# Long Term Wind Trends Analysis of Coastal Belt of Pakistan

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**Abstract:** Pakistan has a long coastal belt, stretched over an area of more than 1000 km from Indian border in east to Iranian border in west, which has varying nature of geomorphic, geologic and climatic setups. In view to understand the characteristic nature of the area in relevance to undertake the wind energy assessment study, it is imperative to carry out the time-series climatic analyses especially for the wind parameters. Pakistan coastal belt has its unique windy nature because of the monsoon period in summer and land-to-sea wind behavior in winter, which further varies respect to coastal geomorphologic features. A research study has been conducted to analyze the long term wind speed trends for the salient cities lying near the coast of Pakistan. The seasonal decomposition technique, i.e. multiplicative model, was applied for the wind trend analyses using the wind data of 60 years for five major cities namely Karachi, Badin & Hyderabad in Sindh province and Lasbella & Ormara in Balochistan province. The present study describes the methodology adopted for the calculation of long term wind speed trends and subsequent the results indicate different wind variables of long term time-series analyses for the selected five cities.

**Keywords**: Wind speed, time series analyses, seasonal decomposition, Pakistan.

## 1. INTRODUCTION

The energy sector is considered as one of the major drivers of economic growth for Pakistan, like agriculture, small & medium industries, information technology, etc. [1], which have close dependence of efficient and sufficient energy supplies. Therefore, energy sector plays a vital role in ensuring all-round development and economic growth of the country.

In the present energy scenario, the induction of renewable energy resources into the conventional national energy mix can play an important role strengthening the energy generation sector. Technologically, all the renewable energy sources are viable and consequently suit to efforts for poverty alleviation and cleaner environment in Pakistan [2-4]. Considering the geological and geomorphologic setups, geographical position and climatic cycles, Pakistan has apparently tremendous wind potential [5].

Till date, the facilities for generating commercial-level electricity from wind are virtually negligible in the country despite of the fact that efforts are in progress on national as well as provincial levels to establish wind farms for the generation of commercial electricity as well as a large network of standalone wind turbines for the electrification of rural areas in Pakistan where layout of national gridline is not viable to extend due to heavy investment costs. Though, Pakistan has about 1000 km long coastline [2], which could be utilized for the installation of wind turbines, but all the efforts are in vain because of the absence of the concrete wind database and the rational thinking to utilized the easily available and cost effective energy.

The present work is an effort to understand the characteristic nature of an area in direct relation to wind speed with relevance to its consideration to undertake the wind energy calculation and subsequent recommendation for site-specific studies. The capability of wind energy to reliability contribute into the nation energy generation mix is essentially related to the characteristics of the wind resource. Therefore, a study has been conducted to analyze the long term wind speed trends for the salient cities of Sindh and Balochistan coastal belt of Pakistan by using the multiplicative time-series analyses.

This paper describes the utilization of time-series analyses for the calculations of wind trends for the five major cities of the coastal belt of Pakistan based on over the last 60 years wind data collected at the regular meteorological weather stations and the subsequent results indicating different wind variables of long term time analyses for these five cities.

## 2. DATA COLLECTION & PROCESSING

The meteorological data is regularly collected from the network of more than 60 weather stations of the Pakistan Meteorological Department spread all over Pakistan [6]. The study area for the current study was consisted of the coastal belt of Sindh and Balochistan

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**Figure 1:** Index map of the coastal belt of Pakistan showing the meteorological stations.

provinces of Pakistan. Only five of these meteorological stations from the PMD network are situated within the study area, namely Karachi, Hyderabad, Badin, Lasbella and Ormara. The locations and the anemometer height [6] of these stations are given in Figure **1** and Table **1**.

The wind and other relevant meteorological data of these five stations were collected from the archive of PMD with their curtsey to support the national researchers. This data contains the monthly averages of different periods for different stations. The data of time periods from January 1942 to December 2002 were available for Badin, Hyderabad and Lasbella. The data from January 1945 to December 2002 were obtained for Karachi area and from January 1961 to December 2002 for Ormara. The archived data consist of the climatic parameters including average monthly wind speeds, average monthly wind directions and average monthly ambient temperatures. Figure **1** show the monthly average wind speeds and direction for Karachi, Badin, Hyderabad, Lasbella and Ormara station at the original anemometer heights.

Since, the wind data from the regular gauges of PMD come from the different anemometer heights, therefore, there was a requirement to normalize the data at the constant heights. The prescribed heights for the current study were 30m and 50m and the results in this paper shown only for the height of 50m.

