Atmospheric Stability and Its Effect on The Polluted Columns of Concentrations in North West of Baghdad City

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Abstract

Atmospheric stability plays the most important role in the transport and dispersion of air pollutants. Different methods are used for stability determination with varying degrees of complexity. Most of these methods are based on the relative magnitude of convective and mechanical turbulence in atmospheric motions, such as Richardson number, Monin-Obukhov length, Pasquill-Gifford stability classification and Pasquill-Turner stability classification. The Pasquill-Turner Method (PTM), which is employed in this study used Observations of wind speed, solar altitude angle and the time of day to classify atmospheric stability with distinguishable indices. As a case study, meteorological data that gathered from European Centre For Medium-Range Weather Forecasts (ECMWF) at latitude 33.75^0 and longitude 43.87^0 that Located north west of Baghdad city (this area consider suburban that a crosses domain wind towards city center) through hours 00,03,06,09,12,15,18,21 from every day in 2010 year . The scheme used two different categories are considered to deduce the pattern of atmospheric stability conditions. First, the annual or total pattern of stability classification is obtained and results show that atmosphere is 54.4 %, 8.7 %, 36.9 %, at stable, neutral and unstable conditions, respectively. It is also observed that days are mostly unstable (61.6%) while nights are mostly stable (94.5%). Second, monthly and seasonal patterns are derived and results indicate that relative frequency RF% of stable conditions decrease during January to June and increase during June to December, while results for unstable conditions are exactly in opposite manner. Autumn is the most stable season with relative frequency of 62.1% for stable condition, whilst, it is 56.2 %, 44.6 % and 54.6% for winter, summer and spring, respectively. Finally, correlation between RF% of stable conditions and NO_X, SO_2, CO, CH_4 columns concentrations in(kg/m^2) is achieved and results show correlation between these elements and stability .The important of this study basically located in assessment air quality of Baghdad city and also in urban planning.

Keywords: Atmospheric stability , Turner classes, pollutant concentration, ECMWF

الاستقرارية الجوية وتاثيرها على تراكيز اعمدة الملوثات الجوية في الشمال الغربي لمدينة بغداد

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الخلاصة

الاستقرارية الجوية تلعب دور مه م في الانتقال وتبدد ملوثات الهواء ، حيث قد استخدمت طرق مختلفة لتحديد الاستقرارية وبدرجات مختلفة من التعقيد ، واغلبها مستندة على السعة النسبية للاضطراب الحملي والقصي في الحركات الجوية مثل طريقة عدد رجادسون ، طول ابو كوف وتصنيف استقرارية جي – فورد وتصنيف استقرارية ترنر – باسكويل . ان طريقة ترنر – باسكويل والتي استخدمت في الدراسة عملت من

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قياسات لسرعة الرياح و زاوية ارتفاع الشمس والوقت من اليوم مع موشرات تقديرية استخدم لتمييز اصناف الاستقرارية الجوية . هذه الدراسة استخدمت بيانات المركز الاوربي للتوقعات الج وية ذات المدى المتوسط (ECMWF) عند خط عرض 33.75^0 وخط طول 43.87^0 والتي تقع الى الشمال الغربي من مدينة بغداد (تمثل منطقة شبه حضرية مفتوحة وممر للرياح السائدة بتجاه مركز المدينة) وعند الساعات 00، 03 ، 06 ، 09 ، 12، 15، 18 ، 21 من كل يوم من سنة 2010 . النموذج استخدم مجموعتين من انماط التحليل في استنتاج ظروف الاستقرارية الجوية . النمط الاول هو النمط السنوي لاصناف الاستقرارية والنتائج بينت انه , 54% 8.9% ,36.9%عند الظروف المستقرة والمتعادلة و الغير المستقرة على التوالي . وتم ملاحظة انه خلال النهار الحالة تكون تقريبا 61.6% غير مستقرة ، بينما خلال الليل تكرار الحالة المستقرة تصل الى 94.5% . والنمط الثاني الفصلي او الشهري والنتائج بينت ان التكرار النسبي للظروف المستقرة تتناقص خلال شهر كانون الثاني بلقجاه شهر تموز ثم تزداد من شهر تموز بلتجاه شهر كانون الاول .بينما زيادة تكرار الظروف الغير مستقرة يكون بالاتجاه المعاكس . وكان فصل الخريف هو الفصل الاكثر تكرارا للظروف المستقرة حوالي 62.1% بينما كانت 56.2% , 44.6% و 54.6% للشتاء و الصيف و الربيع على التوالي . واخيرا تم تناول ارتباط التكرار النسبي للاستقرارية الجوية مع اعمدة تراكيز الملوثات الجويۃ مثل CH_4 , CO , SO_2 , NO_X , بوحدة كيلوغرام /متر^2، والنتائج بينت ارتباط هذه العناصر مع الاستقرارية . ان اهمية هذه الدراسة تقع بشكل اساسي في تخمين اوتقييم نوعية الهواء لمدينة بغداد وايضا في التخطيط الحضري .

