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# The Role of Climate on Malaria Incidence Rate in Four Governorates of Yemen

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**Summary**

The aim of study was to investigate the role of climate on the Malaria Incidence Rates (MIR) in some regions in Yemen. For such purpose, the monthly (MIR) were calculated from the records of the hospitals' laboratories and centers of the Malaria Rollback centers in the main cities of the governorates Hudeidah, Taiz, Sana'a and Hadramout for the period 1989-1998. The readings of the climatic factors (CF) particularly the average monthly temperature (T), relative humidity (RH), volume of rain fall (RF) and wind speed (WS) for the same period of time were also collected from different weather and climatic information resources. Descriptive statistics, simple linear regression and multiple linear regression techniques were used to analyse the relationship between MIR and CF. The analysis shows highly significant relationship between MIR and the CF in these regions of Yemen (p-value 0.001).

*Key Words:* Malaria, Malaria Incidence Rate, Climatic Factors, Linear Regression, Yemen

## Introduction

Every malarious area in the world has its own particular malaria ecology depending on its vector, parasites, vegetation, host population and a variety of other factors. By analysis of the relationship between past climatic changes and malaria, it is possible to begin to anticipate what effect future climatic changes might have on malaria in that region. In this study we assessed the level of correlation between the mean of temperature (T), rain fall (RF), relative humidity (RH), wind speed (WS) and malaria incidence rates in the governorates Hudeidah, Taiz, Sana'a and Hadramout from 1989-1998.

Malaria, particularly falciparum malaria, is considered as one of the major causes of morbidity and mortality throughout many regions of the world where around 40% of the entire world's population are susceptible in over 90 countries[1,2]. The malaria new infections was estimated to be 300 million cases with over 1 million deaths annually[3]. Further, WHO is expecting malaria to be one of the most sensitive vector-borne diseases to long term environmental change[3].

Locally, Al-Mawery (1999) has found that malaria is a common disease in Yemen and distributed differently from area to another due to the topography of areas and the dominant temperature in the different seasons of the year[4]. In Hudeidah (1995), a study was conducted to investigate the effect of seasonality on the incidence of malaria. It was found that malaria is more active during the winter than the summer[5]. In another study, it was found also that while malaria is active in the winter in Tehama (Hudeidah), it is active in the summer at the high mountains (Sana'a)[6].

At the Public Health Laboratory in Sana'a, a study was performed during the period 1994-1995 and found that MIR among the referred cases were slightly higher during the months of January-April (1994) and also during March-April (1995). The lowest incidence rates were in October-December 1994 and August-October

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1995[7]. In 1997, a study was conducted at Socotra Island and found that the percentages of MIR were 26.96% and 17.18% during the cold and hot seasons respectively. In this regard, the best suitable conditions for malaria in this island is the cold season where temperature is normally ranging between 18-28°C. The highest and lowest incidence rates were 27.5% on January and 15% on June and the incidence distribution is taking a U shape throughout the year[8].

In his investigation, Al-Dowbahi 1998 had concluded that around 60% of the entire population of Yemen are susceptible to malaria throughout the year and 15% are susceptible seasonally. Further, only 25% of the entire population are living in disease free areas and between 1.5-2 millions new cases of malaria annually[9]. Internationally, specifically in North Africa, it was found that the areas most susceptible to malaria were those located close to or under the sea level. Additionally, the areas that are climatically unstable are also susceptible to the disease[10].

Martens et al (1995), argued that climatic changes in T, RF, and RH are expected to influence malaria directly. These factors affect the behavior and geographical distribution of malaria vectors and thus can change the length of the life cycle of the parasite[11].