The wind speed generally varies with the elevation, which is commonly termed as wind shear and defined as the wind is affected by friction against the surface of the earth i.e. the roughness [7]. Higher the terrain roughness due to forest or the urban settlements, higher the wind shear and wind speeds tend to be low at elevation. Lower the roughness because of water bodies or the concrete surface causes lower wind shear. The wind speed at a certain height above the ground level can be interpolated/ extrapolated mathematically by using the Wind Shear Equation [8]:

$$v' = v_{ref} \times \left( \ln(z' / z_o) / \ln(z_{ref} / z_o) \right) \qquad (1)$$

where v' = wind speed at the desired height z' above ground level,

**Table 1: Location and Anemometer Height of Meteorological Stations on the Coast of Pakistan**

| Station Name | Karachi | Hyderabad | Badin | Lasbella | Ormara |
|---|---|---|---|---|---|
| Longitude ($^o$E) | 67° 7' 58.7994" | 68° 25' 1.2000" | 68° 54' 0.0000" | 66° 10' 1.2000" | 64° 37' 55.2000" |
| Latitude ($^o$N) | 24° 53' 59.9994" | 25° 22' 58.7994" | 24° 37' 58.7994" | 26° 13' 58.8000" | 25° 13' 1.1994" |
| Elevation[1] | 22 m | 28 m | 9 m | 87 m | 2 m |
| Anemometer Height[2] | 7 m | 9 m | 10 m | 7 m | 2 m |

[1]as measured from sea level, [2]as measured from ground level.

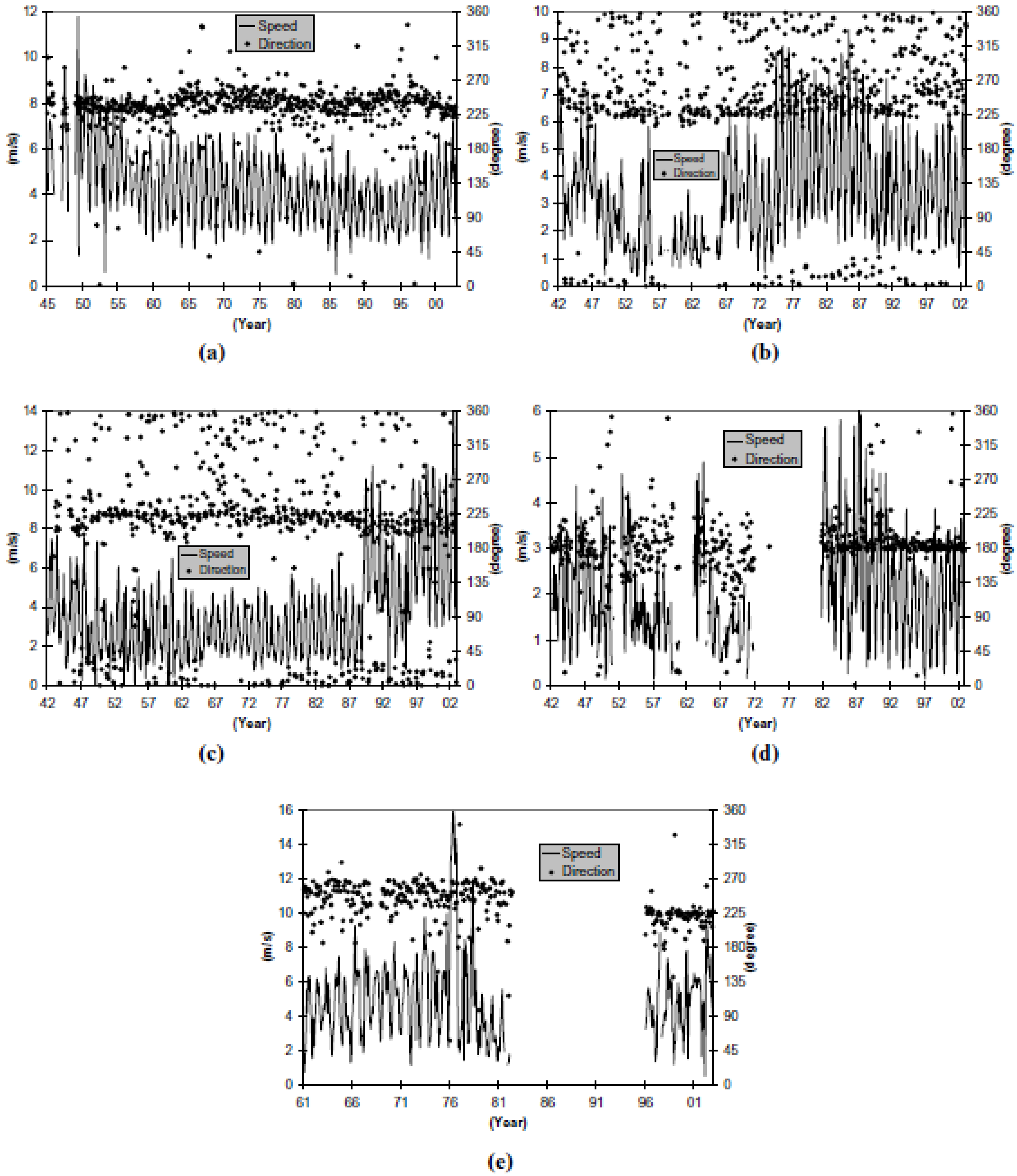


**Figure 2:** Time-series plots showing monthly averages of wind direction (divided into eight sectors) and wind speed (in m/s) for (**a**) Karachi at 7 m, (**b**) Badin at 10 m, (**c**) Hyderabad at 9 m, (**d**) Lasbella at 7 m and (**e**) Ormara at 2m.

