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CORRELATING ANNUAL MEAN RELATIVE HUMIDITY OVER SUDAN AND SOUTH SUDAN TO LATITUDES, LONGITUDES AND ALTITUDES

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Abstract

Annual mean relative humidity percentage for Sudan and South Sudan for the period 1961-1990 was obtained as normal data for 41 stations, and analyzed for correlations between relative humidity percentage on the one hand and latitudes, longitudes and elevations on the other hand. For the 41 stations, relative humidity decreased on average with increase in latitudes at a rate of about 0.93 % per degree showing a significant linear correlation (P= 0.05). With exclusion of 5 South Sudan stations, analysis for the 36 stations showed no significance of correlation between relative humidity % and latitudes. When 5 Red Sea coastal stations were removed, the relative humidity % dropped with latitude for the 31 stations at a rate of about 1.9%. Analysis for the effects of longitudes using the 41 stations showed very week, but significant correlation, (P=0.08). Longitudes showed a higher correlation and significance for the 36 stations, (P =0.002). In both cases the relative humidity increased with longitudes east ward. Altitudes on the other hand showed stronger linkage with annual relative humidity compared to longitudes and the correlations were all significant, where the relative humidity decreased for the 41 and the 36 stations at a rate of about 0.02% per meter above sea level while increased mildly for the 31 stations at a rate of about 0.01% per meter above sea level. The effects of the combination of both latitudes and longitudes and also latitudes and altitudes on annual relative humidity showed even stronger correlations, higher significances and lower standard errors compared to the single parameters while the combination for longitudes and altitudes gave lower significances and higher standard errors. On the average the highest correlations the lowest standard errors and the highest significances were obtained for the three parameters together. Over all, four equations were recommended for prediction of the mean annual relative humidity% in areas where no measurements are available.

Key Words: *Correlation, Latitude, Longitude, Relative humidity, Sudan*

Introduction

The importance of water vapor in the air is well documented in the literature, (Du *et al*, 2012; Laing and Evans, 2011); that it condenses to form precipitation, that it absorbs radiation and contributes to the energy balance of the earth, that it affects the rates of evaporation, transpiration and the life of plants and animals in many ways. An important measure of water vapor in the atmosphere is the relative humidity which is defined as the amount of water vapor present in air expressed as a percentage of the amount needed for saturation at the same temperature. Although Sudan rainfall and thermal environments received considerable attention from numerous researchers, (Ireland, 1948; Hulme, 1990; Mohamed, 2013), little attention was given to variations of relative humidity in time and space in such a large area. The wide range of variation of relative humidity over the concerned area (Ireland, 1948; GasmElseed,1968) and the dependence of the population on irrigated agriculture, (ElNadi,2006) in addition to the correct estimation of crop water requirements,(Allen *etal,*1998) require both, the knowledge about the variation of humidity over the area, and also an easy estimation of relative humidity. The objective of this study is to investigate statistically if there are correlations between mean annual percentage relative humidity of the stations shown in table1 on the one hand and latitudes, longitudes and altitudes on the other hand and to develop simple equations for prediction of percentage relative humidity in areas where no measurements are available.

Methodology

The study area included Sudan and South Sudan (SS) represented by 41 stations scattered along and across the country. Sudan, together with South Sudan represent a large area that extends approximately between latitudes 3 and 23 degrees north and longitudes 21.5 and 38.5 east, (Gasm ElSeed,1968). The topography of the area includes mainly vast plains that stretch from the desert in the north to the equatorial borders in the south. The high lands were restricted to the mountains of the Red Sea coast in the east, Marra Mountain in the west and Nuba Mountains. The terrain, therefore, is mostly flat. The area comprises various climatic zones, extending from the hyper-arid zone in the far north, through the arid, semi arid and sub-humid zones towards the central part of the area, to the humid zone in the far south, (Mohamed, 2010).The annual rainfall ranges almost from virtually nil in the far north to more than 1500 mm/annum in the extreme south. The population is engaged mainly in agricultural production which is rain fed or irrigated depending on the amount of annual rainfall. Irrigated agriculture is practiced in central and northern Sudan, while rain fed agriculture is dominant in the sub humid and humid areas. The economy in the area depends mainly on agricultural production and on live stock raising. The 41 stations were distributed as eight stations in northern Sudan, north of Khartoum, ten stations in central Sudan, nine in each of the western and eastern regions and 5 in South Sudan. The stations were attached to geographical areas as 41 for Sudan and SS, 36 for Sudan, and 31 for Sudan with no Red Sea (RS) stations.Table1 shows the stations and their coordinates and elevations.

