EFFECT OF CLIMATE CHANGE VARIABLES ON THE COASTAL WIND PREDICTION

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ABSTRACT

In case of inadequate or unavailable wave data in the coastal disaster risk studies, one can rely on the techniques of utilizing wind data to estimate wave. Under the consensus of climate change, it is suggested to include climate change phenomena in the study of coastal disaster risks. In this paper, the relationship between climate change variables and the historical coastal wind was studied.The wind data of Selaparang Airport station, Mataram Indonesia from 1988 to 2011 and climate change variables from IPCC data were used in this study. The slope-correlation, trend, non-stationary, and regression analyses were utilized in this study. Slope-correlation was used to understand the relationship between climate change variables and historical local wind data. The value of slope-correlation was also used to develop the regression model. Trend and non-stationary analyses were used to determine the slope and the residuals of a regression model.The case study results show that a positive trend occurred in the Selaparang wind data. The positive trend raises suspicions of a correlation between climate change and wind data. In this paper, the positive correlation between climate change phenomena and local wind data was successfully studied. It was found that the increasing average of wind by 3 knots per-100 years happens in the future.

Keywords:Coastal wind, climate change, slope-correlation, trend, regression

1. INTRODUCTION

Coastal dikes are commonly used in coastal risk reduction management. Failure mechanism of coastal dikes can be caused by failure from scouring at landward toe, failure from the crown or the top of landward armor, parapet failure induced by tsunami runup, failure from scouring at seaward toe, parapet failure induced by tsunami drawdown, seawall overturning by tsunami runup, seawall overturning by tsunami drawdown, and seismic motion (Kato et al., 2012). Moreover in Thomas and Hall (1992), failures of seawall may be because of inadequate assessment of design loads, inadequate assessment of design capacity, construction problems giving actual capacity less than design capacity, maintenance problems giving actual capacity less than design capacity, deterioration of wall capacity with time, increase in loads with time, and the capacity of wall being exceeded.

Engineers utilize the information of ocean wave and current in the coastal disaster risk reduction and coastal protection designs. Wave and current are generated by the magnitude and direction of the wind. Therefore, engineers have to understand characteristics of wind data parameters before using the data in the wave modeling. The important parameters of wind data include wind speed, wind blow duration, fetch, and wind direction. Engineers use the maximum or average of wind data parameters for calculating wave height, peak wave period, and wave growth. However nowadays after climate change consensus, engineers have to beware of the appearance of trend and non-stationary of wind data.

Trend data is the data that have an unstable average (changing mean). In statistics, it can be understood as the data with a pattern of gradual changing average over time, represented by a line or curve on a graph. Heteroscedastic data is the data that have an unequal variability across a set of other predictor variables. A plot of heteroscedastic data has a cone shape on the scatter graph. Without any special treatment on both trend and non-stationary of wind data, they can lead to spurious results of the analysis.

Many engineers rely on the average of maximum waves to design coastal protections. In fact, in most cases, the availability of wave data is inadequate. Therefore, engineers utilize wind data to generate wave data.

As wind is affected by climate change, the average of maximum wind (wind-storm) that is calculated simply from trend data is actually a wrong result.

The paper aims to propose a procedure to determine Impact of Climate Change on Coastal Wind. This article is structured as follows. Section 2 reviews of wind analysis for coastal disaster reduction studies. The proposed procedure is presented in Section 3. Section 4 demonstrates the application of the proposed procedure, and section 5 provides conclusions and some recommendations for future work.

2. REVIEWS OF WIND ANALYSIS FOR COASTAL DISASTER REDUCTION STUDIES

2.1 Wind disasters

Wind disasters can cause tremendous physical damage, starting from wounds to loss of life. Such a thing is proven to cause enormous economic losses (Marchigiani et al., 2013). Wind disasters cause many adverse effects on communities. The effects of wind disaster events may continue for a long time. Moreover, according to Marchigiani, the damage that accompanies such events can be corrected with the best possible preparation.

2.2 Wind waves

Most of the big waves seen on the beach are caused by the long distance wind (Young, 1999). These following five factors: wind-speed, fetch, the width of fetch, wind duration, and water depth influence the formation of flow structures in the wind wave. These factors determine the size of the wind wave and the flow structure within it. The main dimensions of waves are wave height, wave length, wave period, wave speed and wave propagation.

