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# An Empirical Study on Predicting the Wind Speed after Landfall of Tropical Cyclones Over Bay of Bengal

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## ABSTRACT

The post landfall wind speed forecast of tropical cyclones (TC) over Bay of Bengal (BoB) are explained by using an empirical study. The study parameters are obtained from the database of 19 tropical cyclone of 1988-2017. The study is based upon the assumption of tropical cyclone wind speed decay after landfall. A method for correcting the forecast during subsequent observation hours is also presented. The method for predicting the cyclone wind speed is tribute from the most recent study over the Indian and USA coast. Results show that without the correction factor the absolute mean error (MAE) ranges from 10.1 To 5.7 Kt, root mean square error (Rmse) ranges from 12.5 to 7.7 Kt and mean absolute percent error (MAPE) ranges from 30.0 to 10.1 Kt with these parameters decreasing over time for wind speed. A significant improvement in the forecast skill is observed with including the correction procedure. For the operational forecaster, this model will be helpful and important.

**Keywords:** Empirical Study, Prediction, TC, Wind Speed, BoB

## I. INTRODUCTION

Acute rainfall, drastic winds, overland flooding and storm surges due to tropical cyclones cause heavy losses of things and the tropical cyclones are known as the most annihilating hazards on earth [1]. The origins and landfalls of the cyclones are responsible for the effect and destruction [2]. Bangladesh, India and Myanmar face more than 75% of global casualties while only 5% of global tropical cyclones originate in Bay of Bengal [3-5]. Only 1% of all annual tropical cyclones are affected in Bangladesh and that responsible for 50% of all global casualties [6]. Tropical cyclones associated with high winds and huge water levels make drastic property damage and loss of life all over the world, but particularly in this densely populated coastal region of Bay of Bengal [7,8]. Several significant tropical cyclones that happened in 2007 and 2009 provide recent examples of devastating storm-surge and wind speed in Bangladesh as well as killed 4234 and 190 respectively [9,10]. Ineffective detection of cyclones landfall and inaccuracy of wind intensity are responsible for these high casualties [11]. These recent great cyclones have illustrated the need for the accurate prediction of inland effects of tropical cyclones.

Some important factors such as water availability, soil moisture and shape of the coastline have impact on the post-landfall intensity of tropical cyclones [12-15]. The decay of tropical cyclone wind speed is critically linked to the low moisture and heat fluxes from the surface [12,16] and lack of moisture and heat fluxes make the wind speed weaken rapidly than after landfall [16,17]. Considering all of the factors, it is important to correctly determine the wind speed and decay rate of tropical cyclone after landfall. From the last few decades, the prediction of cyclone track has improved very much and very widely in the field of forecast modelling and data gathering research but the prediction of tropical cyclone wind speed has not developed much [18].

The numerical or empirical models has significant socio-economic importance which can accurately predict the wind speed after landfall [19]. Only numerical and empirical model can give the most accurate and easy used because it is not possible to use statistical analysis of the highest annual wind speeds at a particular site in order to determine the extreme wind speeds in cyclone-prone regions [20]. Therefore, measuring the post-landfall wind speed decay of tropical cyclone using observed data can be helpful to develop the wind speed decay model to enhance the skill of intensity prediction. There have some continuous attempts to develop and improve the models for prediction of post-landfall intensity over the US coast [13,21]. Besides, Bhowmik et al. [22] had worked about the intensity of wind speed decay over the Indian Ocean and Bay of Bengal. However, there are a few attempts taken to analyze the nature of post-landfall cyclone intensity over the Indian subcontinent [22] but these regions are the most densely populated and also vulnerable to tropical cyclone. Real time operational applications, this model can be useful for stochastic simulation of cyclone related risk in coastal areas, which helps in designing building and structures that can withstand the impact of land falling cyclones [23].