$v_{ref}$ = reference wind speed at the known height $z_{ref,}$

$z'$ = height above ground level for the desired velocity $v'$,

$z_o$ = roughness length in the current wind direction, and

$z_{ref}$ = reference height.

The wind shear Equation-1 has been applied to calculate the wind speeds at the height of 50m from the PMD stations' data by taking anemometer height as the reference height, given wind speed as the reference wind speed and 0.0024m [9] as the roughness length because all the stations are supposed to be located in a flat smooth terrain. The results have been used to develop the time series plots of the wind speed at the height of 50m (Figure **3a** to **7a**).

Time-series analysis has two main objectives; first, to identify the nature of the phenomenon represented by the sequence of observations and the second is for the forecasting [10-12]. The main objective to perform time-series analysis is to decompose the data for a given variable into one or more of the four components namely, Trend ($\alpha$), Seasonal Variation ($\beta$), Cyclical Variation ($\delta$) and Random Variation ($\varepsilon$) [13]. For the sake of present time-series analysis of the wind speed at 50m, the Multiplicative Model (*y*) has been chosen because it is more accurate in describing and predicting the variations in the time-series data with non-steady seasonal fluctuations like in PMD wind speed datasets as defined as follows:

*Multiplicative Model* $\Rightarrow$ $y_t = \alpha_t \times \beta_t \times \delta_t \times \varepsilon_t$ (2)

where "t" is the observations recorded across a sequence of time periods.

As the wind data plots of Figure **2** represent the non-monotonic nature of wind in the study area, it is difficult to chart out the trend directly. Therefore, for the measurement of the Trend ($\alpha_t$), the moving average smoothing technique has been used, which replaces each element of the dataset by average of *n* surrounding elements, where *n* is the width of the smoothing window.

For the measurements of the Seasonal Variations, the seasonal indexes ($\beta_t$) have been calculated, which indicate the magnitude of seasonal effects and also used to de-seasonalize the observed data to produce a *seasonally adjusted series* by using the equation 3:

$\beta_t = (y_t / \alpha_t) \times 100$ [averaged] (3)

The seasonally adjusted or de-seasonalized series have also been calculated by dividing each observation $y_t$ by the appropriate value of $\beta_t$ as follows:

$y_t/\beta_t = (\alpha_t \times \beta_t \times \delta_t \times \varepsilon_t) / \beta_t = \alpha_t \times \delta_t \times \varepsilon_t$ (4)

The cyclical variations measurement involves the isolation of component $\delta_t$ by the removal of components $\alpha_t$, $\beta_t$ and $\varepsilon_t$ from the series. The series containing cyclic and random variations, *Smoothed Trend Cycle* or *de-trended series*, have been calculated using the equation 5:

$(\alpha_t \times \delta_t \times \varepsilon_t) / \alpha_t = \delta_t \times \varepsilon_t$ (5)

Finally, the last component of the time series decomposition i.e. random variation ($\varepsilon_t$), which was residue in the generated de-trended or smoothed trend cycle series, has been isolated by simply dividing the seasonally adjusted series by the de-trended series.

## 3. RESULTS AND DISCUSSION

In this study, the Trend $\alpha_t$ has been calculated with the smoothing window of 12 months. The resultant trend lines for the time-series wind data have been plotted in the Figures **3a** to **7a** for the five PMD meteorological stations for the given time periods. The trend for the Badin city in Figure **3a** shows a non-monotonic behavior in the wind speed which is oscillatory as well as increasing over the span of time and can be represented by a polynomial fit as:

$$\alpha_{t(BADIN)} = 4.73 - 6.67\times10^{-4}t - 3.15\times10^{-4}t^2 + 1.80\times10^{-6}t^3 \quad (6)$$

The trend in Figure **4a** for the Hyderabad city shows a mixture of linear and non-monotonic nature with increasing wind trend after 1990 and can be fitted by the following polynomial:

$$\alpha_{t(HYDERABAD)} = 6.09 - 0.061t + 4.75\times10^{-4}t^2 \quad (7)$$

Figure **5a** shows the wind speed trend for the Karachi city over the given period that illustrates a decreasing trend till 1995 and onward shows an increasing trend. This trend can be worked out with the following polynomial equation:

$$\alpha_{t(KARACHI)} = 5.97 + 0.04t - 4.45\times10^{-4}t^2 + 1.68\times10^{-6}t^3 \quad (8)$$

Figure **6a** and Figure **7a** show the wind trend lines for Lasbella and Ormara cities respectively. There are gaps in the wind data for both cities and it is difficult to analyze the long-term trends. However, with the existing data, the trend for Lasbella is concluded as increasing and oscillatory nature while it is only oscillatory for the Ormara city. The trend fitting equations for both the cities are:

$$\alpha_{t(LASBELLA)} = 1.73 + 0.03t - 3.53\times10^{-4}t^2 + 1.27\times10^{-6}t^3 \quad (9)$$

$$\alpha_{t(ORMARA)} = 7.04 - 0.06t + 0.001t^2 - 9.47\times10^{-6}t^3 \quad (10)$$