Mean monthly and annual relative humidity data (%) were obtained for Sudan and SS as normal values for the period 1961-1990 for the 41 meteorological stations from various sources including Sudan Meteorological Authority (SMA).The data was analyzed using excel statistical package to investigate if there are linkages between the magnitude of the mean annual percentage relative humidity on the one hand, and latitudes, longitudes, altitudes and their combinations on the other hand using regression to determine the correlation coefficient (R), the exact level of significance(P) and the standard errors(SE) while analysis of variance (ANOVA) was used to investigate variations between stations and between months.

Table 1: The latitudes, longitudes and altitudes of the 41 stations

Station	Latitude	longitude	Altitude	Station	Latitude	Longitude	Altitude
Wadi halfa	21.82	31.35	190	Portsudan	19.58	37.22	002
No.6	20.75	32.55	470	Toker	18.43	37.73	020
Abu hamad	19.53	33.33	315	Aqiq	18.23	38.18	002
Dongola	19.17	30.48	228	Kassala	15.47	36.40	500
Karima	18.55	31.85	249	Aroma	15.85	36.15	431
Atbara	17.70	33.97	345	Halfaelga.	15.32	35.60	451
Hudeiba	17.57	33.93	350	Showak	14.40	35.85	510
Shendi	16.70	33.43	360	Elfasher	13.63	25.33	730
Khartoum	15.60	32.55	380	Geneina	13.45	22.45	805
Shambat	15.67	32.53	380	Elobied	13.17	30.23	574
Eddueim	14.00	32.33	378	Gedaref	14.03	35.40	599
Wadmedani	14.38	33.48	405	Umbenain	13.07	33.95	435
Sennar	13.55	33.62	418	Ennuhood	12.70	28.43	565
Kosti	13.17	32.73	380	Nyala	12.05	24.88	674
Damazine	11.78	34.38	470	Abunaama	12.73	34.13	445
Malakal	09.55	31.65	390	Rashad	11.87	31.05	885
Rumbek	06.80	29.70	420	Babanusa	11.33	27.80	450
Juba	04.87	31.60	457	Kadugli	11.00	29.72	499
Gazala	11.47	26.28	485	Raga	08.47	25.68	545
Arbaat	19.83	36.97	120	Waw	07.70	28.02	435
Halaieb	22.22	36.65	002				

Results and Discussion

Effect of Latitude on Mean Annual Relative Humidity

Table 2 shows parameters of regression between mean annual RH% and latitudes (Lat.) for each of the three geographical locations. RH% generally decreased with increased latitudes at a rate varying between about 0.93 to 1.87% per degree. The table shows high correlation coefficient (R), low standard error, (SE) and very high significance (P=2.5*E*-06) for Sudan –RS. The table also shows low (R) and high (SE) and low significance (P=0.05)) for the 41 stations. The correlation for the 36 stations was not significant, (P=0.73). Similar northward decrease in the relative humidity was evident in the humidity tables for Sudan prepared by Ireland, (1948). A north ward decrease over the area was also reported for July and October relative humidity by Gasm ElSeed, (1968). A similar decrease over Sudan was also reported for rainfall as early as 1948 (Ireland, 1948), while a northward increase was reported for Piche evaporation, (Mohamed, 2015).