The Kaplan and DeMaria [17] wind speed decay model has been chosen and used to complete the empirical modelling. This study is also conferred on Bhowmik et al. [22], where they made an empirical model of tropical cyclone wind speed decay after landfall from 1981 to 2000. The current study is a little bit different from them, because the cyclones' data are selected from 1988 to 2017. The main objective of this study is to apply the empirical model for forecasting of post-landfall wind speed according to the forecast hypothesis of Kaplan and DeMaria [17], Vickery and Twisdale [24], Bhowmik et al. [22] which can be helpful for reducing the death tolls or property damage due to cyclone.

## II. METHODS AND MATERIAL

### Data Sources and Sampling

For this present study, tropical cyclones to be those formed over the Bay of Bengal (BoB) during the period of 1988–2017 were considered. The data period includes 31 cases of landfalling tropical cyclones, but most of them lost their intensity of depression (wind speeds less than 17 Kt and sea level pressure less than 200 hPa) immediately after landfall (within 1–2 hrs.). Tropical cyclones best track records were obtained from the Joint Typhoon Warning Center (JTWC), NASA Earth Observatory and Bhowmik et al. [22].

In order to develop the empirical technique, we used only those 19 tropical cyclones (Table 1) that maintained the minimum intensity of depression (wind speeds of more than 17 Kt) and sustained more than 6 hours after landfall. The tracks of these tropical cyclones are depicted in Figure 1. In Bangladesh, surface wind observations are based upon 3-min-averaged winds. In this study, the landfall intensity was considered as the Maximum Sustained Surface Wind (MSSW) associated with a cyclone at the time of tropical cyclone crosses the coastline. As per the convention of the Bangladesh Meteorological Department, the classification of tropical disturbances is as follows: low: wind speeds less than 17 Kt; depression: wind speeds of 17–33 Kt; cyclonic storm: wind speeds of 34–47 Kt; severe cyclonic storm: wind speeds of 48–63 Kt; very severe cyclonic storm: wind speeds of 64–119 Kt; and super cyclone: wind speeds above 119 Kt. The data period (1988–2017) includes three cases of a super cyclone and 10 cases of very severe cyclonic storms. It is observed that all 19 cases of intense tropical cyclones (wind speed more than 64 Kt) maintained the minimum intensity of depression for more than 6 h after landfall.

**Table 1 :** Database of 19 tropical cyclones from 1988 to 2017.

| Sl. No. | Cyclone Name/Year | Wind Speed (Kt) | | | | | |
|---|---|---|---|---|---|---|---|
| | | 0 h | 6 h | 12 h | 18 h | 24 h | 30 h |
| 1 | NARGIS | 115 | 85 | 70 | 50 | 40 | 30 |
| 2 | SIDR | 130 | 100 | 60 | 50 | 35 | 25 |
| 3 | MALA | 105 | 90 | 65 | 55 | 40 | 32 |
| 4 | 1997 | 115 | 100 | 90 | 65 | 50 | 30 |
| 5 | 1995 | 90 | 85 | 45 | 30 | 30 | 30 |
| 6 | 1994 | 125 | 110 | 80 | 50 | 30 | 20 |
| 7 | 1991 | 135 | 110 | 85 | 60 | 40 | 25 |
| 8 | 1988 | 115 | 65 | 35 | 30 | 16 | 15 |
| 9 | 1988 | 110 | 90 | 60 | 45 | 31 | 20 |
| 10 | MORA | 60 | 35 | 28 | 25 | 15 | 15 |
| 11 | ROANU | 60 | 55 | 55 | 40 | 27 | 27 |
| 12 | MAHASHEN | 45 | 40 | 35 | 30 | 20 | 20 |
| 13 | BIJLI | 50 | 45 | 45 | 40 | 40 | 25 |
| 14 | AILA | 65 | 55 | 55 | 40 | 30 | 15 |
| 15 | 2004 | 65 | 60 | 55 | 30 | 30 | 30 |
| 16 | 2000 | 35 | 30 | 27 | 25 | 25 | 25 |
| 17 | 1990 | 45 | 35 | 35 | 30 | 20 | 20 |
| 18 | 1998 | 70 | 60 | 40 | 25 | 25 | 25 |
| 19 | 1997 | 65 | 55 | 35 | 25 | 25 | 25 |

