Principal Component Analysis to Explore Climatic Variability that Facilitates the Emergence of Dengue Outbreak in Karachi

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Abstract

Various studies have reported that global warming causes unstable climate and many serious impact to physical environment and public health. The increasing incidence of dengue incidence is now a priority health issue and become a health burden of Pakistan. In this study it has been investigated that spatial pattern of environment causes the emergence or increasing rate of dengue fever incidence that effects the population and its health. Principal component analysis is performed for the purpose of finding if there is/are any general environmental factor/structure which could be affected in the emergence of dengue fever cases in Pakistani climate. Principal component is applied to find structure in data for all four periods i.e. 1980 to 2012, 1980 to 1995 and 1996 to 2012. The first four PCs for the period (1980-2012, 1980-1994, 1995-2012 and 2010-2012) are almost the same. The first three PCs of monthly data for Dengue occurrence period (2010-2012) are also similar to the first three PCs, but for this period PC4 is different from other three. The percentage of variance of PC1 and PC2 are highly different to each other, they are around 44 % and 22 % which shows that there are 66 % of total variation factor of Karachi climate. The third component in the variation of Karachi climate is "reverse of variation of wetness and wind speed "which constitutes 18 % of variation. Whereas the PC4 is the contradiction of "temperature" and "wind speed" which is 11.2 % of variation. In the next stage the study is to establish a relationship between climatic variables and dengue fever

Key Words: Principal component analysis, Dengue Fever, Global warming, Environmental condition.

Introduction

Climate is a composite term and this refers to weather conditions over a period of time. It is an average or general conditions of temperature, humidity, atmospheric pressure, wind speed and rainfall of a place. These elements act as climatic factors. Climate is an important subject of scientific enquiry, particularly as it has such an impact on vegetation, soil and health etc. Its importance increases manifold because of its influence on human life. Natural hazards like storms, floods and desertification are results of climatic changes. According to world health organization and Farrar et.al (2007) extreme temperatures, weather hot or cold affect human beings, crops, animals and mosquitoes lifecycles especially Aedes agepty mosquitoes which causes the Dengue Fever (Farrar et. al 2007). World health organization reported that in the medical terminology its another name is "break bone fever". This viral disease has spread in most part of the world. In most of the tropical and sub tropical countries dengue fever has become a serious and dangerous health risk for the public. About two million people are affected by dengue fever in the world. "Den-1, Den-2, Den-3 and Den-4" are used the names of serotypes which causes severe dengue (WHO). Gubler et.al (1997) reveal that the dengue infectious disease spreads in warm climate. Aedes Agepty mosquitoes are seriously sensitive by environmental conditions. The climatic variables i.e., precipitation, humidity, temperature and wind speed are helping for the survival and reproduction of dengue mosquitoes. High temperature helps to decrease the time lag for the replicate of the dengue mosquito virus. This process is called "Extrinsic Incubation Period", in this period virus is transferred from mosquito to human body through the mosquito's salivary glands. In the high temperature mosquito become infectious faster and has higher probability to dangerous for human being before completing its life cycle. Climatic change and environmental factors are helping to flourish the dengue vector but there are some other factors also play a vital role for the dengue outbreak. In the hot weather incubation time of

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virus is lesser, which indicates that there is low probability of survival of mosquito to become infectious. Due to global warming the range of the mosquito is increasing. So we may say that the critical factor is climate by which the situation may be controlled to the mosquito habitat. We can see vast amount of information from the researchers Hii YL et.al (2009), Su GL (2008), Arcari et.al (2007), Johansson et.al (2009), Reiter (2001) and Kuhn et.al (2005) have studied and reported that there is a positive correlation between the amount of rainfall and relative humidity with dengue occurrence. Similar results have also reported by other studied groups G. Chowell et.al (2003), Barbazan et.al (2010) regarding the correlation between rainfall and infection rate of dengue. Jetten et.al (1997) and Russell (1998) have shows the relationship between climatic factors and dengue fever incidence to indicate or predict variation in dengue incidence. Barbazan et.al (2010), Brunkard et.al (2008) have assesed the effects of temperature and precipitation on dengue transmission relation. Amarakoon et.al (2004) has studied the dengue epidemics and its association with precipitation and temperature.