Destructive waves are when the waves have high energy. Coastal reduction occurs when erosion is more than deposition in the beach. Becausemore materials are removed than are deposited on the coast. This happens as the backwash of the waves that is more powerful than the swash.The energy associated with a traveling wave in a stretched string is conveniently expressed as the energy per wavelength. Since this amount of energy is transported a distance of one wavelength along the string in one period, this expression can be used to calculate the power transmitted along a string. If the wavelength is given, the energy can be determined by first using the wave equation ($c = \lambda \times \nu$) to find the frequency, then using Planck's equation to calculate energy (Planck, 1914). Ocean waves contain tremendous energy potential. The Planck equation is

$$E = h\nu (1)$$

Where:

E : Energy in Joules (J)
h : 6.626 x 10-34 J s
ν : frequency in hertz, 1/s or s-1

The power of waves is one of the most significant forces of coastal change. Waves are created by frictional drag as the wind blows over the surface of the ocean. We often think of the air as being weightless and 'nothing' but in fact, it has real power, as you discover when you try to walk into a gale. The same forces you experience when you walk into the wind are applied to the surface of the sea as the air is moved across it. Friction is created at the boundary between the air and water, pushing water in the direction of the wind. This creates a swell and a wave is created. Energy from the wind begins to rotate the water, turning it in a forward moving circle. In this way, the wave can move forward and will continue doing so until it either reaches an obstacle, like land, or it runs out of energy, e.g. the wind stops.

The two main factors that determine the size and power of a wave are the strength of the wind and the distance over which it blows. A strong wind blowing over hundreds of miles of ocean will create a more powerful wave than a weak wind blowing for just a few miles. The uninterrupted distance over which the wind can blow is called the fetch. Fetch is an important factor in the formation, size and power of waves. Despite its importance fetch is a very simple thing. In the most straightforward way, fetch is just the maximum length of open water over which the wind can blow.

2.3 Wind-speed based wave height and wave speed estimation

In Bretschneider (1957), researchers found the relationship between wind-speed and wave height also between wind-speed and wave speed can be expressed as

$$\frac{gH}{U^2} = f_1\left[\frac{gH}{U^2}, \frac{gt}{U}\right](2)$$

$$\frac{C_0}{U} = \frac{gt}{2\pi U} = f_2\left[\frac{gF}{U^2}, \frac{gt}{U}\right] \quad (3)$$

Where:

g : acceleration of gravity, 32.2 feet/second^2
H : significant wave height, feet
U : wind speed, feet/second
t : duration of wind, seconds
C_0 : wave speed in deep water, feet/second
f : fetch length, feet

Moreover according to Bretschneider, those formulas are reasonable under 3 following assumptions: a constant direction of wind blow over time, a constant direction of wind blow over distance, and a short period of time of wind increase.

2.4 Wind-speed Based Wave Length Estimation

A distance between one frequencyof wave peak to another is called the wavelength. The wavelength can determined using the equation (Cassidy et al, 2002) below

$$\lambda = \frac{v}{f} \quad (4)$$

Where:

λ : Wavelength, m;
v : Speed, m/sec;
f : Frequency, Hz.

3. PROPOSED PROCEDURE

It is clearly known that inaccuracy in selecting a method in data analysis can lead to produce wrong results; therefore in this paper, a procedure to identify relationship between climate change variables and historical local wind data is proposed. The procedure also develops a model for predicting future wind data based on climate change variables. The procedure follows a diagram in Figure 1.

As shown in Figure 1, there are three major steps in the proposed procedure:

Step 1: Identification of Slope-Correlation

In this step, slope-correlation between climate change variables and wind data is identified. Slope-Correlation is a correlation between the trend of climate change variable and the trend of wind data. The correlation is used to show the strength of relationship between the two trends. In this study, the Pearson product-moment correlation coefficient, or commonly called simply "the correlation coefficient" was used. The equation (Rodgers and Nicewander, 1988) is expressed as

$$\rho_{X,Y} = \frac{cov(X,Y)}{\sigma_X \sigma_Y} = \frac{E[(X-\mu_X)(Y-\mu_Y)]}{\sigma_X \sigma_Y} \quad (5)$$

Where:

ρ : the correlation coefficient
X : variable X
Y : variable Y
cov : covariance, and
σ : standard deviation
E : the expected value operator
μ : the average