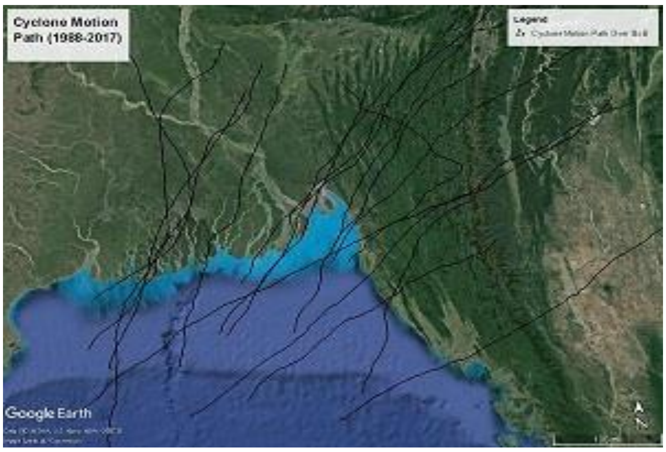


**Figure 1:** Map of the 19 tropical cyclones over Bay of Bengal *(Source: Google Earth, 2018 and JTWC, 2018)*

In order to illustrate the effect of landfall intensity on the decay rate of winds and the increase rate of sea level pressure, the 19 tropical cyclones considered in this study are placed into one of two stratifications, namely, MSSW > 70 Kt as "Category A" and MSSW ≤ 70 Kt as "Category B". This stratification is used to divide the 19 tropical cyclones into two groups and that groups used for wind decay prediction. It may be seen from Table 2 that for the major cyclones (Category A) the wind decay rate, during early hours after landfall, is significantly higher compared to weak cyclones (Category B).

**Table 2:** Six-hourly decay rate of MSSW (Kt) for mean wind speed.

| Hours | 0 - 6 | 6 - 12 | 12 - 18 | 18 - 24 | 24 - 30 |
|---|---|---|---|---|---|
| A (Kt) | 23 | 27 | 17 | 14 | 9 |
| B (Kt) | 9 | 6 | 10 | 5 | 3 |

***(Note: Decay Rate: Difference between the mean value of two-time variation for wind speed. e.g. Difference between 0 hour's average wind speed and 6 hours' average wind speed).***

**Empirical Formula for Tropical Cyclone Wind Speed**

The assumption that tropical cyclones wind speed decay at a rate that is proportional to their landfall intensity is the basic of the empirical inland wind decay model (IWDM) and can be expressed by the following differential equation:

$dV/dt = -\alpha t$……………………………..………..(1)

Where V (Kt) is the MSSW, α is the decay constant ($h^{-1}$), and t (h) is the time after landfall. The differential solution to equation (1) is given by,

$V(t) = V_0 e^{-\alpha t}$ ………………..……………………....(2)

Where $V_0$ is the MSSW at t = 0.

As shown in Table 2, the MSSW decays to some background wind speed $V_b$. This effect can be included by adding an extra term to equation (1) to give,

$dV/dt = -\alpha (V - V_b)$……………………..…………….(3)

Which has a solution given by Bhowmik *et al.* [22]; Kaplan and DeMaria [17],

$V_t = V_b + (V_0 - V_b) e^{-\alpha t}$………………………...…..…(4)

The observational results of Myers [25], Schwerdt *et al.* [26], Powell [27,28], Ho *et al.* [29] and Fung *et al.* [30] indicate that hurricane winds decrease abruptly as the landfalling storm crosses the coastline. Fung *et al.* [30] noted that this rapid decrease in wind speed occurs within a few kilometers of the coastline as onshore winds quickly adjust to the increased roughness of the underlying land surface. Tuleya [12] noted that the primary mechanism responsible for the rapid decay of TCs after landfall is the largely reduced latent heat and sensible fluxes. They introduced a Reduction Factor (R) for model validation. Bhowmik *et al.* [22] determined decay constant from 0.095 to 0.354 and the reduction factors (R) from 0.079 to 0.620 where, this study is introducing a reduction factor (R) for the actual forecast results.