الكلمات المفتاحية : الاستقرارية الجوية ، اصناف ترنر ، تراكيز الملوثات ، المركز الاوربي لتوقعات الجو متوسط المدى.

Introduction

Atmospheric stability plays the most important role in the transport and dispersion of air pollutants. It can be defined as the atmospheric tendency to reduce or intensify vertical motion or alternatively, to suppress or enhance existing turbulence [1]. It is related to the change of temperature with height (lapse rate) and also wind speed . The degree of stability of the atmosphere must be known to estimate the ability of atmosphere to disperse pollutants [2-3]. Different methods are used for stability determination with varying degrees of complexity [4]. Most of these methods are based on the relative importance of convective and mechanical turbulence in atmospheric motions. Difference between such methods is due to use of different indicators for both convective and mechanical turbulence. Generally, when convective turbulence predominates, winds are weak and atmosphere is in unstable condition. When convection decreases and mechanical turbulence increases, atmosphere tends to neutral conditions. Finally in absence of convective turbulence when mechanical turbulence is dampened and there is no vertical mixing, atmosphere is in stable condition [5].

The Pasquill-Turner Method (PTM), which is employed in this study, is based upon the work of Pasquill, that has been reviewed by Turner (1964), and introducing incoming solar radiation in terms of solar elevation angle, cloud amount or cloud height. It classifies atmospheric stability with seven distinguishable categories [6]. The importance of this method lies in the relation of atmospheric dispersion coefficients and classified stability for mechanically and thermally generated boundary-layer turbulence [1]. Also, PTM can simply modify to model used evenly to compute stability.

In this study, an attempt was made to determination of atmospheric stability conditions using PTM over north west of Baghdad city through one year . Also, relation between these conditions of stability and concentrations columns of pollutants is investigated. First, more details about PTM and relative concepts are illustrated. The results are evaluated totally, seasonally, and monthly. Finally, the correlation between atmospheric stability and NO_X , SO_2, CO , CH_4 concentrations columns in (kg/m^2) (from ECMWF) is documented. These polluted is selected because its important in greenhouse effect, it remains at high values within cities, and emitted from the burning of large quantities of fossil fuel .

Location And Data

The location at 33.75^0 latitude and 43.875^0 longitude (near the north west of Baghdad city) is used as a case study, to determine atmospheric stability by PTM. Meteorological data that include cloud cover, wind speed at 10m and total column of Carbon monoxide, Carbon Dioxide , Nitrogen oxide is collected for the 2010 year from the European Centre For Medium-Range Weather Forecasts, these values of ECMWF are not really observed, of course, but determine from a numerical model. The data used in this study covered Iraq and specifically Baghdad as a grid of four points extends from (32.625 °-33.75 °) N latitudes and (42.75 °- 45 °) E longitudes with a uniform grid interval of 1.125 degrees longitude and 1.125 degrees latitude , figure 1 show this grid cover Baghdad city that used in this study where we take horizontal wind speed at 10m ,the color line in fodder title in figure, refer to wind speed values ,we notes wind speed in north-west is high record values (blue color) ,on other hand the sign mines refer to the direction of upwind . We used only one point from this grid located North West of Baghdad city where domain wind speed direction contributed to loaded polluted particles to Baghdad center. The duration is extended from the first day of January of 2010 to last day of December 2010 and for the time (00 , 03 , 06 , 09 ,12 , 15, 18 , and 21) UTC.