Chan et.al (1995) discuss that in Karachi, Pakistan first Dengue fever outbreak reported in 1994 and 1 patient out of 145 died. Hakim et.al (2011), Jahan et.al (2011), Riaz et.al (2009) and Humayaon et.al (2008) have studied and reported epidemics of dengue and its causes from different parts of Pakistan. Pakistan has experienced a number of dengue fever outbreaks since 1994. In October 2005, Dengue again hit Karachi after 10 years and 21 deaths out of total 103 confirmed cases were recorded. Since then, the disease has become widely accepted as one of the major public health problems. Over 21, 204 people were reportedly infected in the country in 2010. The reasons why and how the dengue epidemics become endemic diseases in Pakistan, different reasons are for this problems like poor hygiene and inefficient sewerage system as these are the ideal habitat for the dengue vector to lay eggs and flourish. From the last few years transmission of dengue virus situation is high in the country, Karachi and Lahore are the cities which are heavily threatened by dengue epidemics in pre and post monsoon periods.

Data and Methodology

This study was conducted in Karachi capital of Sindh province, it is the largest and most populous metropolitan city of Pakistan and its main seaport and financial centre. The city has an estimated population of 23.5 million people as of April 2013[35] and a density of nearly 6,000 people per square kilometer (15,500 per square mile) and is the 3rd-largest city in the world by population. The climate of Karachi features an arid climate, albeit a moderate version of this climate. Karachi is located on the coast and as a result has a relatively mild climate. Karachi has two main seasons; Summer & Winter, while spring and autumn are very short [36]. The climate data of Karachi were collected from Pakistan Meteorologist Department, on monthly average basis from 1980 -2012 and daily basis from 2010-2012. Names of five climatic variables which we have studied as explanatory variables are precipitation (P), Maximum temperature (Mx), Minimum temperature (Mn), Humidity (H) and Wind speed (W). The dengue fever (DF) cases in Karachi from 2010 to 2012 are reported on weekly basis used as dependent variables. The data on the number of deaths due to Dengue fever are not available with us; therefore our study will only focus on the dengue occurrence cases only. In 2010 Govt. of Sindh, Pakistan has established the Dengue surveillance cell for not only keeping the records of Dengue Fever reported cases, but also providing the information about the DF and the health facilities to the people in this regard.

In Table 1 we presented number of DF cases by months, for the years 2010, 2011 and 2012. The number of cases repeated for each succeeding year has drastically reduced. The number of dengue fever cases repeated in 2012 is only 14 % of the 2010. This indicates that Government of Sindh has tried to facilitate the people against dengue fever in terms of awareness of DF, health facilities, import medicine and also expert teams to work together with local teams.

Table 1: No. of Dengue cases reported in Karachi (2010 –2012).

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
2010	11	3	14	7	7	12	25	224	128	2510	1902	406	5249
2011	18	5	8	4	17	8	32	40	393	415	104	35	1079
2012	11	14	8	12	16	28	39	40	6	141	262	102	734

Source: Dengue surveillance cell Karachi, Govt. of Sindh, Pakistan.

Figure 1 and 2 shows the weekly and monthly dengue cases. It can be clearly seen from Figure 1 and 2 that the curve of monthly data is only the smoothed form weekly data curve. The high peaks of curve Figure 2 give the same picture as we have described in the earliest paragraph.

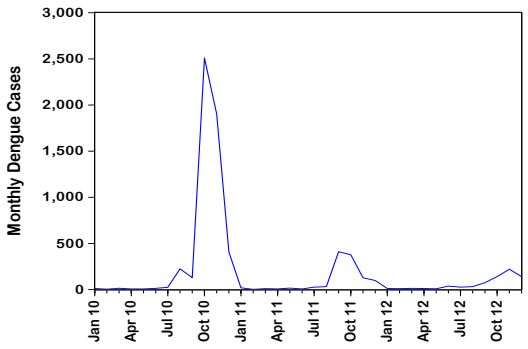

Figure 1: Karachi Weekly Dengue Cases 2010-2012.