Consequently, $V_0$ in equation (4) is multiplied by a reduction factor (R). The optimal value of R was 0.9 [17,31].

From equation (4), the decay constant "α" can be written as

$\alpha = \{\ln [(V_0 - V_b) / (V_t - V_b)]\} / t$…………………....(5)

From equation (5), the decay constant "$\alpha_1$" for the first 6 h after landfall (t = 0 – 6 h) are written as,

$\alpha_1 = \{\ln [(V_0 - V_b) / (V_6 - V_b)]\} / 6$..……..…..…....(6)

The decay constant "$\alpha_2$" for the remaining 12 h (for t = 6 – 18 h) is taken as,

$\alpha_2 = \{\ln [(V_6 - V_b) / (V_{18} - V_b)]\} / 12$...…… …......(7)

It is presumed that for the first 6 h the decay constant is $\alpha_1$ and, thereafter it remains as $\alpha_2$. The corresponding 6-hourly "current reduction factors" are defined as

$R_1 = e^{-\alpha_1 * 6.0}$………………………….………..…..…...(8)

$R_2 = e^{-\alpha_2 * 6.0}$…………………………………..…..…….(9)

Kaplan and DeMaria [17] introduced a correction factor as a function of inland distance to take into account the effect of the tropical cyclone's proximity to water on the rate of decay after landfall. This effect was first discussed by Malkin [32] and was confirmed in the study of Kaplan and DeMaria [17]. Kaplan and DeMaria [17] investigated a reduction factor (R) in their forecast model which have a great similarity to this study.

Now, from Equation (4), the decay equation for 6-hourly forecasts (Appendix-IV and V) is written as,

$$V_{t+6} = V_b + (V_t - V_b) R_1 \quad \text{for } t = 0$$
$$= V_b + (V_t - V_b) R_2 \quad \text{for } t = 6, 12, 18 \ \& \ 24 \ldots (10)$$

The decay coefficients ($\alpha_1$, $\alpha_2$, $R_1$, $R_2$, and $V_b$) computed from the decay rate of wind speed (Table 2) using equation (6) – (9), taking the mean intensity as a function of time after landfall, are shown in Table 3. Once $V_0$, the landfall intensity is known, 6-hourly forecasts valid up to 30 h can be made using parameters ($R_1$, $R_2$, $V_b$) from Table 4 in Equation (10).

**Table 3:** Wind speed decay parameters from the decay rate of table 2.

| MSSW (Kt) | $\alpha_1$ ($h^{-1}$) | $R_1$ $(6\ h)^{-1}$ | $\alpha_2$ ($h^{-1}$) | $R_2$ $(6\ h)^{-1}$ | $V_b$ (Kt) |
|---|---|---|---|---|---|
| A | 0.049 | 0.747 | 0.090 | 0.582 | 25 |
| B | 0.053 | 0.727 | 0.092 | 0.577 | 23 |

## III. RESULTS AND DISCUSSION

### Mean Wind Speed Decay Curve

The mean wind speed rate for the all 19 cyclones are decreasing within a time interval and at the last time the wind speed dissipated (Figure 2). From the landfall of a cyclone the wind speed is constantly decreased by the influence of various parameters like temperature, sea level pressure and wind flux. From the historical cyclone event it's easy to seem that the wind speed decreasing phenomena is actual and constant.