Table 2: Effect of latitude on annual percentage relative humidity

Area	No. of stations	R	R^2	P	SE	Equation
Sudan + SS	41	0.30	0.09	0.055	12.11	RH%=54.08-0.93Lat……….(1)
Sudan	36	0.05	0.00	0.73	11.72	RH%=34.88-0.21 Lat……..(2)
Sudan - RS	31	0.73	0.53	2.54*E*-06	05.06	RH%=62.49-1.87 Lat………(3)

E = Exponent to base 10

The north ward decrease of the relative humidity is expected as the rainfall gets scarce and as the environment becomes drier. The evaporative demand of the atmosphere there fore becomes very high and hence the high rates of evaporation recorded by the measuring instruments. Figure1 shows the scatter of RH% versus latitudes for the 41 stations. Two humidity patterns can be seen in figure1; an eastern Sudan pattern represented by the upper most 5 points in the figure, which are the 5 maritime stations, and a general Sudan–South Sudan pattern represented by the remaining 36 stations and shows a clear highly linear trend. When the 5 RS and the 5 SS stations were removed from the scatter, the 31 stations gave a highly significant (P=2.54*E*-06) linear correlation as in figure2. Although the studies on the distribution of relative humidity over the area or similar areas seems to be scarce, analysis of data from Ireland (1948) for 34 stations in the Sudan for the period 1900/1940 yielded almost a similar trend.

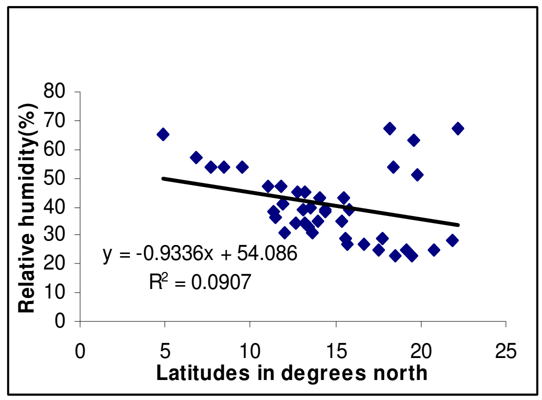

Figure 1: RH% vs. latitudes for 41 stations

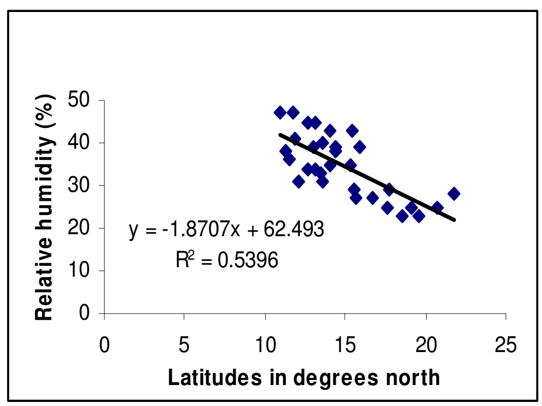

Figure 2: RH% vs. latitudes for 31 stations

Effect of Longitude on Mean Annual RH

Table 3 shows the analysis for the effect of longitudes (Lon.) on RH%. The effect was mildly significant for the 41 stations, (P=0.08), and highly significant for the 36 stations (P=0.002).However, longitudes showed no significant effects on RH% for the 31 stations, (P=0.3), because the influence of the maritime RS stations was lost with their removal from the scatter. Generally, mean annual RH% increased at a rate varying between 0.91 and 1.51% per degree longitude east ward. This is due to the effects of Red Sea and the Indian Ocean in the east. The air over such large water bodies is expected to be laden with water vapor, which will eventually move into nearby areas and even far away. The SE was generally high and none of the equations is good enough for prediction purposes. Figure3a and b show the scatter of RH% vs. longitudes for the 41 and the 36 stations. There is a clear linear correlation as shown in table 3. There was an increasing trend of humidity east ward. The scatter of RH% did not show any clear localized patterns associated with the various topographical locations as was the case for Piche evaporation, (Mohamed,2015), a part from the difference shown between the points on the two graphs which represents the South Sudan stations. In fact the variation of the RH% with longitudes reflects to a good extent the topography of the area which is a sort of a locked land surrounded by the Red Sea hills in the east, the Marra Mountains in the west while the central part is more or less flat representing the Niles and their tributaries.