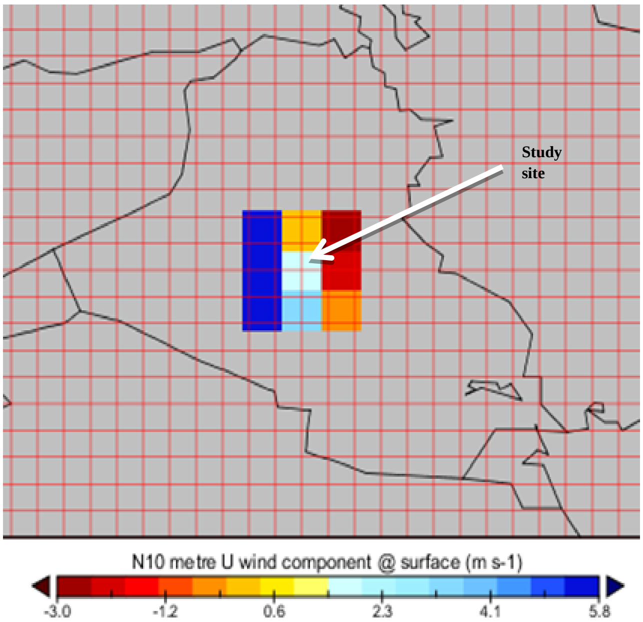

Figure 1- The grid points over area of Baghdad city and site study for wind speed data at ECMWF .

Materials and Methods

Richardson number, Monin-Obukhov length, Pasquill-Gifford stability Classification and Turner stability classification are some of common schemes. The Richardson number is a turbulence indicator and also an index of stability which is defined as [2]:

$$R_i = \frac{g\left(\frac{\Delta\theta}{\Delta z}\right)}{T\left(\frac{d\bar{u}}{dz}\right)^2} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots (1)$$

where, g is the gravity acceleration, $\frac{\Delta\theta}{\Delta z}$ is the potential temperature gradient, T is the temperature and $\frac{d\bar{u}}{dz}$ is the wind speed gradient. In this equation, $\frac{g\left(\frac{\Delta\theta}{\Delta z}\right)}{T}$ is indicator of convection and $\left(\frac{d\bar{u}}{dz}\right)^2$, is cursor of mechanical turbulence due to mechanical shear forces.

The other key stability parameter is the Monin-Obukhov length, *L*, which treats atmospheric stability proportional to third power of friction velocity, u_*^3 , divided by the surface turbulent (or sensible) heat flux from the ground surface, H_s Monin-Obukhov length is defined as [2]:

$$L = \frac{-\left(\frac{u_*^3}{k}\right)}{\left(\frac{gH_s}{C_p\rho T}\right)} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots (2)$$

where u_* is friction velocity, g is the gravity acceleration, C_p is the specific heat of air at constant pressure, ρ is the air density, T is the air temperature, and k is von- Karman constant taken to be 0.40 (constant used in aerodynamic wind flow)[7] . H_s is positive in daytime and negative at nighttime . Table 1 shows the atmospheric stability classification using mentioned schemes and relationship between it[5] [8].

Pasquill-Gifford method for estimating atmospheric stability, incorporating considerations of both mechanical and buoyant turbulence was proposed by Pasquill (1961). It is a simple method because it is easy to use and tends to give satisfactory results[1]. In this classification, it is assumed that stability in the layers near the ground depends on net radiation as an indication of convective turbulence and on wind speed at 10m height as an indication of mechanical turbulence. Pasquill used meteorological routinely data available from surface, such as wind speed, solar radiation and cloudiness at surface for the characterization of atmospheric stability and derived six categories from A for (extremely unstable) to F for (stable) conditions. This can be done through depending indices and tables used to derived these classes and don't on mathematic equations , but these criteria to classification put in model in this study to expected Turner-Pasquill classes .

Net radiation could be determined based on insolation (incoming solar radiation),and cloud cover at day or night time [9] [10]. Turner improved this scheme by introducing Net Radiation Index (NRI) as indicator of insolation. This produced a new version of Pasquill 's algorithm in which radiation is categorized into classes related to solar altitude, cloud cover and cloud height [6]. The method is generally acceptable for studies of atmospheric pollution, even if it overestimates the neutral stability class [1]. The NRI in PTM can be determined according to table 2, depend on the cloud amount and the time of day [1][5]:

Corrections of NRI during daytime are as follows:

1. If the total cloud cover is <4/8, then the indices are used as from Table 2 .
2. If the cloud cover is >4/8 two cases are distinguished:
a- Cloud height ceiling <2000m, then 2 is subtracted
b- Cloud height ceiling >2000m and <4571m then 1 in subtracted.
3. If the total cloud cover is 8/8 and the ceiling height is >2000m, then 1 is subtracted.
4. If the corrected value is less than 1, then it is considered equal to 1.