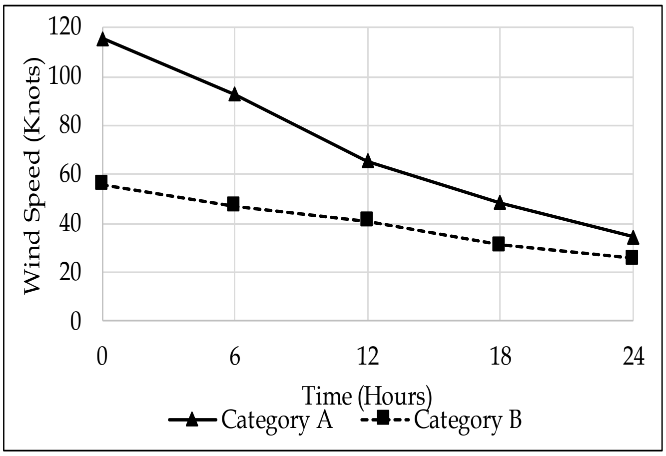


**Figure 2:** The mean wind speed decay curves for category A (dotted line) and for category B (solid line) cyclones.

The wind speed of Category A cyclones has a strong and significant trend for decreasing. Bhowmik *et al.* [22] proved that the wind speed >65 knots cyclones had a strong trend to dissipate sooner than the ≤ 65 knots wind speeds cyclone. Besides, Kaplan and DeMaria [17] also agreed to this decrease trend where this study shown the actual decreasing system with time interval. Actual decay system of wind speed for tropical cyclone had a great difficulty to be explained. Therefore, some analytical methods were followed and also inputting some important factors for describing the actual wind speed decay.

**Individual Cyclone Wind Decay Parameters**

The present study of 19 cyclones post landfall wind decay rate had no significant regional variation. In order to examine how the decay constant and current reduction factors change from cyclone to cyclone, decay constants ($\alpha_1, \alpha_2$) and current reduction factors ($R_1$, $R_2$) computed for each of the 19 cyclones are presented in Table 4. These coefficients for the individual cyclone are computed, taking $V_b$ as the lowest intensity reached by each of them by using the equation 6 and 7.

**Table 4:** Wind decay parameters for individual 19 cyclones over Bay of Bengal.

| Sl. No. | $\alpha_1$ ($h^{-1}$) | $\alpha_2$ ($h^{-1}$) | $R_1$ $(6h)^{-1}$ | $R_2$ $(6h)^{-1}$ |
|---|---|---|---|---|
| 1 | 0.068 | 0.073 | 0.667 | 0.645 |
| 2 | 0.056 | 0.092 | 0.714 | 0.577 |
| 3 | 0.035 | 0.064 | 0.813 | 0.679 |
| 4 | 0.030 | 0.052 | 0.833 | 0.730 |
| 5 | 0.013 | 0.207 | 0.923 | 0.289 |
| 6 | 0.027 | 0.102 | 0.850 | 0.542 |
| 7 | 0.043 | 0.074 | 0.773 | 0.642 |
| 8 | 0.135 | 0.173 | 0.444 | 0.354 |
| 9 | 0.045 | 0.098 | 0.765 | 0.555 |
| 10 | 0.188 | 0.149 | 0.324 | 0.408 |
| 11 | 0.024 | 0.053 | 0.865 | 0.729 |
| 12 | 0.043 | 0.074 | 0.773 | 0.642 |
| 13 | 0.034 | 0.021 | 0.815 | 0.879 |
| 14 | 0.045 | 0.053 | 0.762 | 0.729 |
| 15 | 0.021 | 0.139 | 0.881 | 0.435 |
| 16 | 0.090 | 0.104 | 0.583 | 0.535 |
| 17 | 0.101 | 0.045 | 0.545 | 0.764 |
| 18 | 0.040 | 0.243 | 0.787 | 0.232 |
| 19 | 0.045 | 0.231 | 0.762 | 0.250 |

Figure 3 shows a scattered diagram that explains a regression equation relating $R_1$ and $R_2$, as given as $R_2 = 0.74R_1$.