Table 3: Effect of longitude on annual percentage relative humidity

Area	No. of stations	R	R^2	P	SE	Equation
Sudan + SS	41	0.27	0.07	0.08	12.22	RH%=11.18+0.91 Lon……(4)
Sudan	36	0.49	0.24	0.002	10.20	RH%=-11.23+1.51 Lon.….(5)
Sudan - RS	31	0.18	0.03	0.30	07.32	RH%=22.05+0.39 Lon.…..(6)

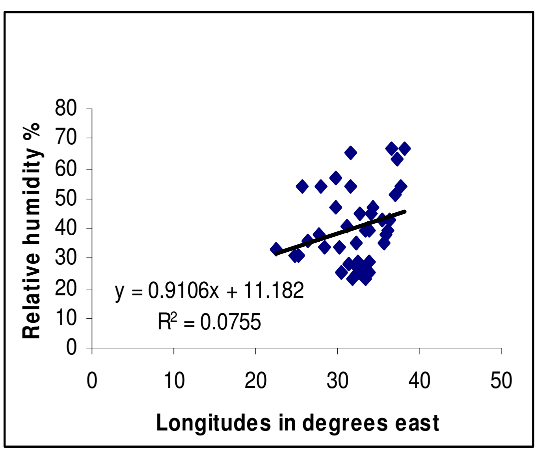

Figure 3a: RH% vs. longitudes for 41 stations

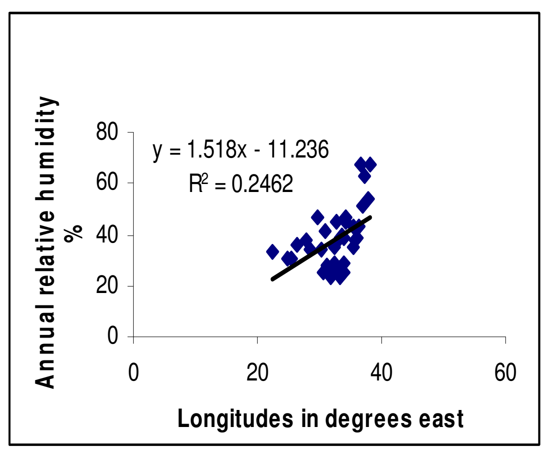

Figure 3b: RH% vs. longitudes for 36 stations

Effect of Altitude on Mean Annual RH

Altitudes (Alt.) on the other hand, compared to longitudes, showed in general a more significant effect on Sudan and SS RH%, but still with week correlations. The humidity decreased with altitude for the 41 and the 36 stations at a rate of about 0.02% per meter above sea level, but increased slightly for the 31 stations at a rate of about 0.01% per meter above sea level. The cause of this slight increase in the RH% for the 31 stations with altitudes may require further investigation. The SE were high, therefore, none of the equations is sufficiently good to be used for prediction. (table 4). Figure 4 shows the general trend of regression of RH% on altitudes. Although complicated, the figure is explainable, as it shows three different patterns. The first pattern is a coastal-Northern Sudan component in which RH% declined with altitudes for stations which are either maritime or hyper-arid stations, between altitude zero and about 300 MASL. This is expected since the air immediately over the large water bodies will contain more moisture than the air at higher altitudes. In addition, at high altitudes higher wind speeds prevail, therefore higher rates of vapor transport will also prevail. The second pattern presents a component which comprises mainly the Western Sudan stations with a very low negative slope in the range of 500 to 800 MASL. The third component comprises most Central Sudan and SS stations, and it showed a mild positive trend in the range 300 to 500 MASL. The overall trend though week is linear and negative. Figure5 shows the trend for Sudan when the 5 SS stations were removed. Figure 6 on the other hand shows the effect when the 5 RS stations were also removed from the scatter, where the RH% increased with altitudes at a rate of about 0.01% for the 31 stations in Sudan with no RS stations.