Table 1- Show four different stability schame [5] [8] .

Stability condition	***Richardson***	***Monin-Obukhov***	***Pasquil-Gifford***	***PTM***
Extremely unstable	Ri < -0.04	-100 < L < 0	A	1
Unstable		-105 ≤ L ≤ -100	B	2
Slightly unstable	-0.03 < Ri < 0		C	3
Neutral	Ri=0	|L| > 105	D	4
Slightly stable	0 < Ri < 0.25	10 ≤ L ≤ 105	E	5
Stable	Ri > 0.25		F	6
Extremely stable		0 < L < 10		7

Table 2- Value of NRI dependent on cloud cover

Atmospheric Cloud condition	***The value of NRI***
When the total cloud cover is 8/8 and the ceiling height of cloud base is less than 2000m (low clouds).	0
during the night if the total cloud cover is <3/8, and if it is >3/8, then -1	-1 to -2
(high radiation levels) take 4 ranging to 1 (low radiation levels) during daytime and depending on the solar altitude .	1 to 4

When the solar altitude is higher than 60 degrees, i.e. in the afternoon summertime, then the atmosphere is unstable. Moderate instability occurs during a summer day with few clouds, where solar altitude is between 35°- 60° degree. Weak atmospheric instability happens usually in the afternoons of autumn or summer days with few low clouds. The neutral category governs during cloudy days and nights. Finally, the creation of inversions during nights with clear sky indicates stable atmosphere [8].Stability class in PTM is determined according to the corrected NRI and the wind speed, as it is shown in Table 3 . The main methodology of this study consists of two parts , First part Calculate solar altitude angle, where solar altitude is calculated by solar altitude , solar declination and solar hourly angle, the number of days from the beginning of Julian year 2010 [11][12] , where Orbital elements such as mean distance from sun, eccentricity, etc. are calculated by using number of days[13] and parameter of angles above (declination ,latitude, hour) are determined by means of these elements that results from measurement of solar altitude in time and location of interest. Second Part determine Stability Class**,** This part uses solar altitude angle obtained from first part and meteorological data include wind speed, cloud cover, to determine turner's stability class for specific time and location according to PTM algorithm described in last section.

Table 3- Turner Stability Class as a function of NRI and wind speed

Wind speed (m/s)	***Net radiation index (NRI)***						
	4	**3**	**2**	**1**	**0**	**-1**	**-2**
$0 \leq u < 1$	1	1	2	3	4	6	7
$1 \leq u < 2$	1	2	2	3	4	6	7
$2 \leq u < 3$	1	2	3	4	4	5	6
$u = 3$	2	2	3	4	4	5	6
$3 < u < 4$	2	2	3	4	4	4	5
$4 \leq u < 5$	2	3	3	4	4	4	5
$u = 5$	3	3	4	4	4	4	5
$5 < u < 6$	3	3	4	4	4	4	4
$u \geq 6$	3	4	4	4	4	4	4

Results and Discussion

Three different time categories for stability pattern are obtained from the results of this study include: total, seasonal, and monthly patterns . These patterns are compared also with concentration of pollutant columns .