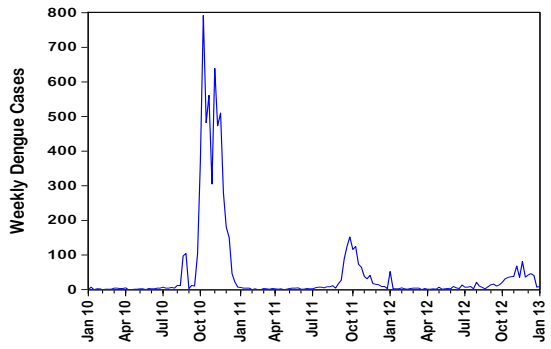

Figure 2: Karachi Monthly Dengue Cases 2010-12.

In this study our focused is to explore the climatic variables and/or the climatic factors (structure) which may influence in the increase or decrease in the number of dengue fever cases in Karachi. To find the climatic structure we used Principle component analysis (PCA) method. Will et.al(1999) discussed that PCA technique is recognized as reduction and extraction for dimensionality of the data and rating as much of the variation present in the original data set . This is one of the ways of identifying patterns in the data. It is difficult to find patterns in the data for this purpose we use PCA which highlight the similarities and difference in the data. The pattern in the data can be found by squeezing the data. In other words by suppressing the dimensionality of the data by avoiding the losses of information. According to Jonathon Shlens this procedure is also used in the image compression or image reorganization. Edwards (1999) discuss that the purpose to apply the PCA is to reduce the manifest variables, in this way the set of components will be reduced. The new components are called PC1, PC2, PC3 and so on, (for the first, second and third principal components) are independent and decrease the amount of variance from the original data set. PC1 (the first component) captures most of the variance, PC2 captures the second most of the variance and so on until all the variance is accounted for, in this way very few will retain for further study.

The components have been treated as climatic factors or climatic structures. The Principle component method transforms correlated observed variables in to uncorrelated variables which are linear combination of observed data. The required condition to apply this technique is correlation/covariance can be defined. So we don't find any problem in the application of principle component analysis.

For the purpose of statistical studies, we have applied PCA and other statistical techniques also fitting different statistical models to find the relations between DF and climatic variables Hii et al. (2009), Jury MR (2008) and Su (2008) have also discussed the relation between climatic variable and dengue incidence.

For the purpose of study we have categorized the whole data into four periods i.e. from 1980-2012, 1980-1994, 1995-2012 and 2010-2012. Firstly, we analyze the whole data from 1980-2012 and then divided the

whole data into three periods from 1980-1994, 1995-2012 and 2010-2012. For the purpose of statistical analysis we have taken the monthly and weekly data in dengue period 2010-2012. The reason for breaking the climatic period into different segment i.e., from 1980-1994 pre dengue period and post dengue period 1995-2012 is because we have been informed that the case was reported in 1994 [Chan YC et al.(1994)] as first dengue case in Pakistan. The reason why we have considered the data of the period 2010-2012 is that dengue data is available for this period only.

We have applied Principal Component Analysis technique for all four periods i.e., 1980-2012, 1980-1994, and 1995-2012 for monthly data and 2010-2012 for monthly and weekly data to explore if there is any difference in the structure of climate in these time period. Sadiq.et al(2010) Jacquelynne et al. (1999), Benzl et al. (1997), Ehrendorfer (1987), Gibson et al. (1984), Molteni et al.(1983) and Jolliffe et al. (1972) have also applied Principal Component Analysis technique for the characterization of climatic variables.

Results and Discussion

The following table is the combine table constructed for the correlation between Karachi weekly and monthly Dengue fever and climatic variables for the dengue period 2010 to 2012.

Table 2: Correlation among weekly, daily and monthly DF and C.V (2010-2012).

