.01/-0.06/-326
Multiple	MANN	0.8/-**4.9**/568	0.77/-**0.06**/3101	0.51/**0.33**/1579	0.78/**0.32**/-186	0.47/**0.01**/-288
	MLR	0.66/-0.49/213	0.72/0.45/2874	0.5/0.49/1377	0.61/0.54/-423	- 0.6/- 1.38/-377
	MNLR	0.67/-0.33/247	0.68/-0.32/2723	0.5/0.26/1225	0.66/0.47/-510	0.35/-0.88/-382
	HYAS	**0.95/0.73/**	**0.98/0.78/**	**0.96/0.75/**	**0.97/0.72/**	**0.93/0.73/**

Where:
ANN = Artificial Neural Networks model
CF = Change Factor method
LR = Linear Regression approach
NLR= Non Linear Regression approach
HYAS= Hybrid of Algebraic and Stochastic

Table 3 showed that the ANN model performs the best result in calibration and validation processes among the simple models; however among multiple models, the HYAS model performs best. This investigation is verified also by the range of predicted variables simulated by those models as shown in Table 4.

Table 4 The range of predicted variables resulted from simulations

Regional Variables	Ranges		ANN		CF		LR		NLR	
	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min
Humidity (%)	**100**	**0**	85.1	75	88.7	85	89.5	76.3	90.1	76.4
Rainfall (mm)	**+ inf**	**0**	989	7	590	7	456	-27	2516	26
Sunshine (%)	**100**	**0**	94	38	96	38	89	39	89	41
Air Temp(°C)	**+ inf**	**- inf**	36.7	22.8	29.9	22.8	28.8	24.7	28.7	24.7
Wind Speed (knots)	**+ inf**	**0**	22.6	1.9	29.6	-2.1	5.3	5.0	5.3	5.0

Regional Variables	Ranges		MANN		MLR		MNLR		HYAS	
	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min
Humidity (%)	**100**	**0**	**178.9**	**64.2**	**85**	**75**	**91.1**	**76.4**	**100**	**75**
Rainfall (mm)	**+ inf**	**0**	**1700.5**	**-1500.4**	**363.1**	**7**	**516.5**	**-7.4**	**619**	**7**
Sunshine (%)	**100**	**0**	**164**	**-159**	**96**	**38**	**89**	**58**	**98**	**33**
Air Temp(°C)	**+ inf**	**- inf**	**37.8**	**8.7**	**30**	**23**	**29.7**	**24.8**	**33**	**24**
Wind Speed (knots)	**+ inf**	**0**	**12**	**-6**	**9**	**3**	**6**	**4**	**13**	**3**

Table 4 shows that only ANN, MLR, and HYAS did not produce unrealistic variables. The next investigation is based on the analysis of mean and variance of predicted variables as shown in Figure 4.

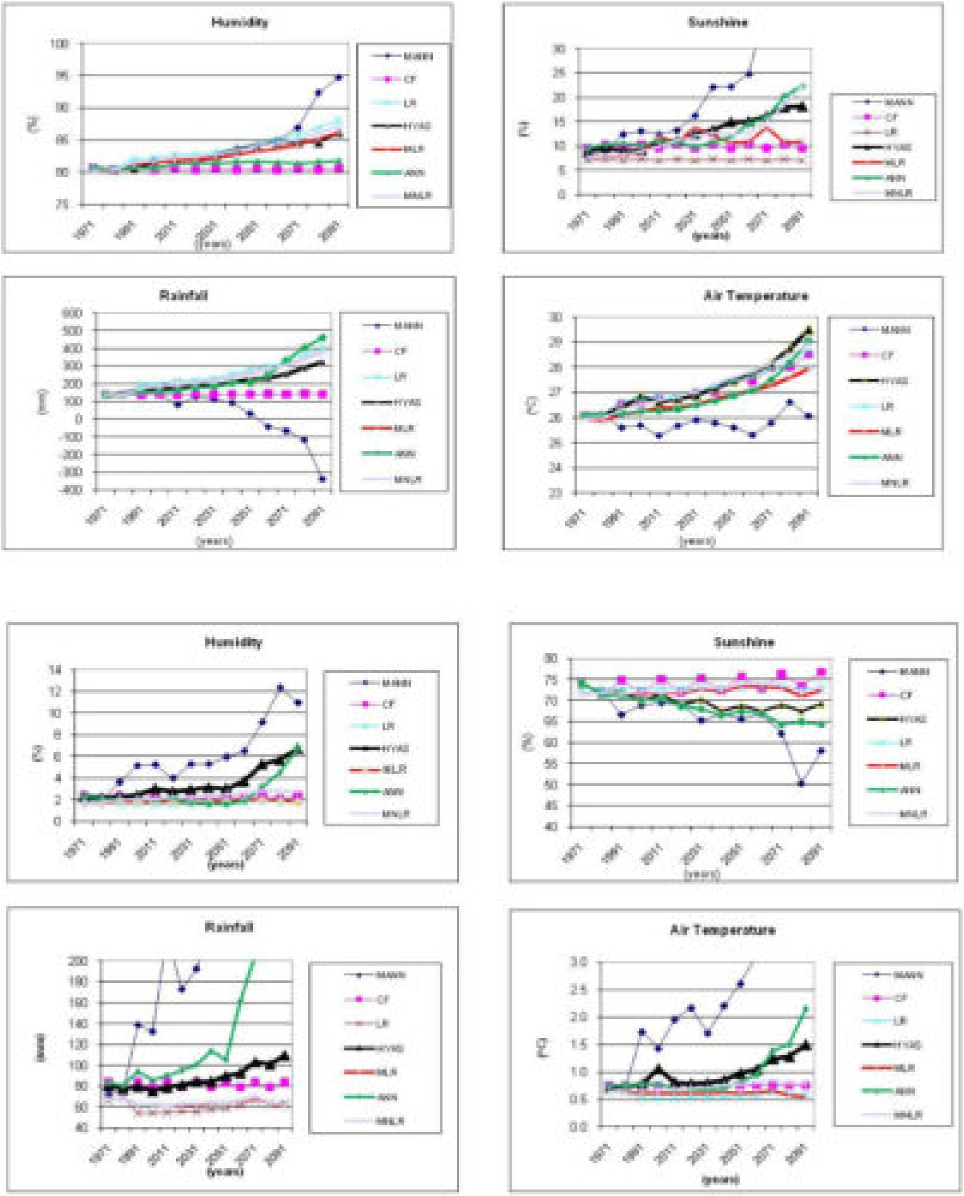


Figure 4 Mean and Standard Deviation of simulated variables.

Figure 4 shows that the HYAS model significantly performs changing in mean and standard deviation of simulated variables.

CONCLUSION

1. Characteristics of population, economic, and technology growths in the region of interest meet the assumptions of A2 emission scenario.
2. Screen Specific Humidity, Screen Temperature, and Surface Temperature are the top 3 most sensitive GCM variables to model regional climatic variables in the region of interest.
3. Among the presently used downscaling models, ANN is the best downscaling model using a single driving GCM variable.
4. The new downscaling HYAS model has a better performance than ANN for simulating regional variables in the region of interest using multiple GCM variables

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