Total Stability Pattern

Implementation of stability on the meteorological data of study area, shows that atmosphere is mostly stable with relative frequency (here after RF) of 54.3% for stable condition Fig. 2. From more comprehensive aspect Fig.3, show RF of stability according to PTM where extremely unstable category 1 is 7.8% that is considerably less than RF of extremely stable category 7 with quantity of 23%. As a consequence, air pollution accumulation, could occurs most of times . During days, where solar radiation is present, it is expected that atmosphere be chiefly unstable. Dividing total stability pattern into two parts and investigate daytime and nighttime stability separately, we find that about 61.6% of RF unstable is concentrated at daytime in opposite to 11.5% is stable at daytime , but this ratio is change at nighttime we see that about 94.5% of RF is stable atmospheric condition, but unstable located about 0.1% . This phenomenon could be explained by physical realities that there is at nighttime no solar radiation president and, NRI is between -2 to 0 that spans classes 4 to 7. Perhaps this conditions can be founded in the open remote area (rural area) where there large temperature difference between the daytime and nighttime and wind speed recorded large rate, relative to the inside Baghdad city where air environment ambient is dirty and there is huge of drawback represented by the building that limited the movement wind, this make the H_s inside the city is positive along the time but the matter become complex when the greenhouse effect become active inside city and interacted with the sensible heat flux H_s . Overall these situations will reflect on the atmospheric stability that depends largely on the wind speed and on heating the surface by the solar radiation.

Seasonal and Monthly Stability Pattern

In Table 4, and figure 4 comparisons between stability patterns of different seasons reveals that atmosphere is more stable during cold seasons than warm ones. It is also Observable that the autumn is the most stable season with 62.1%, 0.96%, 36.95% RF for stable, neutral and unstable conditions, respectively.

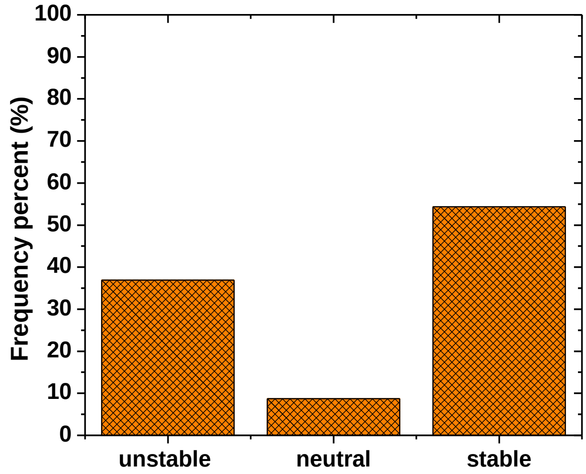

Figure 2- Total pattern of atmospheric stability conditions

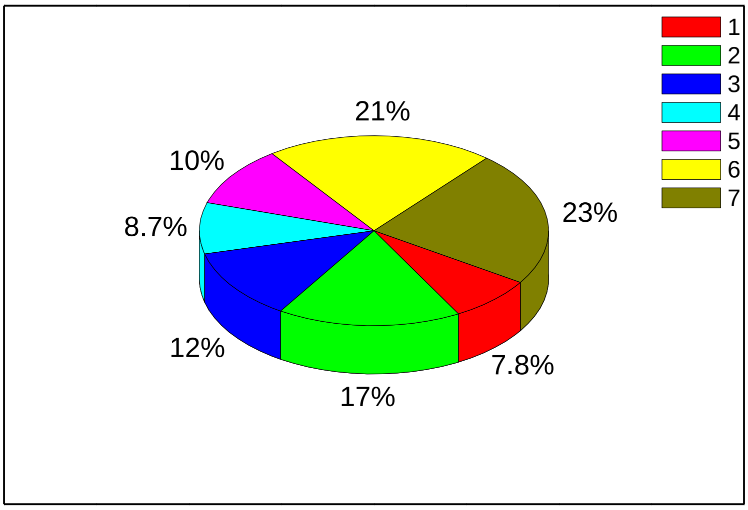

Figure 3- Total pattern of atmospheric stability based on Turner's classification

Table 4- Show comparison between atmospheric stability through the seasons

	Unstable%	***Neutral %***	***Stable%***
Winter	29.624478	14.18637	56.18915
Spring	37.687075	7.619048	54.69388
Summer	43.188011	12.26158	44.55041
Autumn	36.950549	0.961538	62.08791

This stability (for autumn) configure about 90.49% , 88.09% and 71.76% from the RF% stability condition at the seasons winter , spring and summer respectively , Consequently, air pollution accumulation during this season is more probable than other ones , table 4.This values for stability at this season may be belong to the low solar radiation and large cover of low clouds this can be tracked by the less active wind speed, figure 6, these atmospheric condition is responsible for the large ratio of

RF% in stable atmospheric condition at this season , see group 5,6,7 of turner Classes at autumn season in figure 4. Monthly stability variations are presented in Fig. 5 where a relative decrease in RF% of instability From June 46.25% to September 37.5% , at these periods instability is dominant, at the same periods where an increase in stability are obvious during warm months to cold ones from June RF% about 35% to 62.5% at September month and through these months stability is applicable . This matter could be elucidated regarding the fact that during warm months, insolation is high and there are no strong winds, so convective eddies,(H_s have large positive values) play main role in atmospheric motions and atmosphere is more unstable than cold months where there is less insolation and stronger winds, see figure-6 .