Variable		DF	Precipatopn	Humidity	Max Temp	Min Temp	Wind Speed
DE	**W**	1	0.115	0.133	0.099	-0.043	0.143
	M	1	-0.02	-0.131	0.138	-0.043	-0.274
Precipitation	**W**	0.115	1	0.209**	0.051	0.155	0.061
	M	-0.027	1	0.551**	0.125	0.371*	-0.025
Humidity	**W**	0.133	0.209**	1	0.202*	0.034	0.534**
	M	-0.131	0.551**	1	0.681**	0.924**	0.597**
Max Temp	**W**	0.099	0.051	0.202*	1	0.559**	0.367**
	M	0.138	0.125	0.681**	1	0.891**	0.500**
Min Temp	**W**	-0.043	0.155	0.034	0.559**	1	0.557**
	M	-0.043	0.371*	0.924**	0.891**	1	0.656**
Wind Speed	**W**	-0.143	0.061	0.534**	0.367**	0.557**	1
	M	-0.274	-0.025	0.597**	0.500**	0.656**	1*

Note: W = weekly based data; M = Monthly based data
**: significance at α =0.01
*: significance at α =0.05

In this section we try to understand the Karachi environment by studying correlation between all pairs of variable.

Correlation coefficient are computed for weekly and monthly data and shown in Table 2. It can be seen in Table 2 that DF is not linearly correlated with any of environmental component. The highest correlation obtained between humidity and minimum temperature is 0.924. This means that for high average monthly minimum temperature, the environment of Karachi is becoming more humid. The structures of correlation are represented in Figure 3a and Figure 3b for weekly and monthly data. The path of correlation is shown by double $\Longleftrightarrow$ line arrows. This represents positive correlation.

Observing these two correlation structure, we find that these differences in correlation structure of weekly and monthly data it can also be seen in case of Karachi data the DF's ball is lying outside the main structure, this indicated that DF is not correlated with any of climatic variables.

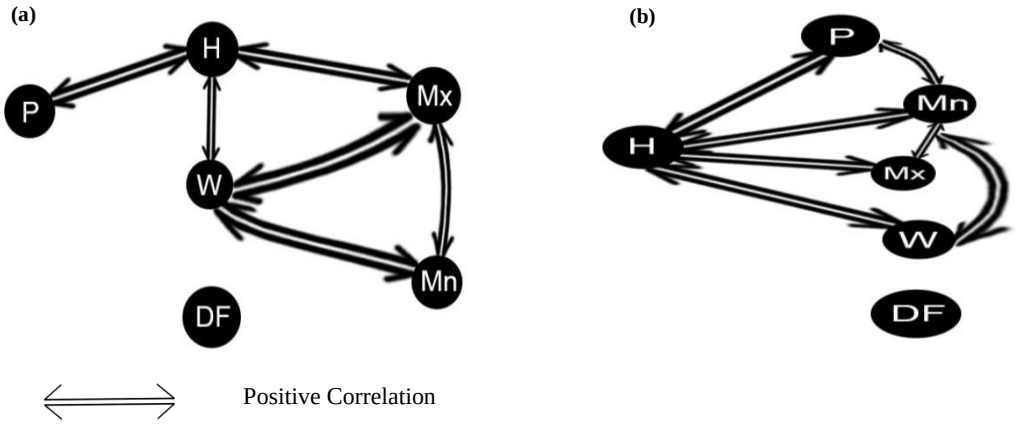

Figure 3: (a) Correlation structure of Weekly DF and climate variables
(b) Correlation structure of Monthly DF and climate variables.

PCA to Explore Climatic Structure of Karachi

For explanation and understanding purposes we present all four PCs for all considered period in Table 4a & Table 4b. Table 4a & Table 4b are summarized form of all tables mentioned in the above paragraph. These tables contains, in columns; the linear combination (PCs) in approximate and simplified form, percentage of variation explained by respective Principle components and abbreviation of labels of the PC.

Table 3: (a) PCA for three Different Periods of Karachi Monthly Climate (1980 – 2012).
(b) PCA for Monthly and weekly Climatic variables: (2010 – 2012).