The relationship between climate changes and malaria was noticed in many studies[12,13,14,15]. However, a study in the highlands of Kenya claimed that climate was not a factor in malaria transmission there because the average T and RF did not change during the time that malaria rates changes[16]. Further, although an epidemic in Ethiopia was attributed to higher T's, RF and RH, it was also noted that while no malaria is widen with excess RE in 1993, there was high malaria incidence in 1984-5 with very little RF[17]. Another study mentioned that along with the climatic changes, there are many other variables that affect malaria transmission such as environmental modification, population growth, limited access to the health care systems and lack of or unsuccessful malaria control measures[18].

About the effect of T on the life cycle of mosquitoes, it was found that the time required for its development decreases as T increases from 21°C to 27°C[19]. The minimum T for mosquito development is between 8-10°C, the minimum T for parasite development is between 14-19°C, the optimum T for mosquitoes development is 25-27°C and the maximum T for both vectors and parasites to still able to develop is 40°C[20].

It is believed that less than 60% average monthly RH would shorten the mosquitoes life and no malaria transmission would occur[21]. Winds produces a positive and negative effect on malaria. The positive effect is that winds would decrease the biting rates of mosquitoes. Conversely, the negative effect of strong winds would extend the flight distance of the mosquito to reach farther points[22].

Loevinsohn 1994 had studied the relationship between the monthly MIR and some CF particularly the monthly average of temperature (maximum and minimum) and rain fall[14]. He arrived at a conclusion that the monthly MIR can be estimated by the following multiple regression equation:

$$LnI_m = -4.32 + 1.64LnT_{m-1} + 0.83LnT_{m-2} + 5.34 \times 10^{-4} R_{m-2} + 7.7 \times 10^{-4} R_{m-3}$$

Where:

$m$ : is the number of observations in months;

$LnI_m$ : Logarithm of the monthly MIR;

$Ln\ T_{m-1}$: Logarithm of the minimum average temperature of a month before;

$Ln\ T_{m-2}$: Logarithm of the minimum average temperature of two months before;

$R_{m-2}$ : Volume of the average rain fall of two months before;

$R_{m-3}$ : Volume of the average rain fall of three months before.

With p-value $< \mathbf{0.001}$ and $R^2 = 0.794$

This equation is indicating a strong positive relationship between the MIR and both temperature and volume of rain fall. It also indicates that while the effect of temperature on malaria is starting after 1-2 months, the effect of rain fall is starting after 2-3 months. Further, the minimum temperature rather than the maximum is the important indicator of malaria incidence.

The aim of the present investigation is to apply Loevinsohn's approach and including more CF specifically relative humidity and wind speed to estimate MIR of some regions in Yemen.

## Materials and Methods

This is a retrospective study based on data collected during the period 1989-1998 for the governorates Hudeidah, Taiz, Sana'a and Hadramout. The collected data were on MIR, T, RH, RF and WS. The MIR data were collected from the hospitals, Malaria Rollback Centers at the main cities of these governorates and also from the Headquarters of Malaria Rollback Project in Sana'a. MIR's were calculated according to the formula:

$$MIR = \frac{Total\ for\ Malaria\ Positive\ Cases}{Total\ Number\ of\ Cases\ Tested\ for\ Malaria}$$

The CF data were collected from Sana'a Airport, The General Authority of Civil Aviation, The General Authority of Water Resources, Taiz Airport, Al-Rayan Airport, Hudeidah Airport and Tehama Development Authority.

The study is limited to these governorates for two reasons; the availability of data and the location of these governorates. Topographically, Yemen is classified into five regions:

a. The Coastal Strip Region and is represented here by Hudeidah from west and Hadramout from the south.
b. The Western Mountainous Region and is represented here by Sana'a.
c. The Middle Low Region and is represented here by Taiz.
d. The Desert Region.
e. The Yemeni Islands.

So, excluding the Desert Region and the Yemeni Islands where no data are available yet, the data sample has covered the most important geographical regions in Yemen[23,24]. It is of importance to note that the data of 1994 were missing due to the Yemeni internal civil war. Hence, the data were for 9 years and since the mean monthly values of the CF were utilized, the total number of observations were 9x12 =108 values for each variable.