The seasonal indexes ($\beta_t$) was also plotted (Figures **3b** to **7b**). The maximum ratio of seasonal indexes have been found as 148, 155, 134, 135 and 130 for Badin, Hyderabad, Karachi, Lasbella and Ormara cities respectively. It is also noted the average maximum seasonal indexes sustain only during the monsoon period, i.e. from June to August. The results of the de-seasonalized series reflect the combine effect of trend, cyclical and random variations (Figures **3c** to **7c**).

The de-trended or smoothed trend cycle series for the five stations was plotted from Figures **3d** to **7d**. The smoothed trend cycle series relevant to Badin city shows four distinct cycles (Figure **3d**). Each cycle terminates sharply and also shows different behavior.

The cycle commencing from 1942 to 1966 shows a declining wind speed trend from 7 m/s to 2 m/s. From 1966 to 1975, the peak again rises to about 6 m/s but subsequently decreases to about 2.5 m/s. The next cycle shows constant behavior ranging between 5 m/s and 6 m/s upto 1988. The last cycle shows more or less constant trend ranging between 3 m/s and 4 m/s till 2002 and seems to continue onward.

The smoothed trend cycle series of Hyderabad city shows a consistent cycle from 1942 to 1989 with an average wind speed of 4 m/s (Figure **4d**). Onward it