PCs	1980 -2012			1980 – 1994			1995 -2012		
	Linear combination	Label	%	Linear combination	Label	%	Linear combination	Label	%
PC1	0.9H+0.8Mx+Mn+0.8W	GAC	62	0.9H+0.7Mx+Mn+.8W	GAC	61.6	0.9H+0.8Mx+Mn+0.8W	GAC	63.9
PC2	0.9P-0.3Mx	CTP	21	0.9P-0.5Mx	CTP	22.6	0.9P-0.3Mx	CTP	20.9
PC3	0.5(Mx-W)	CTW	11	0.5(Mx-W)	CTW	11	0.5Mx-0.4W	CTW	10.4
PC4	0.3(W-H)	CWH	5	0.2W-0.3H	CWH	3.9	0.3(W-H)	CWH	4.4

PCs	2010 -2012(Monthly Dengue Period			2010 -2012 (weekly Dengue Period)		
	Linear combination	Label	%	Linear combination	Label	%
PC1	0.9H+0.9Mx+Mn+0.7W	GAC	65.6	0.6H+0.7Mx+0.8Mn+0.8W	GAC	44
PC2	0.9P-0.5W	CPW	21.8	0.5P+0.7H-0.4Mx-0.4Mn	C[PH][T]	22
PC3	0.5W-0.5Mx	CWT	10	0.7P-0.4H+W	C[P][WH]	18
PC4	0.2P+0.1Mx-0.3	C[PT][H]	2.4	0.5Mx-0.4W	CTW	11

Where: GAC is General Atmospheric condition. CTP is Contrast between Temperature & Precipitation
CTW is Contrast between Temperature & Wind speed CWH is Contrast between Wind speed & RelativeHumidity.
CPW is Contrast between Precipitation & Wind speed. CWT is Contrast between Wind speed & Temperature.
C[PT][H] is Contrast between the combination of Precipitation and Temperature with Humidity.
C[PH][T] is Contrast between the combination of Precipitation & Humidity with Temperature.
C[P][WH] is Contrast between of Precipitation and the combination with Wind speed & Humidity.

According to the elbow rule, all plots show that two Factor model (PC) is sufficient to explain the variation in the data. But for the comments and interpretation we consider four PCs: as the percentage explained by 3rd and 4th PC in some case are quite large. The small variation in weather may affect the general atmospheric condition which can affect life. Table 4b is prepared for the monthly and weekly basis for the period 2010-2012.

The first four PCs for the period (1980-2012, 1980-1994, 1995-2012 and 2010-2012) are almost the same. The first three PCs of monthly data for Dengue occurrence period (2010-2012) are also similar to the first three PCs shown in Table 4a for non Dengue occurrence period, but for this period PC4 is different from other three.

The Table 3b of weekly dengue period data shows that percentage of variance of PC1 and PC2 are highly different from each other. They are around 44 % and 22 % which shows that there are only 66 % of total variation factor of Karachi climate is namely PC1 and PC2 variation in temperature with humidity and wind speed and contradiction of wetness and temperature.

The third component in the variation of Karachi climate is "reverse of variation of wetness and wind speed "which constitutes 18 % of variation. Whereas the fourth component is the contradiction of "temperature" and "wind speed "which is 11.2 % of variation. Explanation and interpretation of PCs one by one, for all data sets, shown in Table 3a & 3b.

PC1s are being constructed as the linear combination of Humidity, Maximum temperature, Minimum temperature and Wind speed. In other words it is the weighted average of these four climatic variables for all of periods 1980-2012, 1980-1994 and 1995-2012, and all the four variables are related to General Atmospheric Condition (GAC). For the reader to understand that how we have interpreted and labeled the PCs, let us take the example of first PC of the data of year 1980-2012. It is (PC1) weighted average;[PC1= 0.8(H+ Mx+ Mn+ W)] of the Humidity (H), Maximum temperature (Mx), Minimum temperature (Mn) and Wind speed (W). Thus it may interpret that major source of variation in the data occur is due to "General Atmospheric Condition". Then we label it or name it as General Atmospheric Condition GAC. This PC (GAC) contributes/explains (62 %) of total variation. The percentage (%) of variation of the PC1s in these 4 periods (1980-2012, 1980-1994, 1995-2012 and 2010-2012) monthly data varies from 62 to 65.6 % that are almost equal.