**Regression and Correlation Analysis Outline**

Regression and correlation analysis are statistical methods developed to study the relationships between and among variables. The aim of regression analysis is to use one or more independent variables to predict or to estimate the value of a dependent variable. For such purpose, a mathematical equation (model) should be developed. In contrast, for the correlation analysis our concern is not of developing a mathematical model but determining the extent to which two or more variables are related[25].

To study the relationship between one independent variable and one dependent variable a simple linear regression model of the following form (referred as model (1)) is usually used:

$$Y_i = \beta_o + \beta_1 = X_i + \varepsilon_i,\ i = 1,2,3,\ldots,\ n \qquad (1)$$

*where* $\beta_0$ and $\beta_1$ are the regression coefficients to be estimated and $\varepsilon_i$ is the error term which supposedly to be normally distributed with mean ($E(\varepsilon_i)$=0), variance ($V(\varepsilon_i)=\sigma^2$) and covariance ($Cov(\varepsilon_i,\varepsilon_j)$=0). Regression analysis involving two or more independent variables is called multiple regression analysis and it has the following mathematical format (referred as model (2)):

$$Y_i = \beta_0 + \beta_1 X_{i1} + \beta_2 X_{i2} + \ldots + \beta_{p-1} X_{i,p-1} + \varepsilon_i$$

Or more concisely

$$Y_i = \beta_0 + \sum_{k=1}^{p-1} \beta_k X_{ik} + \varepsilon_i, \qquad (2)$$

Several methods are available to estimate the regression coefficients. However, the most reliable estimates are those generated by the well known method of Least Squares[26]. Applying this method would make models (1,2) above to be rewritten as:

$$\hat{Y}_i = \hat{\beta}_0 + \hat{\beta}_1 X_i + e_i$$

$$\hat{Y}_i = \hat{\beta}_0 + \sum_{k=1}^{p-1} \hat{\beta}_k X_{ik} + e_i,$$

Where $\hat{Y}_i$ are the estimated values of the dependent variable $Y_i$, and $\beta_0$, $\beta_1$ and $\beta_k$ are the estimated regression coefficients and $e_i$ are the estimated values of the error term. It is usually useful to have a measure of the extent to which two variables are related to each other. For such reason, statisticians have developed what is called the Pearson correlation coefficient or simply the correlation coefficient[27]. Mathematically, this measure has the following format:

$$r_{xy} = \frac{\sum (X_i - \overline{X})(Y_i - \overline{Y})}{\sqrt{\sum (X_i - \overline{X})^2 \sum (Y_i - \overline{Y})^2}}$$

Where $r$ falls within the range to such that the closer $r$ to -1 or +1 the stronger the relationship between the two variables and $\overline{Y}$, $\overline{X}$ are the sample means of $X$ and $Y$. Squaring the correlation coefficient gives the variation proportion of one variable that explained by the other. This new value denoted by $R^2$ is usually called the multiple correlation coefficient or determination coefficient[26,28]. It has the following mathematical format:

$$R^2 = \frac{\sum (\hat{Y}_i - \bar{Y})^2}{\sum (Y_i - \bar{Y})^2}$$

So, in simple linear regression it is clear that $R = r$. It can be seen that $R^2$ is more general form than $r$ to study the relationships among variables since it can be used for both simple and multiple regression analysis. It is also clear that $R^2$ values falls only within $0 \leq R^2 \leq 1$. (For more details about regression analysis, the reader may refer to many advanced statistical references among them Draper and Smith 1981, Neter, Wasserman and Kutner 1985, Wonnacott and Wonnacott 1981[26,29,30]). For the present investigation MIR is the dependent variable and each factor of CF is an independent variable.