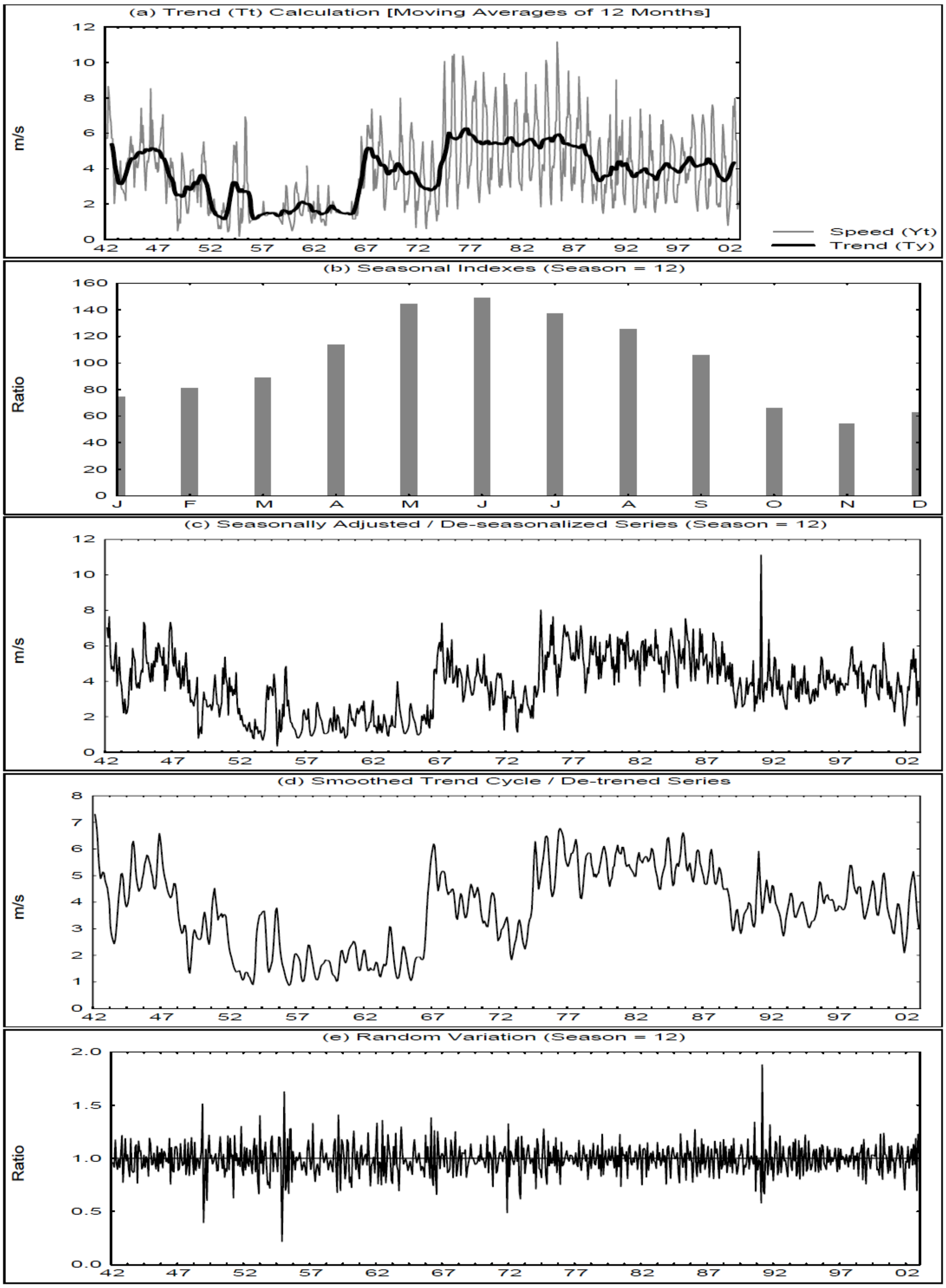


**Figure 3:** Time-series analysis plots showing (**a**) trend, (**b**) seasonal indexes, (**c**) de-seasonalized series, (**d**) de-trended series and (**e**) random variations of wind speed at 50m for Badin city from 1942 to 2002.

shows raising trend with average wind ranging between 5 m/s - 9 m/s.

The smoothed trend cycle series of Karachi city shows constant behavior of wind with an average of 5 m/s speed (Figure **5d**). Cyclical behavior seems to be insignificant.

The smoothed trend cycle series of Lasbella city shows frequent cyclic behavior of about 14 years cycle with wind speed ranging between 2 m/s - 3.5 m/s (Figure **6d**).

Similar to cyclical variation behavior of Karachi city, the smoothed trend cycle series of Ormara city also

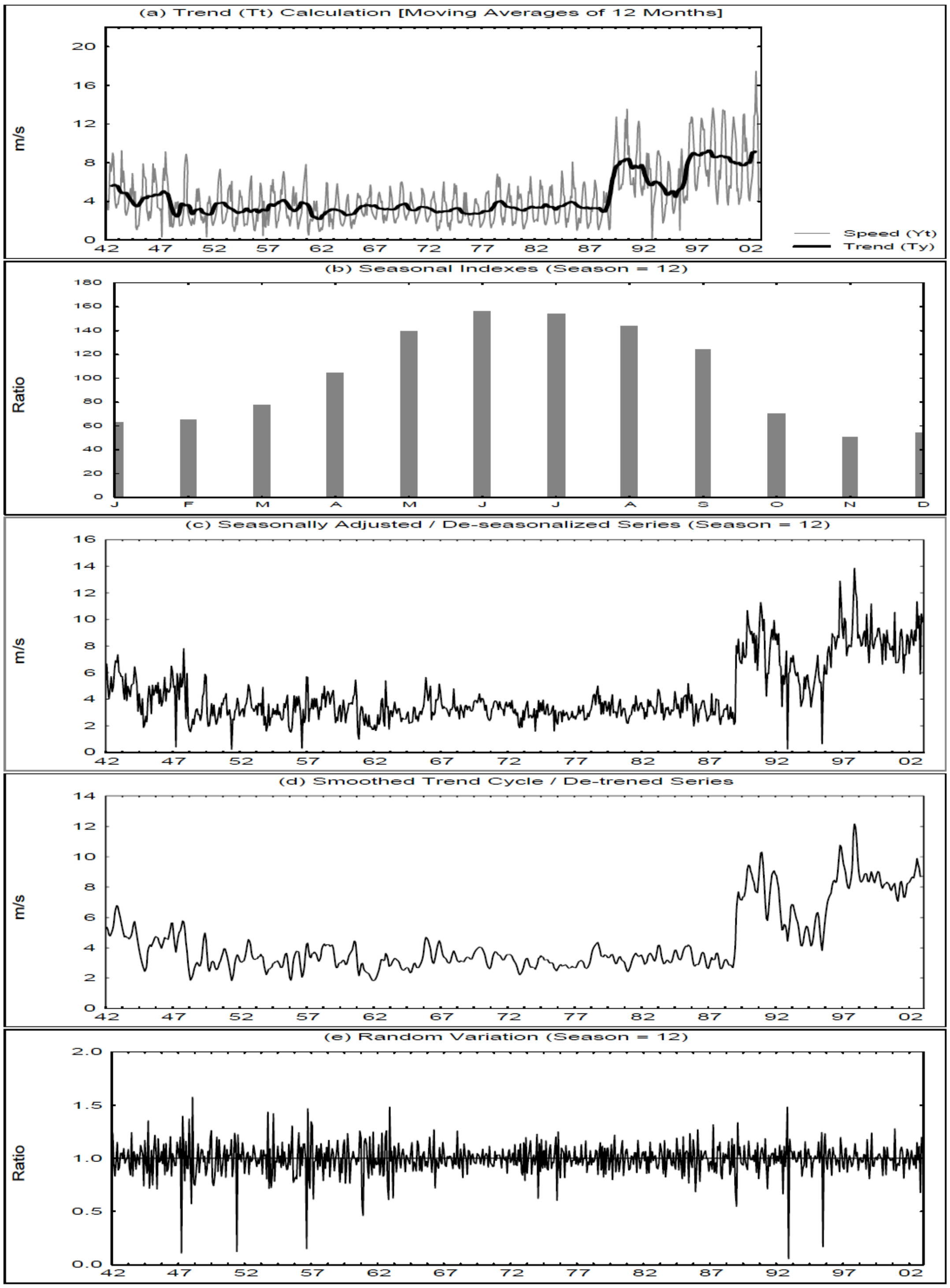


**Figure 4:** Time-series analysis plots showing (**a**) trend, (**b**) seasonal indexes, (**c**) de-seasonalized series, (**d**) de-trended series and (**e**) random variations of wind speed at 50m for Hyderabad city from 1942 to 2002.