PC2 is constructed for the first three periods (1980-2012, 1980-1994, and 1995-2012), as a difference between precipitation (P) and maximum temperature where the contribution of precipitation is greater than the contribution of maximum temperature (Mx). This PC2 may be labeled as Contrast between precipitation and maximum temperature. PC2 for the Dengue period is different from the other three periods and it is contrast between precipitation and wind speed and the contribution of PC2s varies from 21 to 22.6 percentages. As second PC, this contribution may be considered as large contribution. Thus we may conclude that this factor play an important role in the formation of weather of city Karachi.

PC3 for all four periods (Monthly data) are same and constructed as the weighted difference between maximum temperature and wind speed, the percentage (%) of contribution varies from 10 to 11.4. This factor cannot be considered as insignificant, we may find this factor also shows an important contribution of variation in the Karachi atmosphere. But for the weekly based data the linear combination can be seen as difference between precipitation (P) and weighted mean of humidity and wind speed. This factor shows that during weeks of Dengue period the weather condition is different from non-Dengue period, and it contributed 18 % in the variation of Karachi climate.

PC4 for Dengue (Monthly) period is constructed as contrast of humidity against weighted average of precipitation and maximum temperature, which contributes only 2.4 of the total variation, PC4 of the non-Dengue periods is the weighted difference of wind speed and humidity which contributes 3.9 to 4.9 % which is almost twice of the PC4 of Dengue period. PC4 for the weekly data is the contrast between Mx and W and it explaining11.2 % of variation.

Principal component time series graphs

Figure 4a & 4d show the time series plot of PC1 to PC4 for weekly data of Dengue period, While Figure 5a to 5d show the time series plot of PC1 to PC4 for monthly data for the same period.