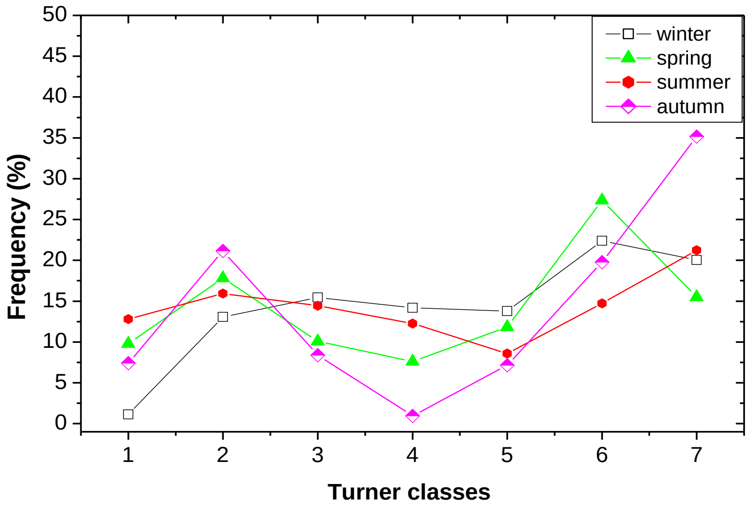

Figure 4- Seasonal comparison of atmospheric stability condition according to Turner- classification

As a result, there is relatively more chance for pollution accumulation during cold months due to more stable condition. It should be noted that, the most stable month is the September with 62.5% RF for stable condition while the June is the most unstable month with 46.25% RF for unstable condition, this ratio form about 75.67% of the RF% stable condition at the same month, while its form about 135.2% from the stable condition at September month . thus we can consider June month is the best month in consider the dispersion of air masses in the upward but September month in opposite it's the months that there is damping of air masses and accumulated air pollution . on the other hand the neutral condition that don't consider any effect on the air movement is dominated at hot and moderate months and have large value at June month about 18.8% from RF , because the domain wind speed at this month, see figure-6. But its near to zero at August and September, figure-5.

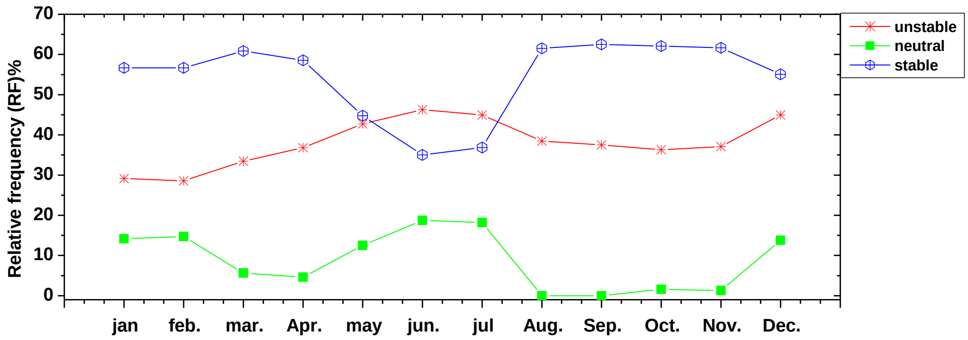

Figure 5- Variations in atmospheric stability patterns during different Months (unstable , neutral , stable)