## Results and Discussion

Table I shows a summary of the mean and standard deviation (SD) of the mean values of T, RH, RF and WS for the period 1989-1998 of the four governorates. Through the table, it can be seen that the range of T in Hudeidah is 25.2°-33.04°C, in Taiz is 18.41°-25.28°C, in Sana'a is 14.3°-22.4°C and in Hadramout is 23.3°-30.14°C. For RH the range in Hudeidah is 62.1%-70.7%, in Taiz is 63.8%-68.5%, in Sana'a is 34.6%-54.1% and in Hadramout is 65.52%-75.56%. These results indicate that, both T and RH are within the suitable range for the development of mosquitoes in all governorates.

Statistically, and to exclude any possibility of collinearity or multicollinearity among the independent variables (CF) it is usually plausible to study the correlations among them[22]. Accordingly, Table II describes the correlation matrix of these variables. Generally, it is clear that the correlation coefficients are weak and so no collinearity or multicollinearity could be detected.

As mentioned early, Loevinsohn 1994 has estimated the MIR from two climatic factors namely, T and RF by developing a linear multiple regression equation[14]. Here, we had applied the same approach but in two stages. Firstly, by studying the effect of each factor separately (model 1) and secondly by studying the effect of all factors (model 2) in estimating MIR. For the first stage, Table III presents the simple regression analysis between MIR and each climatic factor in each governorate separately. From this table, several points can be drawn. Firstly, the CF data were for a month before. Secondly, there is a strong negative relationship between MIR and T in both Hudeidah and Taiz and weak positive relationship in Sana'a and Hadramout. An explanation for this is that due to the high altitude of Sana'a, T is usually low and so it gives unsuitable conditions for the malaria parasites to grow and reversely for Hadramout where T is high which also provides unsuitable conditions (refer to Table I). Thirdly, RH correlates negatively and weakly with MIR in Hudeidah, strongly and inversely in Sana'a and strongly and positively in Taiz and Hadramout. An explanation for Hudeidah, is that humidity is due to the sea and not from the rain fall aquatic pots. Fourthly, RF correlates with MIR significantly and inversely in Taiz and weakly inversely on the other governorates. This result could be due to the long drought that hit and still hitting these givernorates for years. Finally, WS correlates with MIR significantly and inversely in both Hudeidah and Taiz. It is also correlates significantly and positively in Sana'a and Hadramout. This result cast the need for further research about the mechanism how WS is affecting MIR.

We may conclude here that WS followed by RH are the two factors mostly affecting MIR levels in these regions.

Naturally and tentatively, the effects of the CF are interchangeable, so separating the effect of each factor on the MIR seems doubtful. Therefore, the second stage of the present analysis is to study the effect of all these factors together on estimating MIR. Table IV is summarizing the multiple regression anlaysis for each governorate. From Table IV, it can be noticed that all the regression relationships between MIR and CF are highly significant. The relationship is negative between MIR and T in all governorates and inverse relationship between MIR and all CF in Hudeidah. MIR is increasing with RH in Taiz but decreasing with the other factors. MIR is increasing with both RF and WS in Sana'a and decreasing with the other factors. MIR is increasing with RH and WS in Hadramout but decreasing with the other factors.

In a sense, these results seem positive as it ensures that MIR levels are behaving differently according to the climatic characteristics of each region. It also indicates that separating the effect of each climatic factor on MIR is no longer suitable.

It is of importance to indicate here that during the analysis several regression models such as the logarithmic, exponential, inverse, polynomial, ...etc were applied. Also, data for two months and three months before were used and tested for the CF. However, the best results were those obtained by the multiple linear regression and from the data of one month before. For brevity the details are ignored.

The regression models results on Table IV were found to satisfy the most desirable conditions of linear regression. In essence, the residuals were found to be normally distributed and have constant variance. Further, since the data were chronically collected (over time), Durbin-Watson Test was used and found that no serial correlation obtained among the residuals[26,27,29].

In addition, the analysis of variance (ANOVA) enforces the robustness the previous regression models Table V.

Finally, when the MIR values were drawn against time (1989-1998) in each governorate it was found that there are specific months where the highest and lowest malaria incidence occur Table VI. In addition, an increasing trend in MIR was noticed over the years 1989-1998.