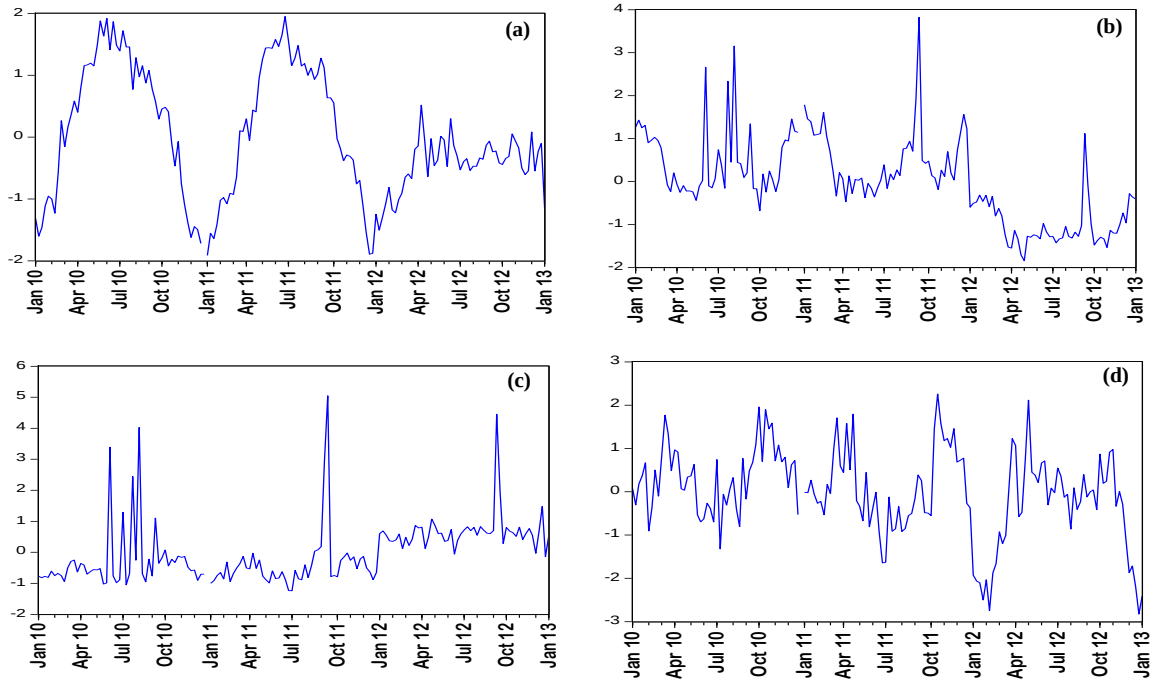

Figure 4: (a-d) Score plots for Karachi Weekly Climatic factors of Dengue period (201-2012) **(a)** PC1 General Atmospheric Condition (GAC) **(b)** PC 2 Contrast between the combination of Precipitation and Humidity with Temperature C [PH] [T] **(c)** PC3 Contrast between a Precipitation and Combination with Wind Speed & Humidity C [P] [WH]. **(d)** PC4 Contrast between Wind Speed & Precipitation [CWT].

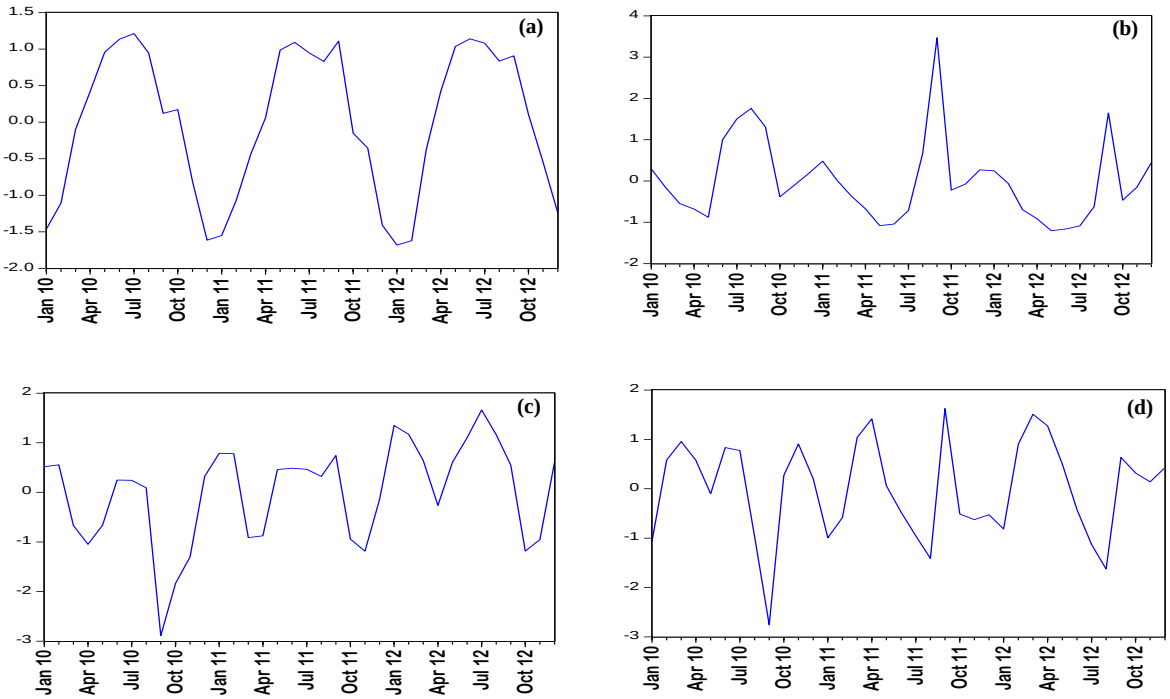

Figure 5:(a -d) Score plots for Karachi Monthly Climatic factors of Dengue period (2010-12) **(a)** PC1 General Atmospheric Condition (GAC) **(b)** PC2 Contrast between Precipitation & Wind Speed (cpw) **(c)** PC3 Contrast between Wind Speed & Temperature (cwt) **(d)** PC4 Contrast between the combination of Precipitation & Humidity with Temperature.