In Bangladesh, in the case of a cyclone situation, warnings/ forecasts issued by the Bangladesh Meteorological Department are updated at 3–6-h intervals, based on the latest available synoptic observations. In such a case, additional synoptic observations are taken at hourly intervals for the likely affected coastal stations, until the cyclone weakens into a low-pressure area. Thus, in the Bangladesh scenario, the first forecast (valid up to 24–30 h) issued at the time of landfall can be corrected and updated during the subsequent observation hours, taking into account the trend of the decay rate. Because a dense population resides at or near the Bay of Bengal coasts, this update forecast has direct relevance to daily activities over a coastal zone (such as transportation, tourism, fishing, sports, etc.) apart from disaster management.

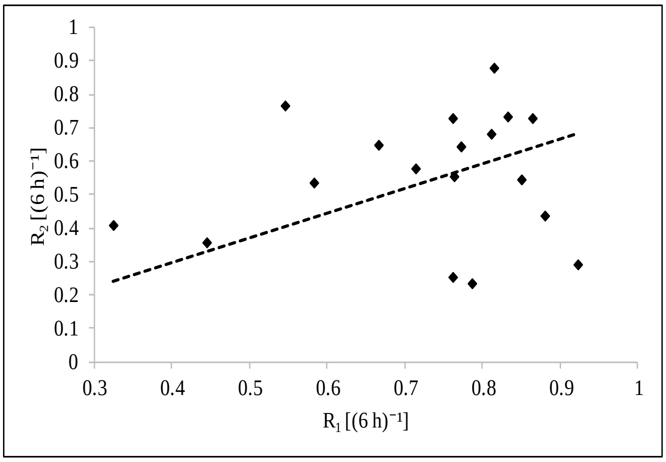


**Figure 3 :** The scatter diagram relating $R_1$ and $R_2$ [Current reduction factors at t = 6 h and for t = 12 h, respectively; Units: (6 h)$^{-1}$].

**Six Hourly Wind Speed Forecast**

In order to verify the method, we apply the technique for the development database of 19 cyclones. Results of 6-hourly forecasts after landfall for the 19 cyclones, both with and without the correction procedure based on subsequent observations, are shown in Table 5. The table shows that there is generally good agreement between the predicted and observed values when the correction procedure is included. Without correction procedures there have no agreement among the results. From 6 hours to 30 hours, almost the cyclones have agreed to their observed and predicted values.

**Table 5:** Comparison between observed, without correction and with correction procedures of six-hourly wind speed (Kt).