## Conclusions and Recommendations

This study has afforded the following conclusions:

- The MIR levels are strongly affected by CF (T, RF, RH and WS) at the governorates of Hudeidah, Taiz, Sana'a and Hadramout.
- The effect of each climatic factor on the MIR levels is different from one governorate to another.
- The maximum effect of the CF on MIR occurs a month after its occurrence in these governorates.
- The effect of each climatic factor is less accurate than the effect of all CF in estimating MIR. This result provide an evidence that each climatic factor is affecting the other interchangeably and separating the effect of each one on MIR is unindicative.
- The multiple linear regression models are very useful tools for studying the relationship between CF and MIR.
- The outcomes of this study should be taken into consideration for future related studies in these areas.

**Table I: Mean and standard deviation (SD) of the mean values of T, RH, RF and WS of Hudeidah, Taiz, Sana'a and Hadramout for the period 1989-1998**

| Months | Governorate | WS | | RF | | RH | | T | |
|---|---|---|---|---|---|---|---|---|---|
| | | SD | Mean | SD | Mean | SD | Mean | SD | Mean |
| Jan. | Hudeidah | 3.41 | 4.0 | 5.96 | 2.3 | 5.09 | 69.7 | 1.16 | 26.09 |
| | Taiz | 0.77 | 6.01 | 18.73 | 12.5 | 3.57 | 68.5 | 1.09 | 18.41 |
| | Sana'a | 0.91 | 3.7 | 2.81 | 1.7 | 3.68 | 47.9 | 1.15 | 14.3 |
| | Hadramout | .85 | 5.87 | 4.56 | 2.53 | 6.72 | 66.64 | .90 | 24.54 |
| Feb. | Hudeidah | 3.04 | 4.0 | 21.71 | 12.4 | 4.68 | 70.7 | 1.91 | 25.2 |
| | Taiz | 0.94 | 5.9 | 32.78 | 30.7 | 4.12 | 67.3 | 1.26 | 18.63 |
| | Sana'a | 1.45 | 4.2 | 1.22 | 0.6 | 6.09 | 49.8 | 1.31 | 15.2 |
| | Hadramout | .94 | 6.00 | 4.41 | 5.46 | 7.22 | 67.6 | .44 | 23.30 |
| Mar. | Hudeidah | 3.44 | 4.3 | 6.97 | 7.5 | 5.20 | 70.4 | 1.97 | 26.7 |
| | Taiz | 1.49 | 6.2 | 25.53 | 22.9 | 3.37 | 67.8 | 1.38 | 19.64 |
| | Sana'a | 0.88 | 3.9 | 22.32 | 13.2 | 5.10 | 50.2 | 1.09 | 16.6 |
| | Hadramout | 1.09 | 5.63 | 5.92 | 6.41 | 4.08 | 70.20 | .80 | 25.02 |
| Apr. | Hudeidah | 3.44 | 4.3 | 6.97 | 7.5 | 5.20 | 70.4 | 1.97 | 27.9 |
| | Taiz | 1.77 | 6.5 | 15.94 | 14.8 | 2.69 | 67.3 | 1.72 | 21.67 |
| | Sana'a | 0.99 | 3.7 | 21.01 | 19.1 | 7.70 | 54.1 | .68 | 18.4 |
| | Hadramout | 1.08 | 5.80 | 3.17 | 1.95 | 3.34 | 73.21 | .65 | 26.30 |
| May | Hudeidah | 2.99 | 3.9 | 18.69 | 19.3 | 6.06 | 65.4 | 3.13 | 29.9 |
| | Taiz | 1.20 | 5.8 | 23.73 | 20.4 | 4.08 | 65.9 | 1.94 | 22.96 |
| | Sana'a | 1.13 | 4.8 | 16.01 | 26.7 | 7.87 | 44.5 | 1.87 | 19.4 |
| | Hadramout | .93 | 5.92 | 8.07 | 5.02 | 4.84 | 73.67 | 1.17 | 27.39 |