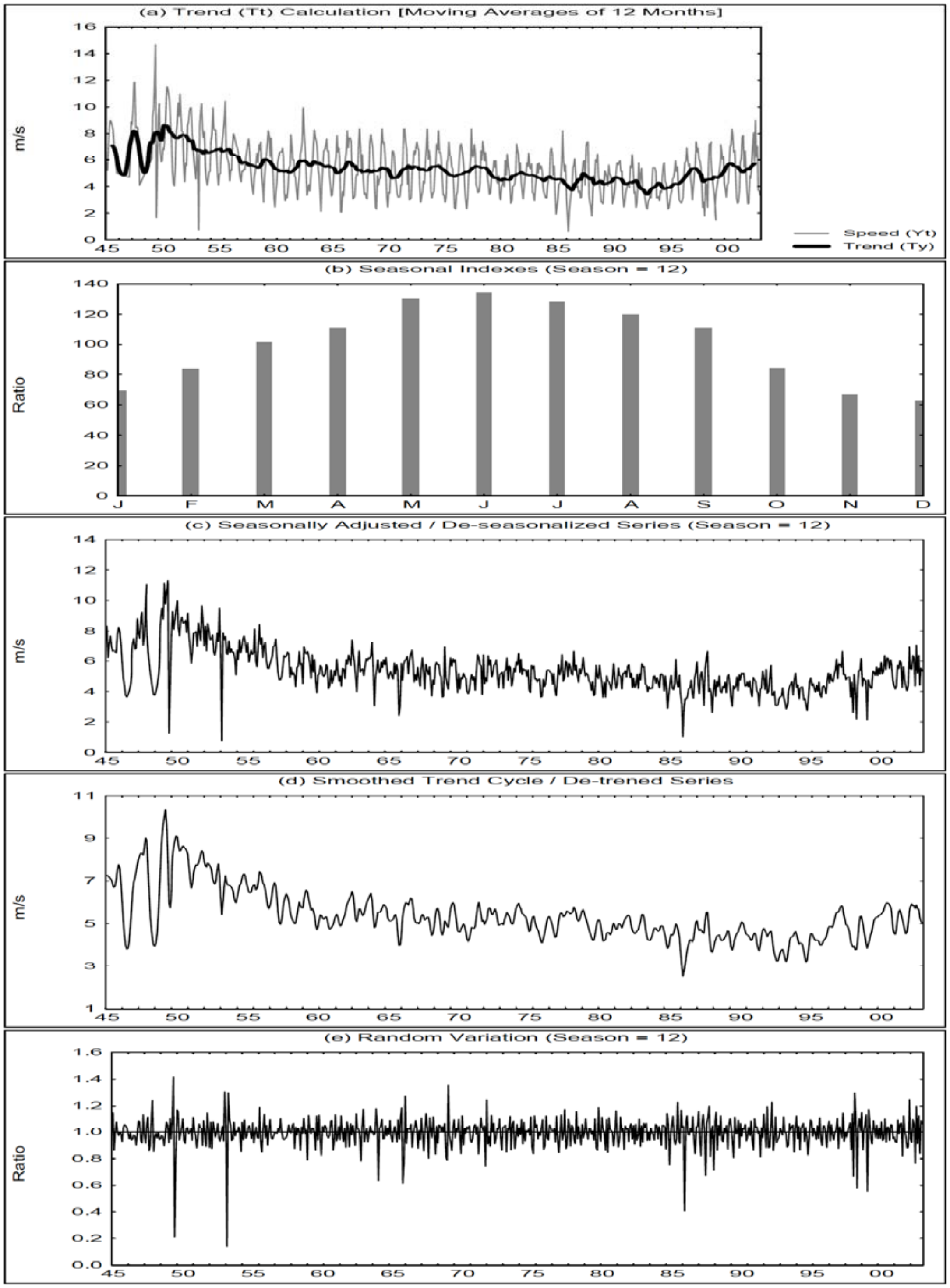


**Figure 5:** Time-series analysis plots showing (**a**) trend, (**b**) seasonal indexes, (**c**) de-seasonalized series, (**d**) de-trended series and (**e**) random variations of wind speed at 50m for Karachi city from 1945 to 2002.

seems consistent with wind speed ranging between 5 m/s - 7 m/s (Figure **7d**).

The random variation ($\varepsilon_t$), as the last component of the time series decomposition, was also calculated and plotted for the given meteorological stations (Figures **3e** to **7e**). The random variations have been calculated as 0.5 for Badin, Hyderabad & Ormara cities; 0.2 for Karachi city and 0.8 for Lasbella city.