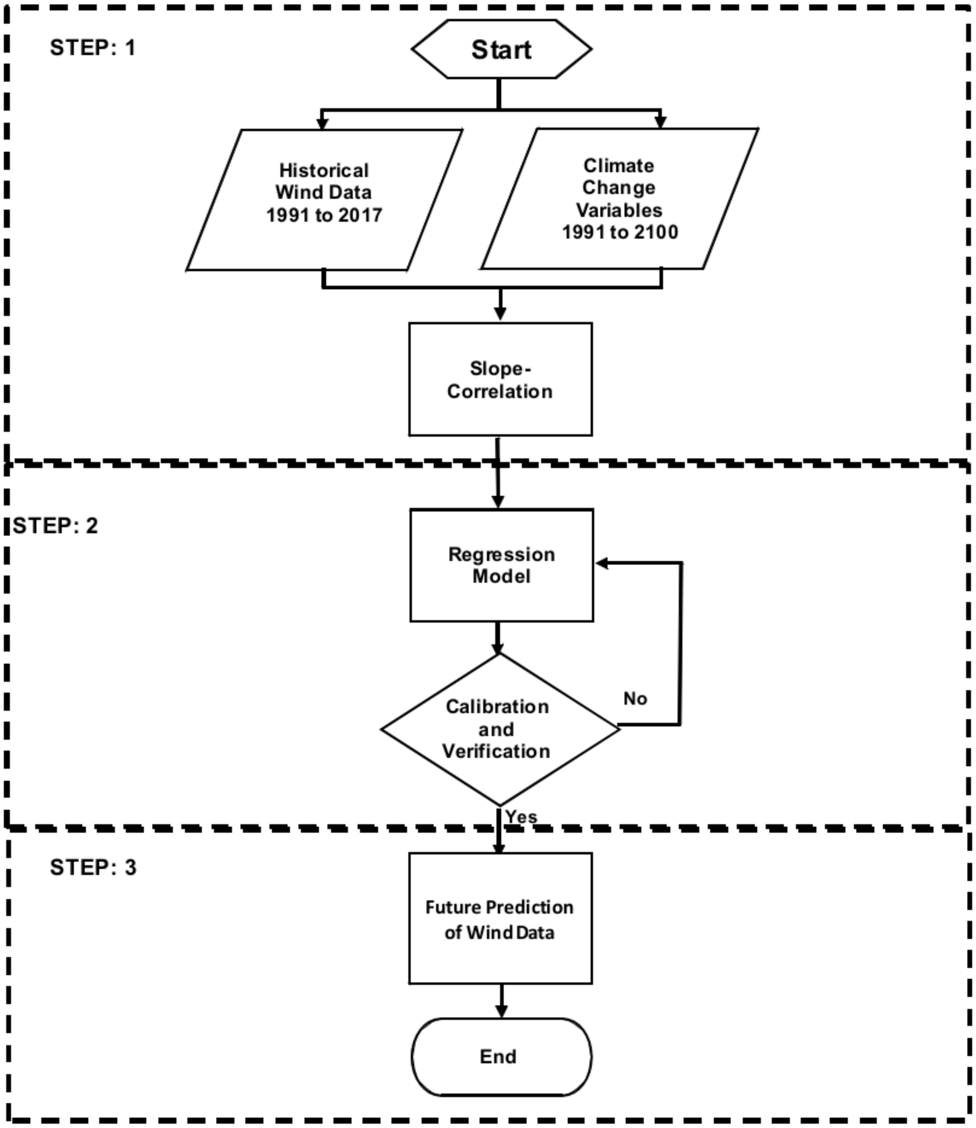

Figure 1. Proposed Procedure

After extraction of equation 5, the expression will become

$$r = \frac{N\sum XY - \sum(X)(Y)}{\sqrt{[N\sum X^2 - \sum(X^2)][N\sum Y^2 - \sum(Y^2)]}} \quad (6)$$