| Months | Governorate | WS | | RF | | RH | | T | |
|---|---|---|---|---|---|---|---|---|---|
| | | SD | Mean | SD | Mean | SD | Mean | SD | Mean |
| June | Hudeidah | 2.90 | 4.6 | 27.32 | 30.9 | 7.31 | 62.9 | 1.16 | 32.5 |
| | Taiz | 0.74 | 5.7 | 28.71 | 31.3 | 5.76 | 65.2 | 1.68 | 23.92 |
| | Sana'a | 0.88 | 5.2 | 20.22 | 14.6 | 7.32 | 40.2 | 1.03 | 21.3 |
| | Hadramout | .68 | 6.41 | 5.91 | 3.47 | 4.07 | 74.89 | 1.65 | 29.19 |
| July | Hudeidah | 3.63 | 4.9 | 19.47 | 24.2 | 5.76 | 64.8 | 2.21 | 32.1 |
| | Taiz | 1.69 | 6.3 | 29.27 | 28.6 | 5.32 | 64.0 | 1.17 | 25.28 |
| | Sana'a | 0.78 | 5.7 | 23.68 | 20.9 | 5.88 | 40.03 | 1.17 | 22.4 |
| | Hadramout | .95 | 6.75 | 1.55 | 1.08 | 2.69 | 75.56 | .98 | 29.81 |
| Aug. | Hudeidah | 2.72 | 4.8 | 24.93 | 24.8 | 3.18 | 62.1 | 0.56 | 33.04 |
| | Taiz | 1.77 | 6.1 | 32.61 | 24.2 | 4.64 | 65.4 | 1.68 | 24.4 |
| | Sana'a | 0.70 | 5.16 | 31.45 | 23.9 | 6.70 | 42.4 | 1.10 | 22.4 |
| | Hadramout | 1.21 | 6.74 | .29 | .16 | 5.62 | 73.89 | 1.61 | 29.78 |
| Sept. | Hudeidah | 2.87 | 3.1 | 28.40 | 35.7 | 2.05 | 64.8 | 0.72 | 32.5 |
| | Taiz | 0.99 | 5.5 | 30.52 | 29.4 | 4.23 | 67.5 | 2.19 | 23.36 |
| | Sana'a | 0.75 | 5.2 | 10.11 | 11.0 | 5.61 | 36.2 | 1.59 | 20.4 |
| | Hadramout | .80 | 6.24 | 4.49 | 2.43 | 4.73 | 72.22 | 1.98 | 30.14 |
| Oct. | Hudeidah | 3.73 | 3.9 | 26.85 | 39.2 | 1.63 | 66.2 | 3.22 | 30.2 |
| | Taiz | 1.08 | 6.1 | 12.92 | 7.4 | 3.81 | 66.3 | 2.12 | 21.81 |
| | Sana'a | 0.76 | 4.0 | 15.11 | 10.2 | 4.54 | 34.6 | 2.15 | 17.5 |
| | Hadramout | .94 | 6.14 | 5.51 | 3.54 | 5.29 | 71.02 | 2.11 | 27.54 |
| Nov. | Hudeidah | 3.88 | 3.7 | 29.32 | 26.0 | 3.78 | 66.4 | 1.84 | 29.1 |
| | Taiz | 1.19 | 5.5 | 0.97 | 0.5 | 5.25 | 63.8 | 1.53 | 20.10 |
| | Sana'a | 0.32 | 2.9 | 5.95 | 2.2 | 7.12 | 40.4 | 2.09 | 15.9 |
| | Hadramout | 1.22 | 5.86 | 1.69 | .93 | 4.26 | 68.06 | 1.54 | 27.00 |
| Dec. | Hudeidah | 4.27 | 3.8 | 16.63 | 7.8 | 5.29 | 66.7 | 2.08 | 26.8 |
| | Taiz | 1.37 | 5.1 | 1.43 | 0.7 | 5.46 | 66.1 | 1.47 | 18.66 |
| | Sana'a | 0.37 | 2.6 | 0.00 | 0.00 | 7.76 | 46.7 | 1.50 | 14.7 |
| | Hadramout | 1.18 | 5.84 | 1.04 | .46 | 4.10 | 65.52 | 1.39 | 25.48 |