## 4. CONCLUSIONS

- Wind data of PMD gauges of Karachi, Hyderabad, Badin, Lasbella, and Ormara cities

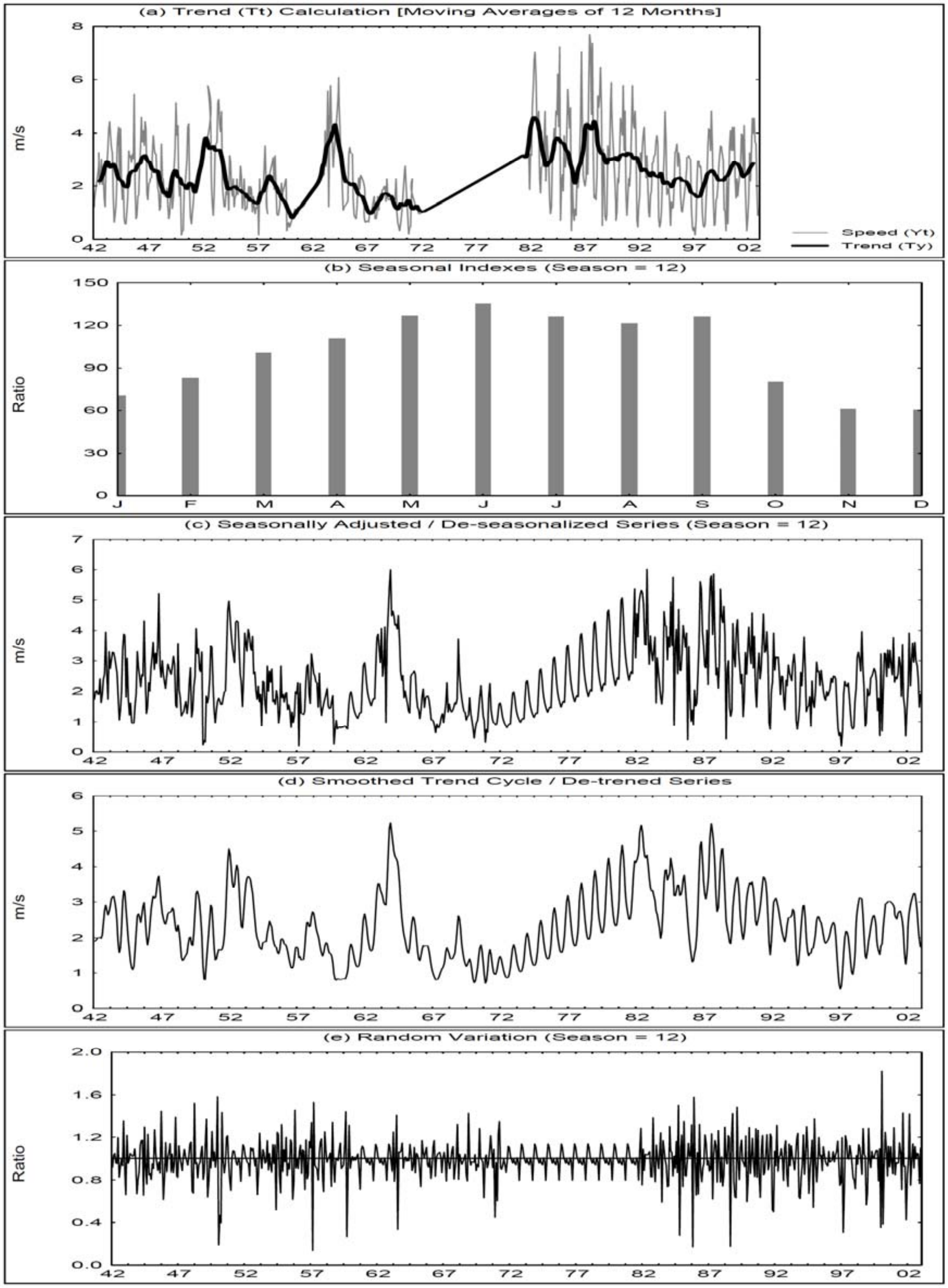


**Figure 6:** Time-series analysis plots showing (**a**) trend, (**b**) seasonal indexes, (**c**) de-seasonalized series, (**d**) de-trended series and (**e**) random variations of wind speed at 50m for Lasbella city from 1942 to 2002.

recorded at different anemometer heights has been extrapolated to 50m and calculated respective wind trends and seasonal behaviors.

Badin trends show a non-monotonic oscillatory behavior of wind speed that also increasing over the span of time, whereas Hyderabad trends show a mixture of linear and non-monotonic nature.

- Karachi trends show a decrease in wind speed till 1995, but onward an increase is encountered.