All the Time series plots reveal the seasonal trend in the weather factors. It is interesting to note that the pattern for all four corresponding pairs PCs (monthly and weekly data) showed the same. However the PC3 of monthly and weekly pair are opposite to each other, but this does not affect the interpretation of these PCs as in this case positive (+i ve.) and negative (– ve.) sign just show that direction of variation is opposite (contradictory) to each other. Negative sign does not mean negative effect as in case of regression models.

Viewing at time series plot of PC1 (Figure 4a) for weekly data we observed little difference in year 2012. The peak for years 2010 and 2012 are same but, for year 2012 the behavior of the variation is very different thus, we think that, the general atmospheric condition in 2012 was different from previous two years

Table 4 shows correlation between Climatic factors (PCs) and Dengue fever occurrence in Karachi for the monthly and weekly data for 2010-2012.

Table 4: Correlation between Karachi Weekly and Monthly Dengue and PCs (2010-2012).

Dengue Period / PCs	Monthly Dengue		Weekly Dengue	
PC1	-0.078	GAC	-0.058	GAC
PC2	0.045	CPW	0.053	C[PH][T]
PC3	-0.423*	CWT	-0.054	C[P][WH]
PC4	0.131	C[PT][H]	0.282**	CTW
N	36		157	

* Correlation is significant at the 0.05 level (2-tailed).
** Correlation is significant at the 0.01 level (2-tailed).

We may observe from the above table that PC3 of monthly and PC4 of the weekly data climate are significantly correlated with dengue occurrence. PC3 of monthly data which we have labeled as contradiction between precipitation and humidity with wind speed. This supports our earlier idea of considering four PCs for their interpretation and understanding weather's behavior in the previous section.

The correlation between PC3, for monthly data and DF occurrence is -0.423, this means that PC3 which represent the variation in contrast between Wind speed and Maximum temperature is causing to reduce the number of DF cases but if we consider weekly data, the correlation between PC4, for weekly data and DF occurrence is 0.282, this means that PC4 which represent as contrast between temperature and Wind speed is causing an increase the DF cases.

It is interesting to note that PC3 in monthly data is (W-Mx) and PC4 in weekly data is (Mx-W), in the first case correlation is negative while in the second case correlation is positive. The contradiction in the sign is due to computation condition, i.e. at the same time software gives positive sign to a variable while it give negative sign to the same variable. In our opinion PC3 of monthly data and PC4 of weekly data are same. That if weather is windy with low maximum temperature; chance of large number of DF case is low. But when the maximum temperature is high with low wind, the chance of large number of DF case is high.

Conclusion and Recommendations

Correlation coefficients computed for weekly and monthly data revealed that DF is not linearly correlated with any of environmental component. The highest correlation is between humidity and minimum temperature. This shows for high average monthly minimum temperature, the environment of Karachi

becomes more humid. From the correlation structure of weekly and monthly data we may see that the DF is not correlated with any of climatic variables.

PC1s in General Atmospheric Condition (GAC) revealed that major source of variation in the data is due to "General Atmospheric Condition". For the pre dengue period PC2 is Contrast between precipitation and maximum temperature whereas PC2 for the Dengue period is different from the other three periods and it is contrast between precipitation and wind speed and this factor play an important role in the formation of weather of city Karachi. PC3 is the weighted difference between maximum temperature and wind speed for all the periods. This factor cannot consider as insignificant.PC4 is contrast of humidity against weighted average of precipitation and maximum temperature for Dengue period whereas it is weighted difference of wind speed and humidity for non dengue period. In this study we may conclude that relative humidity and minimum temperature have some impact on the occurrence of dengue fever. If the minimum temperature recorded increases from previous day, the number of dengue cases is expected to increase in next days. It is suggested that surveillance teams should keep eyes on the changes in relative humidity and minimum temperature and if the minimum temperature for several take serious remedial measures. Since in months of August and September large number of dengue cases are expected so remedial measures should be taken in the months of June and July. The data we have is related to the number of dengue cases reported with respect to time, but we suggest further studies about the number of deaths due to dengue locality from where the patient are coming. Measure of awareness of the people are also needed to be studied. We also suggest some Bio-statistical studies of the patient and the cause of spread of diseases.

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