Table 4 Effect of altitude on annual percentage relative humidity

Area	No. of stations	R	R^2	P	SE	Equation
Sudan + SS	41	0.33	0.11	0.033	11.98	RH%=49.09 - 0.02 Alt...…(7)
Sudan	36	0.43	0.18	0.008	10.59	RH%=47.82 - 0.02 Alt.…. (8)
Sudan - RS	31	0.36	0.13	0.045	06.95	RH%=26.75 + 0.01 Alt…...(9)

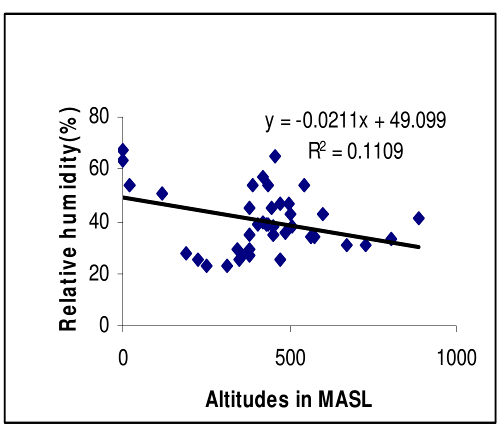

Figure 4: RH% versus altitudes for 41 stations

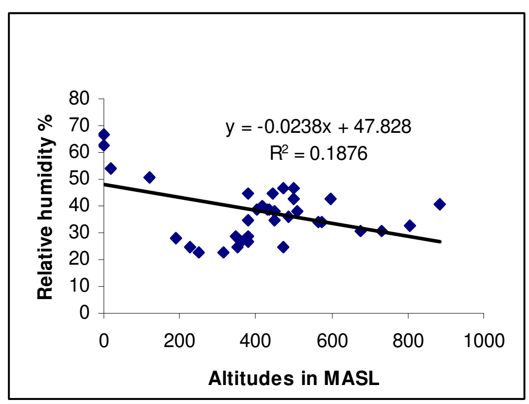

Figure 5: RH% vs. altitudes for 36 stations

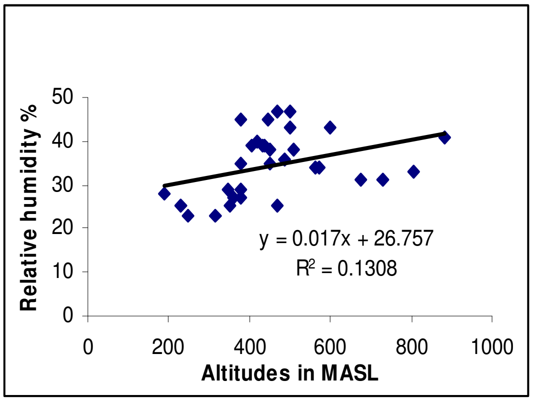

Figure 6: RH% vs. altitudes for 31 stations

Effect of Latitude and Longitude on Mean Annual RH

Table 5 shows the combined effect of both latitude and longitude on mean annual RH%. The two factors together showed very strong effects on RH% for the 31 stations with small SE (3.91), and very high significance and correlation. The effects were also highly significant for the 41 and the 36 stations, with significances of P=0.0003 and P=0.003 respectively, but with a high SE. Equation (12) for Sudan – RS seems reasonably acceptable for prediction of RH% in the Sudan, but without the Red Sea coastal area and the nearby interior.

Effect of Latitudes and Altitudes on Mean Annual RH

Table 6 shows that the correlations of RH % versus latitudes and altitudes together in the three areas were highly significant, with a minimum P of 0.001, and the SE was between 5 and 10. The lowest (R) was obtained for the 36 stations. The SE was lowest for Sudan with no RS or SS stations and highest for Sudan with RS stations. Equation (15) seems to be good for prediction purposes.