WS: Wind Speed, RF: Rain Fall, RH: Relative Humidity, T: Temperature

**Table II: The correlations among T, RH, RF and WS in each governorate**

| WS | RF | RH | T | Governorate | Variables |
|---|---|---|---|---|---|
| 0.14 | 0.33 | 0.27 | 1 | Hudeidah | T |
| 0.15 | 0.35 | 0.27 | 1 | Taiz | |
| 0.30 | 0.19 | 0.25 | 1 | Sana'a | |
| 0.15 | 0.13 | 0.29 | 1 | Hadramout | |
| 0.03 | 0.16 | 1 | | Hudeidah | RH |
| 0.13 | 0.01 | 1 | | Taiz | |
| 0.16 | 0.18 | 1 | | Sana'a | |
| 0.09 | 0.25 | 1 | | Hadramout | |
| 0.27 | 1 | | | Hudeidah | RF |
| 0.11 | 1 | | | Taiz | |
| 0.10 | 1 | | | Sana'a | |
| 0.02 | 1 | | | Hadramout | |
| 1 | | | | Hudeidah | WS |
| 1 | | | | Taiz | |
| 1 | | | | Sana'a | |
| 1 | | | | Hadramout | |

WS: Wind Speed, RF: Rain Fall, RH: Relative Humidity, T: Temperature

**Table III: The regression relationships between MIR and T, RH, RF and WS separately in each governorate**

| Governorates | The Regression equations | $R^2$ | $r$ | $P-value$ |
|---|---|---|---|---|
| Hudeidah | $\hat{MIR}_i = 0.996 - 2.5\times10^{-2}T_{i-1}$ | 0.323 | 0.568 | 0.000 |
| Taiz | $\hat{MIR}_i = 0.537 - 1.71\times10^{-2}T_{i-1}$ | 0.259 | 0.509 | 0.000 |
| Sana'a | $\hat{MIR}_i = 5.063 + 3.13\times10^{-3}T_{i-1}$ | 0.023 | 0.153 | 0.114 |
| Hadramout | $\hat{MIR}_i = 0.129 + 1.15\times10^{-3}T_{i-1}$ | 0.001 | 0.030 | 0.760 |
| Hudeidah | $\hat{MIR}_i = 0.379 - 1.97\times10^{-3}RH_{i-1}$ | 0.005 | 0.068 | 0.487 |
| Taiz | $\hat{MIR}_i = -0.65 + 1.24\times10^{-2}RH_{i-1}$ | 0.343 | 0.586 | 0.000 |
| Sana'a | $\hat{MIR}_i = 0.34 - 5.1\times10^{-3}RH_{i-1}$ | 0.471 | 0.686 | 0.000 |
| Hadramout | $\hat{MIR}_i = -0.258 + 5.89\times10^{-3}RH_{i-1}$ | 0.127 | 0.336 | 0.000 |
| Hudeidah | $\hat{MIR}_i = 0.28 - 1.11\times10^{-3}RF_{i-1}$ | 0.036 | 0.189 | 0.030 |
| Taiz | $\hat{MIR}_i = 0.211 - 2.24\times10^{-3}RF_{i-1}$ | 0.363 | 0.602 | 0.000 |
| Sana'a | $\hat{MIR}_i = 0.108 - 1.07\times10^{-5}RF_{i-1}$ | 0.002 | 0.003 | 0.975 |
| Hadramout | $\hat{MIR}_i = 0.168 - 2.92\times10^{-3}RF_{i-1}$ | 0.024 | 0.154 | 0.112 |
| Hudeidah | $\hat{MIR}_i = 0.355 - 2.3\times10^{-2}WS_{i-1}$ | 0.266 | 0.516 | 0.000 |
| Taiz | $\hat{MIR}_i = 0.339 - 2.89\times10^{-2}WS_{i-1}$ | 0.156 | 0.395 | 0.000 |
| Sana'a | $\hat{MIR}_i = -9.82\times10^{-3} + 2.76\times10^{-2}WS_{i-1}$ | 0.283 | 0.532 | 0.000 |
| Hadramout | $\hat{MIR}_i = -0.152 + 5.122\times10^{-2}WS_{i-1}$ | 0.304 | 0.552 | 0.000 |