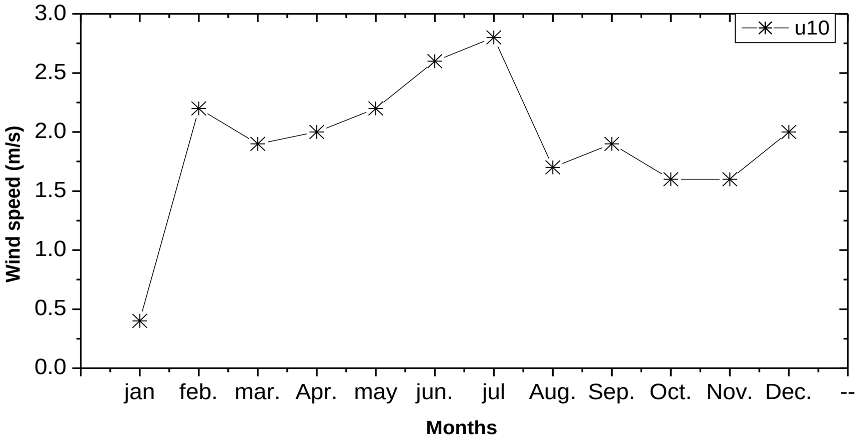

Figure 6- Mean monthly wind speed at 10m height through the period study .

Air Pollution concentrations Columns Versus Atmospheric Stability

Basic assumption here is that the short-term evolution of air pollution in any area is mainly dependent on atmospheric stability. To reveal and examine the relationship between atmospheric stability and air polluted ,we plotted monthly averages of total concentrations columns , NO_X , SO_2, CO , CH_4 (kg/m^2) that archived from ECMWF and at duration (January- December) 2010 , with relative frequency (RF%) of stable conditions in the same period , this essential to evaluated the effect of atmospheric environment on concentrations particulate that diffused in air , and specially the pollutant concentrations that consider a poisonous to human being , such as carbon and sulfur oxides . The relatively appropriate correlation between these columns and stability conditions is obvious and both have similar trends. For instance, from April to August, where RF% of stability conditions is decreased, NO_X , SO_2 concentrations is at lowest levels about $4.3*10^{-6}$ and $6.34*10^{-6}$(kg/m^2) respectively, while from September to November, dominance of stability leads to occurrence of maximum NO_X , SO_2 concentrations ($8.93*10^{-6}$ and $7.11*10^{-6}$ kg/m^2) respectively, but in CO there is decreases in concentration With decreases frequency of stability from April to July, the case is change from July to December where it decreases with increases of stability RF% , this may return to the nature interaction of this gas with other atmospheric elements, the largest source of carbon monoxide is natural in origin, due to photochemical reactions in the troposphere ,Other natural sources of CO include volcanoes, forest fires, and other forms of combustion. but Anthropogenic source chiefly from the exhaust of internal combustion engines (including vehicles, portable and back-up generators, lawn mowers, power washers, etc.), but also from incomplete combustion of various other fuels (including wood, coal, charcoal, oil, paraffin, propane, natural gas, and trash) , and because study location is suburban the nature sources is domain , and anthropogenic sources may come by locale wind speed or from near target. But this case is different in CH_4, there are decreases in concentration pollutant column from January to April with increases in stability, directly wind speed is become active from April and the next hot months. overall we see strong relationship between air quality and atmospheric stability in summer months stated in figures 7(a),(b),(c),(d) , and rather weak in winter is revealed in Figs. 7(c) and 7(d), respectively while in spring and autumn months, correlation is fairly weak in (Figs. 7(b), 7(c).

In fact, strong winds in spring and autumn dominate nonlinear character of atmosphere and lead to disappearance the dependence between stability and pollution concentration in air ambient , on other hand the concentrations columns of CO and CH_4 is found in large concentration in urban , while the location you selected is represent suburban. In this area the profile of movement methane for example is through soil and bodies of water to atmosphere. This diffusion varies per wetland based on the type of soil and vegetation. Wetlands with drier plays a much bigger role in diffusion .Thus we see the behaved of CH_4 in cold season months methane concentration is large but it's began to decreases with starting the hot months and very large until the wet of soil finished last the summer season .On other hand Inaccuracy of Pasquill –Turner model in presence of strong wind could be another reason for weak correlation in these two seasons .The relationship obtained between stability condition and air columns pollution can be used as a decision support to modify traffic management schemes in different seasons and months in Baghdad city. through applied this model in different portion in Iraq, this model can give also the real environment of weather being clear or dirty relative to air pollution ,you can used that model in urban planning and select any place to build project in several fields . The important of this study can be determine the local and mesoscale of ratio of pollutants that enter to Baghdad city from known the rate of pollutant concentration that diffused in air , where it moved after by domain wind speed direction that transfer from north west to south east passing by center of Baghdad city . It must be emphasized that, by this approach, we can intended to forecast the monthly and seasonal trend of pollutant in Baghdad.