| Sl. No. | 6 h | 12 h | 18 h | 24 h | 30 h |
|---|---|---|---|---|---|
| 1 | 85 | 70 | 50 | 40 | 30[a] |
| | 92 | 64 | 48 | 38 | 33[b] |
| | – | 70 | 56 | 47 | 41[c] |
| 2 | 100 | 60 | 50 | 35 | 25[a] |
| | 103 | 71 | 52 | 40 | 34[b] |
| | – | 70 | 51 | 40 | 34[c] |
| 3 | 90 | 65 | 55 | 40 | 32[a] |
| | 85 | 60 | 45 | 37 | 32[b] |
| | – | 68 | 56 | 49 | 43[c] |
| 4 | 100 | 90 | 65 | 50 | 30[a] |
| | 92 | 64 | 48 | 38 | 33[b] |
| | – | 75 | 63 | 54 | 48[c] |
| 5 | 85 | 45 | 30 | 30 | 30[a] |
| | 74 | 53 | 41 | 35 | 31[b] |
| | – | 43 | 34 | 31 | 30[c] |
| 6 | 110 | 80 | 50 | 30 | 20[a] |
| | 100 | 68 | 50 | 40 | 34[b] |
| | – | 63 | 43 | 33 | 27[c] |
| 7 | 110 | 85 | 60 | 40 | 25[a] |
| | 107 | 73 | 53 | 41 | 34[b] |
| | – | 78 | 59 | 47 | 39[c] |
| 8 | 65 | 35 | 30 | 16 | 15[a] |
| | 92 | 64 | 48 | 38 | 33[b] |
| | – | 42 | 25 | 18 | 16[c] |
| 9 | 90 | 60 | 45 | 31 | 20[a] |
| | 89 | 62 | 46 | 37 | 32[b] |
| | – | 58 | 41 | 32 | 26[c] |
| 10 | 35 | 28 | 25 | 15 | 15[a] |
| | 50 | 39 | 32 | 28 | 26[b] |
| | – | 29 | 21 | 17 | 16[c] |
| 11 | 55 | 55 | 40 | 27 | 27[a] |
| | 50 | 39 | 32 | 28 | 26[b] |
| | – | 44 | 39 | 36 | 33[c] |
| 12 | 40 | 35 | 30 | 20 | 20[a] |
| | 39 | 32 | 28 | 26 | 25[b] |
| | – | 32 | 28 | 25 | 23[c] |
| 13 | 45 | 45 | 40 | 40 | 25[a] |
| | 43 | 34 | 30 | 27 | 25[b] |
| | – | 41 | 39 | 37 | 36[c] |
| 14 | 55 | 55 | 40 | 30 | 15[a] |
| | 54 | 41 | 33 | 29 | 26[b] |
| | – | 43 | 35 | 30 | 26[c] |
| 15 | 60 | 55 | 30 | 30 | 30[a] |
| | 54 | 41 | 33 | 29 | 26[b] |
| | – | 40 | 34 | 32 | 31[c] |
| 16 | 30 | 27 | 25 | 25 | 25[a] |
| | 32 | 28 | 26 | 25 | 24[b] |
| | – | 29 | 27 | 26 | 26[c] |
| 17 | 35 | 35 | 30 | 20 | 20[a] |

| Sl. No. | 6 h | 12 h | 18 h | 24 h | 30 h |
|---|---|---|---|---|---|
| | 39 | 32 | 28 | 26 | 25[b] |
| | - | 35 | 31 | 28 | 26[c] |
| 18 | 60 | 40 | 25 | 25 | 25[a] |
| | 57 | 43 | 34 | 30 | 27[b] |
| | - | 32 | 27 | 25 | 25[c] |
| 19 | 55 | 35 | 25 | 25 | 25[a] |
| | 54 | 41 | 33 | 29 | 26[b] |
| | - | 32 | 27 | 25 | 25[c] |

***Note: a = Observed Wind Speed; b = Wind Speed without Correction Procedures; c = Wind Speed with Correction Procedures.***

Comparing the forecast data with Kaplan and DeMaria [17], have made an agreement that can be effective to this study. The observed data set and prediction of this study is strongly similar to the hypothesis of Kaplan and DeMaria [17]. From the methods, model implementation and results of that hypothesis is quietly agreed to this study. They worked out a huge dataset and this study is implemented a limited dataset but the prediction rate is more than 80% accurate on depending the methods of Kaplan and DeMaria [17].

Bhowmik *et al.* [22] implemented a study about the wind decay model after landfall and the predicted results of that study is quite consistent to this present forecast of wind speed. From the above table observation, a decision can be made that the prediction of wind speed is not void or invalid. The comparison between observed wind speed data with the corrective and non-corrective data have shown a significand variation. The comparison is made for understanding the variation among these three-dimensional observation and analysis. Without correction procedure the data show that huge similarity to the observed data where with correction procedure have a different magnitude. Mainly, the purpose of this comparison is to determine the actual and better forecast data than the observational wind speed data.