Table 5: Effect of latitude and longitude on annual percentage relative humidity

Area	No. of stations	R	P	SE	Equation
Sudan + SS	41	0.58	0.0003	10.45	RH%=5.4-1.8Lat +1.9Lon……..(10)
Sudan	36	0.53	0.003	10.05	RH%= -9.3-0.8Lat +1.8Lon……(11)
Sudan - RS	31	0.85	8.9*E*-09	03.91	RH%= 37.07-2.2Lat +0.9Lon…...(12)

Table 6: Effect of latitude and altitude on annual percentage relative humidity

Area	No. of stations	R	P	SE	Equation
Sudan + SS	41	0.70	2.7*E*-06	09.19	RH%=95.1-2.3Lat.-0.04Alt…....(13)
Sudan	36	0.57	0.001	09.74	RH%= 88.4-2.0Lat-0.04Alt……(14)
Sudan - RS	31	0.74	1.2*E*-05	05.07	RH%= 69.3-2.1Lat-0.01Alt…....(15)

Effect of the Three Factors on Mean Annual Relative Humidity

Table 7 shows the combined effect of the three parameters together. The correlations were strong and highly significant, with a minimum P of 0.0005 for the 36 stations. The highest correlation coefficient was that of the 31 stations, which also showed the highest significance, (P = 5.7E-08) and the lowest SE, (3.97). According to their R, P and SE values equations 16 and 17 were the best to predict RH% in their respective areas, while equation 18 may also be used for prediction together with equation 12 in Sudan with no Red Sea stations.

Table 7: Effect of the three parameters on annual percentage relative humidity

Area	No. of stations	R	P	SE	Equation
Sudan + SS	41	0.73	2.1*E*-06	08.85	RH%=62.5-2.5Lat+0.9Lon.-0.03Alt..(16)
Sudan	36	0.64	0.0005	09.25	RH%= 45.5-2.0Lat+1.1Lon-0.03Alt.. (17)
Sudan - RS	31	0.85	5.7*E*-08	03.97	RH%= 33.0-2.1Lat+1.0Lon.+0.00Alt..(18)

Variations of Mean Annual RH between Months and Between Stations

Investigation of RH% variations between stations and between months showed highly significant differences between months (P=6.31E-47) with March as the month of the lowest RH% (28.7) and August as the month of the highest RH % (56.9). Across stations, the lowest RH % was recorded as 22.7 for Abuhamad in the far north while the highest RH % was recorded as 66.8 for Aqiq on the Red Sea cost. In fact, in March the whole of the area is under the influence of north-easterly dry winds, while in August almost the whole area is under the influence of the southerly moist winds, and the inter tropical convergence zone is at its northern most position.

Conclusion

The analysis showed that Sudan and South Sudan %RH decreased with latitudes at an average rate of about 0.93% per degree for the whole area to about 1.87% for Sudan with no Red Sea stations. Longitudes, on the other hand showed a positive effects on the %RH where it increased at a rate varying between 0.91% per degree for the whole area and 1.51% per degree for the Sudan. The %RH decreased with altitudes for both the whole area and Sudan at a rate of 0.02%, while increased for Sudan – RS at a mild rate of 0.01% per meter above sea level. Across the whole area, March was the month of the lowest %RH while August was the month of the highest relative humidity. March is one of the driest and hottest months in the area while August is the month of the highest rainfall. On the other hand, the stations with the lowest and highest %RH were both in the northern area, but one is a hyper arid station and the other is a coastal maritime station. Four equations were recommended for prediction of %RH in their respective areas with a standard errors as low as 4.0. These are equations number 12, 16, 17 and 18. Sellers (1960) used the mean air temperature to estimate the %RH from a regression equation. However, the current equations can be used to predict mean annual RH% in the absence of any data a part from the coordinates and elevations. Similar correlations were developed for rainfall, (Diskin, 1970) and Piche evaporation, (Mohamed, 2015).

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