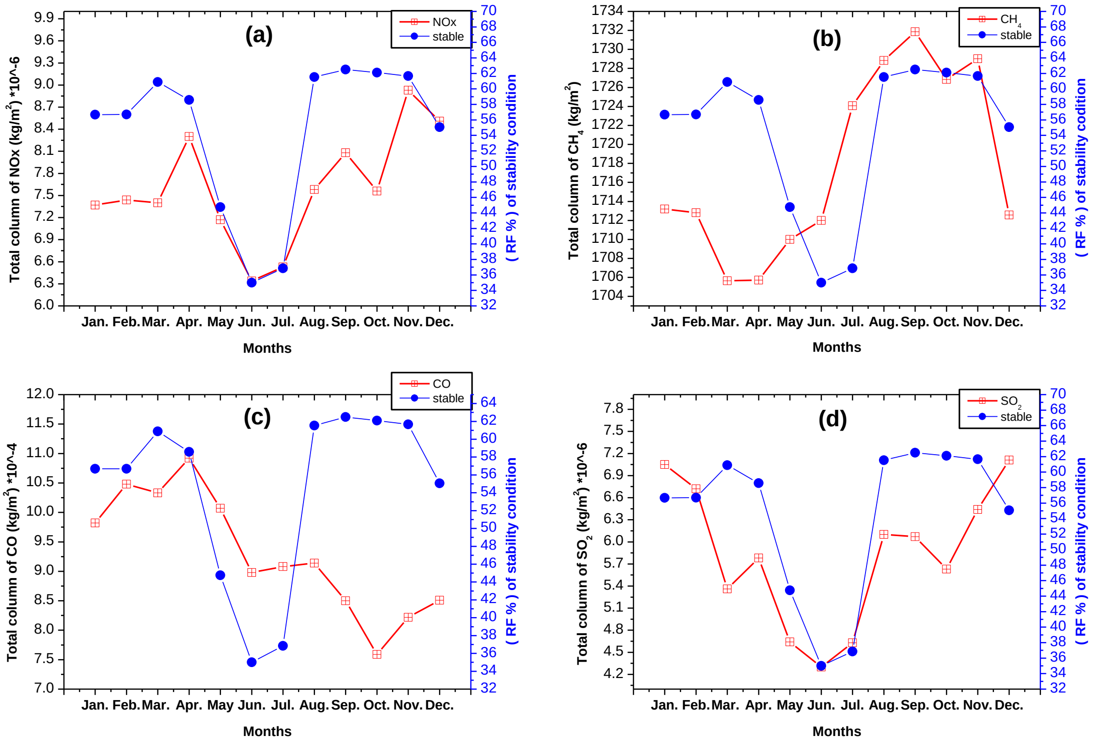

Figure 7-Time series of frequency of stable condition and (a) NO_X ,(b) CH_4, (c) CO , (d) SO_2 columns concentration at months of year 2010 .

Conclusion

This study was an effort to represent a scheme to determine stability condition of atmosphere using PTM. In comparison with other stability indexes, PTM seems to be a suitable method without complexities of others. This method classifies the atmospheric conditions in to seven categories based on wind velocity and net radiation index NRI. Recent parameter is determined as a number between -2 to 4, using a set of routine meteorological data include solar altitude, cloud cover and cloud height. Approach is developed based on mentioned parameters and is applied on data of latitude 33.75^0 and longitude 43.87^0 that located in the north west of Baghdad city that taken from European Centre For Medium-Range Weather Forecasts . Results show the relevance of instability in days and stability at nights with relative frequency of 61.6%and 94.5% respectively. Instability is decreased from spring to winter in such way that during the autumn most relative frequency (62.1 %) for stability is occurred. As a result, based on hourly stability pattern, nights of the autumn have the most risk for pollution accumulation.

Evaluation of correlation between stability pattern and total columns concentration NO_X , SO_2, CO , CH_4 reveals that a decision support model could be proposed for summer and winter, using applied trends . But for spring and autumn that nonlinear nature of atmosphere is dominant due to presence of strong winds, and the nature of references of these pollutant .

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