WS: Wind Speed, RF: Rain Fall, RH: Relative Humidity, T: Temperature

**Table IV: The multiple regression relationships between MIR and T, RH, RF and WS in each governorate**

| Governorate | The Regression Equations | $R^2$ | $P-value$ |
|---|---|---|---|
| Hudeidah | $\hat{MIR}_i = 1.478 - 3.02\times10^{-2}T_{i-1} - 6.96\times10^{-3}RH_{i-1} - 9.99\times10^{-4}RF_{i-1} - 2.91\times10^{-2}WS_{i-1}$ | 0.771 | 0.000 |
| Taiz | $\hat{MIR}_i = -0.316 - 4.87\times10^{-3}T_{i-1} + 1.107\times10^{-2}RH_{i-1} - 1.97\times10^{-3}RF_{i-1} - 1.82\times10^{-2}WS_{i-1}$ | 0.799 | 0.000 |
| Sana'a | $\hat{MIR}_i = 0.35 - 7.96\times10^{-3}T_{i-1} - 5.08\times10^{-3}RH_{i-1} + 7.23\times10^{-4}RF_{i-1} + 2.75\times10^{-2}WS_{i-1}$ | 0.673 | 0.000 |
| Hadramout | $\hat{MIR}_i = -0.39 - 8.6\times10^{-3}T_{i-1} + 7.18\times10^{-3}RH_{i-1} - 3.25\times10^{-3}RF_{i-1} + 4.7\times10^{-2}WS_{i-1}$ | 0.453 | 0.000 |

WS: Wind Speed, RF: Rain Fall, RH: Relative Humidity, T: Temperature

**Table V: ANOVA Table**

| Source | Governorate | Sum of Squares | Degrees of Freedom | Mean of Squares | $F-value$ | $P-value$ |
|---|---|---|---|---|---|---|
| Regression | Hudeidah | 1.741 | 4 | 0.435 | 86.694 | 0.000 |
| | Taiz | 0.757 | 4 | 0.189 | 101.795 | 0.000 |
| | Sana'a | 0.300 | 4 | $7.504 \times 10^{-2}$ | 53.036 | 0.000 |
| | Hadramout | 0.430 | 4 | 0.107 | 21.364 | 0.000 |
| Residuals | Hudeidah | 0.157 | 103 | $5.02 \times 10^{-3}$ | | |
| | Taiz | 0.191 | 103 | $1.859 \times 10^{-3}$ | | |
| | Sana'a | 0.146 | 103 | $1.415 \times 10^{-3}$ | | |
| | Hadramout | 0.518 | 103 | $5.029 \times 10^{-3}$ | | |
| Total | Hudeidah | 2.258 | 107 | | | |
| | Taiz | 0.948 | 107 | | | |
| | Sana'a | 0.446 | 107 | | | |
| | Hadramout | 0.948 | 107 | | | |

**Table VI: The MIR months at the Governorates**

| Governorates | Highest MIR | Lowest MIR |
|---|---|---|
| Hudeidah | February | August |
| Taiz | December | July |
| Sana'a | October | January |
| Hadramout | July | January |

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