Where:

r : Pearson r correlation coefficient

N : number of value in each data set

$\sum XY$: sum of the products of paired scores

$\sum(X)$: sum of x scores

$\sum(Y)$: sum of y scores

$\sum X^2$: sum of squared x scores

$\sum Y^2$: sum of squared y scores

X : wind data subtracted by the normal random

Y : climate change variable subtracted by the normal random

In many references, the degree of correlation is defined as shown in Table 1

Table 1.Definition of Correlation Values

Value of r	Definition of relationship
0.80 ~ 1.00	Very strong correlation and in the same slope
0.60 ~ 0.79	Strong correlation and in the same slope
0.40 ~ 0.59	Moderate correlation and in the same slope
0.20 ~ 0.39	Weak correlation and in the same slope
0.01 ~ 0.19	Very weak correlation and in the same slope
0.00	No correlation
- 0.01 ~ - 0.19	Very weak correlation but in the oppositeslope
- 0.20 ~ - 0.39	Weak correlation but in the oppositeslope
- 0.40 ~ - 0.59	Moderate correlation but in the oppositeslope
- 0.60 ~ - 0.79	Strong correlation but in the oppositeslope
- 0.80 ~ - 1.00	Very strong correlation but in the oppositeslope

(Source: Evans, 1996)

Step 2: Development of Regression Model,

In this step, the best regression model for these data was developed. The best model is selected if its goodness of fit model criteria were accepted. The acceptance criteria used in this study were the sign, the P-value, the Variance Inflation Factor (VIF) of variables, and the R^2 of regression model (Sulistiyono, 1999; Sulistiyono and Lye, 2010; Lye and Sulistiyono, 2014).

The sign of independent variables has to be reasonable, for example: the sign of global variable of wind speed has to be a positive sign in the regression, as it is to model the local wind speed. Next, the VIF of all independent variables has to be smaller than 5 to indicate no multicollinearity or at least only very weak multicollinearity among the independent variables. P-value of all considered variables in the model has to be smaller than 5%. And finally, the R^2 of regression model has to be close to 1 to indicate the degree of acceptance (Sulistiyono, 1999; Sulistiyono, 2012).

Step 3: Generation of Predicted Wind data in The Future

In this step, future prediction of wind data until 2100 were generated based on related climate change variables found in step 1 and using the regression model developed in the step 2.

4. CASE STUDY

The application of the proposed procedure can be demonstrated using a case study. Consider coastal disaster at the Ampenan Beach. Ampenan Beach is a sandy beach in the western part of Lombok Island. This beach area overlooks the Lombok Strait. Coastal flood and erosion often occur in the Ampenan coastal area due to the average ground elevation are less than 5 m above normal sea level, tidal influences, ocean current patterns and waves. The problem of coastal erosion has been a major attention in the last 10 years since it became much detrimental to the coastal communities, such as the loss of coastal land. Coastal erosion and abrasion along the Ampenan Beaches occur due to various factors, such as the construction of jetty structures, the development of coastal beach krib along the SenggigiBeach, and sea level rise. The local government has built a concrete seawall along this coast to protect beaches and people's homes. But this protection was only lasted one year before being destroyed by a great wave.

As reported by many people living in the Ampenan coastal region, the annual maximum speed of wind is getting higher and the reduction of land on the beach is getting exacerbate. A highly possible occurrence of trend and non-stationary in the wind data is caused by the impact of climate change (Eichelberger et al., 2008; Kulkarni et al., 2015)

Case Study Step 1: Identification of Slope-Correlation

In the first step of this study, slope-correlations between the 10 climate change variables available in the IPCC data file (Sulistiyono and Lye, 2011; Sulistiyono and Lye 2012; Sulistiyono, 2012) and the local wind data were analysed. The 10 climate change variables are denoted as B, C, D, E, F, G, H, I, J, K with its slope-correlation value related to the local wind data are shown in Table 2.

Table 2.Climate change variables with their slope-correlation to the local wind data

No	Name of climate change variables	Notation	Unit	r
1	Wind Speed at 2 m	B	knots	-1
2	Geopotential Height at 500 hPa	C	M	0.969
3	Geopotential Height Thickness	D	m	0.969
4	Evaporation	E	mm	1
5	Incident Solar Flux	F	W/m^2	-1
6	Precipitation	G	mm	-1
7	Screen Temperature	H	^oC	0.969
8	Screen Humidity	I	%	0.968
9	Sea Level Pressure	J	hPa	1
10	Surface Temperature	K	^oC	0.969

Note: Symbol "A" is not used in variables as it is used to denote local wind variable

Case Study Step 2: Development of Regression Model

Regression model is analysed below, where:

A: Local wind

Regression Analysis: A versus B, C, D, E, F, G, H, I, J, K

The coefficients of following terms cannot be estimated and were removed: D, E, F, G, H, I, J, K. The remaining variables that will be used in the regression model and their coefficients are shown in Table 3 and Table 4, respectively.