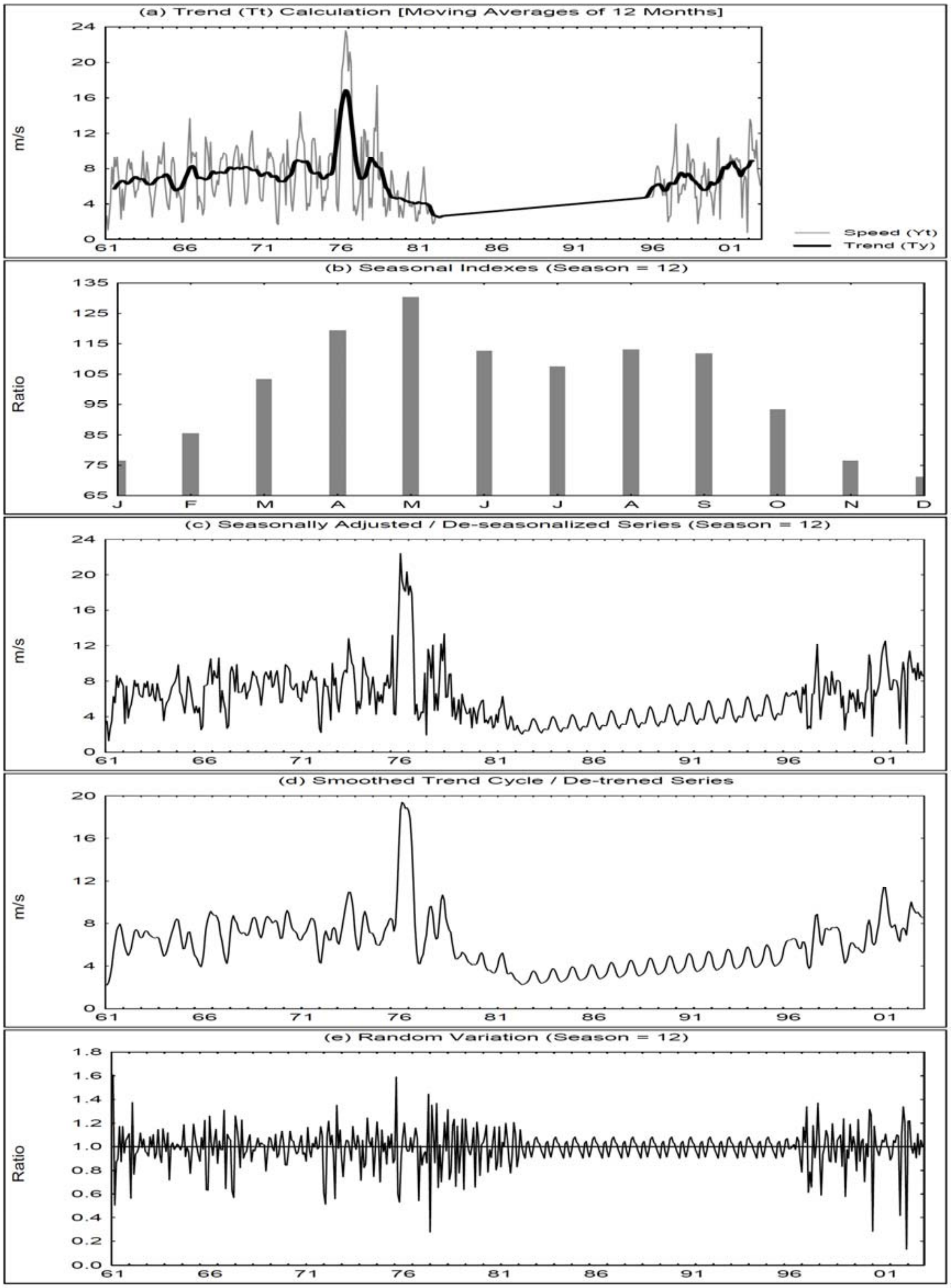


**Figure 7:** Time-series analysis plots showing (**a**) trend, (**b**) seasonal indexes, (**c**) de-seasonalized series, (**d**) de-trended series and (**e**) random variations of wind speed at 50m for Ormara city from 1961 to 2002.

- As a result of wind data gaps for Lasbella and Ormara cities, the precise analyses of long-term trends were difficult. But with the available data analyses, however, and increase and oscillatory nature of Lasbella trends and only the oscillatory for the Ormara trends could be estimated.

- Average maximum seasonal indexes sustain only during the monsoon period from June to August.

- The smoothened trend cycle series relevant to (i) Badin shows four distant cycles during the last 60 years, (ii) Karachi, Hyderabad and Ormara show the consistent cycles, and (iii) Lasbella shows cyclic behavior of 14 years.

- The average random variations ratios in the long-term wind speed are about 0.5 for Badin, Hyderabad & Ormara, but for Karachi is 0.2 and for Lasbella is 0.8.

- It is inferred from the current study that wind speed trends at the given coastal cities of Pakistan generally remain sustained and consistent over a period of time, which is a vital requirement for the sustainable energy generation through the wind resource.

- It is also inferred by the seasonal indexes calculations that the maximum wind occurred during May to August that corresponds to the summer season, when the energy demand is relatively high.

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