**Skill Score for Wind Speed**

Table 6 shows the error statistics for the model with and without the use of the correction procedure. For the case without the use of the correction procedure, Mean Absolute Error (MAE) ranges from 10.1 to 5.7 Kt, the Root-Mean Square Error (Rmse) from 12.5 to 7.7 Kt and Mean Absolute Percent Error (MAPE) from 30.0 to 10.1 Kt, all of the errors decreasing with time. When the correction procedure to the forecast from the use of the current observations is applied, MAE becomes 6.4 to 2.8 Kt, Rmse is from 8.2 to 3.3 Kt and MAPE is from 26.1 to 8.1 Kt. Kaplan and DeMaria [17,21] obtained MAE of 6.5 and 8.8 Kt and Rmse of 8.8 and 11.4 Kt, respectively, for the southern (south of 37°E latitude) and northern latitudes over the United States. With the incorporation of the correction procedure, a significant improvement in the wind forecast skill is noticed for the case in which it is tested using the dependent sample in the present study.

**Table 6:** Skill scores (MAE, Rmse and MAPE; Kt) of 6-hourly wind forecast made for the 19 cyclones.

| Skill | 6 h | 12 h | 18 h | 24 h | 30 h |
|---|---|---|---|---|---|
| MAE (without correction) | 6.2 | 10.1 | 6.6 | 6.1 | 5.7 |
| MAE (with correction) | - | 6.4 | 2.8 | 3.6 | 6.1 |
| Rmse (without correction) | 8.7 | 12.5 | 8.4 | 8.2 | 7.7 |
| Rmse (with correction) | - | 8.2 | 3.3 | 4.6 | 8.0 |
| MAPE (without correction) | 10.1 | 20.1 | 18.5 | 25.8 | 30.0 |
| MAPE (with correction) | - | 11.7 | 8.1 | 12.9 | 26.1 |

**Procedures for Application of the Methods**

In order to apply this method in operational forecasting and correct the forecast at 6-h intervals, the following steps are suggested:

1. At the time of landfall (at t = 0), employ the observed landfall intensity $V_0$ and climatological values of $R_1$, $R_2$, and $V_b$, which are obtained based upon the sample average decay rates (Table 3), to make 6-hourly predictions of $V_t$ using Equation (10).
2. Six hours after landfall (at t = 6), use the observed $V_0$, $V_6$, and climatological $V_b$ to compute the actual $R_1$ from Equations (6) and (8). Then, get the new $R_2$ from Equation (9) and use Equation (10) to revise the forecast for 12 h after landfall and later.
3. Twelve hours after landfall (at t = 12), employ the observed $V_{12}$ to make a 6-hourly prediction using Equation (10).
4. Eighteen hours after landfall, employ the observed values of $V_0$ and $V_{18}$ to calculate the actual $R_2$ from Equations (7) and (9) and revise the forecast for 24 h and beyond using Equation (10).
5. Twenty-four hours after landfall, use the observed $V_{24}$ to make a final forecast for $V_{30}$.
6. The climatological background wind speed ($V_b$) from Table 3 is considered for these computations.

## IV. CONCLUSION

The burning topic of the present era is considered as the inland wind speed of any cyclone to the disaster or hurricane community. This present study explains a formulation for predicting six-hourly maximum sustained wind speed that is valid up to 30 hours after landfalling tropical cyclone by using the decay equation of Kaplan and DeMaria [17] and also followed the hypothesis of Bhowmik et al. [22] for supplementary documents, data etc. A modified correction procedure (current reduction factors) is introduced to update the first forecast (valid up to 24–30 h, issued at the time of landfall) at 6- hours intervals taking into account the trend of the decay constant and increase constant as well as the use of current observations. With applying the correction procedure, a significant improvement in the forecast skill is noticed. Results of skill score are well comparable with the results obtained by Kaplan and DeMaria [17,31] and Bhowmik et al. [22]. The method appears to be very important and promising for operational application in Bangladesh scenario in which a dense population lives in most coastal areas. For reducing the damage of properties and deaths, this model would help to forecast accurate wind speed and sea level pressure. A few limitations were raised when preparing this model and that's why some important features such as, cyclone trend plotting, dynamic observation and actual live prediction was avoided. But a further study is required to implement these kinds of features. Applying similar technique, another model will be developed for the coast of Bay of Bengal with a huge database and other features in my Ph.D. or other research.

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