Table 3.Analysis of Variance

Source	DF	Adj	SS
Regression	2	28.3505	14.1753
B	1	1.7592	1.7592
C	1	0.00	0.00
Error	261	0.00	0.00
Total	263	28.3505	
R^2		$R^2_{(adj)}$	$R^2_{(pred)}$
100.00%		100.00%	100.00%

Table 4.Coefficients of Model Variables

Term	Coef	SE	T-Value
Constant	4.807	0.00	≈ 0
B	-0.002720	0.00	≈ 0

Therefore, the final regression equation is

$$A = 4.807 - 0.002720*(rB)* B$$

$$A = 4.807 - 0.002720*(-1)* B$$

$$A = 4.807 + 0.002720* B+ \quad {}_{B}$$

According to the result from step 2, the future prediction of local wind data (A) is only based on wind variable (B) of climate change data and its residuals ($_{B}$).

Case Study Step 3: Future Prediction of Wind Data

Future prediction of wind data is generated based on the regression obtained in the step 2 with the additional random variables based on random variables of climate change variables. The future prediction of wind data is shown in Figure 2.

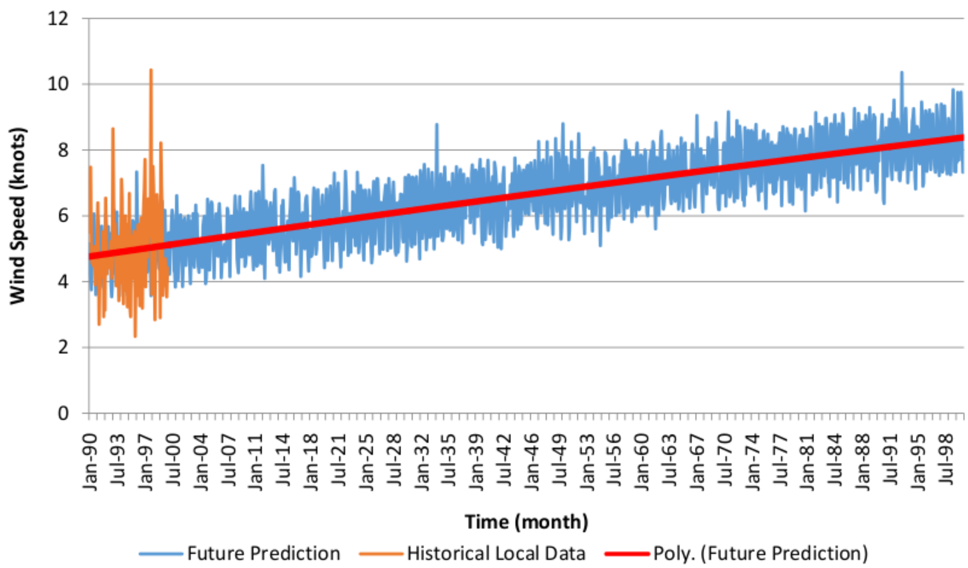

Figure 2. The future prediction of wind data

5. CONCLUSIONS AND RECOMMENDATIONS

To ensure the result of coastal disaster risk reduction, the cause of disasters must be identified. Appropriate information of future wind is a key to the study of coastal disasters by wave and wind. Although some engineers have utilized maximum historical wind data be used as design maximum wind for coastal protection, there is no official procedure that can be applied to develop a reasonable wind characteristic This paper proposed a technique to identify the relationship between climate change variables and historical local wind data, also to develop a climate change based model of predicted wind data. Based on slope-correlation, the relationship between climate change variables and historical local wind data can be determined. Generation of statistic model residual for predicting future wind is obtained from the connate properties of climate change variables. The proposed approach was validated through a real-world case.

This study has developed a methodology for the development of future predicted wind data for coastal disaster risk management. The procedures involve statistical analysis and consequence quantifications. The predicted future wind data were obtained from the model that was developed using the proposed procedure.

From the case study, the result shows that the proposed methodology can be reasonably applied. Moreover, based on the existing historical local wind data, it was found that the wind speed is the only variable of climate change that can be used to develop the statistical model of local coastal wind. This local model is then called as the climate change statistical model of local coastal wind. The model is very useful to evaluate wind and wave that cause coastal disasters.

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