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Research Article

On the Main Factors Affecting Piche evaporation over Sudan and South Sudan

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Abstract: Monthly mean Piche evaporation, mean air temperature, relative humidity and wind speed data over Sudan and South Sudan for the period 1971- 2000 were obtained as normal data for 19 stations from Sudan Meteorological Authority and analyzed to study the effect of temperature, relative humidity and wind speed on Piche evaporation. The results showed strong linkages between Piche evaporation and either of mean air temperature and relative humidity in the hyper-arid, sub humid and humid regions. The results also showed strong linkages between Piche evaporation and wind speed in the sub-humid and humid regions of the Sudan and South Sudan. Piche evaporation for various stations can easily be predicted from equations incorporating air temperature, relative humidity or their combinations.

Keywords: Piche evaporation, Air temperature, Relative humidity, Wind speed, Sudan.

INTRODUCTION

Evaporation is an important attribute of the hydrological cycle, and its role is well documented in the literature [1-4]. In our every day life, evaporation is evident in our sweating under a harsh hot climate, in transpiration of plants and their consequent welting and in the dryness of soils after heavy showers of rainfall in the tropical arid. Evaporation rate is measured using various instruments types and estimated using various types of equations [5]. Piche tube or evaporimeter is one of the instruments used to measure evaporation and its importance stems from the fact that it is a simple, cheap and light device and can easily be handled and provides quick measurement of the evaporative demand of the atmosphere. Piche measurements although may overestimate evaporation can be calibrated or mathematically adjusted to any preferred method like Class (A) Pan. Evaporation measurements are of at most importance, for example, for the use in agriculture and other ecosystem studies [2], and in water budget calculations [3]. Evaporation measurements are essential for the estimation of crop water requirements, particularly in areas like the semi arid tropics, where irrigation water is a major factor behind high costs of production and low productivity of crops. It's also well documented in the literature that generally the most important climate factors affecting evaporation are the air temperature, relative humidity, wind speed and solar radiation [6, 7]. However, the relative effects of each of these factors and their combinations remains a research area as it is affected by other factors including the geographical location of an area [8]. The objective of this study therefore was to understand more thoroughly the effects of these factors on Piche evaporation and to develop prediction equations for various stations.

Experimental Methodology

The study included a set of 19 meteorological stations scattered a long and across the Sudan and South Sudan, and included the data for the period 1971/2000. Mean air temperature, relative humidity and wind speed data was obtained from Sudan Meteorological Authority as normal monthly data. Normal data refers to a statistical average of a climatic factor for thirty years, a period considered to be long enough to yield a reliable mean for scientific purposes. Solar radiation was considered as secondary factor, since its effect is to a great extent manifested by air temperature and also because of its constancy over a wide range of geographic areas. Table-1 shows the stations and their latitudes, longitudes and altitudes.

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Table-1: Meteorological stations used in the study period 1971/2000 and their coordinates and elevations

City	Latitude(N)	Longitude(E)	Altitude (masl)
W.halfa	21.82	31.35	190
Portsud	19.58	37.22	2
Abuham	19.53	33.33	315
Dongola	19.17	30.48	228
Karima	18.55	31.85	249
Atbara	17.7	33.97	345
Khart.	15.6	32.55	380
Kassala	15.47	36.4	500
Medani	14.38	33.48	405
Gedaref	14.03	35.4	599
Fasher	13.63	25.33	730
Sennar	13.55	33.62	418
Kosti	13.17	32.73	380
Elobied	13.17	30.23	574
Nyala	12.05	24.88	674
Damaz.	11.78	34.38	470
Kadugl	11	29.72	499
Malakal	9.55	31.65	390
Juba	4.87	31.6	457

The data was analyzed using Excel statistical package for regression and correlations between Piche evaporation on the one hand and air temperature, relative humidity, wind speed and their combinations on the other hand.

RESULTS AND DISCUSSION

Effects of Air Temperature on Piche Evaporation

According to the effect of mean air temperature on Piche evaporation, the 19 stations can be divided into three groups. The first group includes stations that showed highly significant and linear correlations between Piche evaporation and mean air temperature. These were the six stations north of Atbara (latitude 17.7º N). They are hyper-arid stations. With exception of Karima, their determination coefficient (R^2) varied between 0.72 and 0.93 and the change in Piche evaporation per degree Celsius varied between 0.46 and 0.73 with an average of about 0.6 mm/$^o{}_C$. In fact Karima also showed linear correlation with a lower (R^2) of 0.51. However, when the analysis for Karima was made for the 1961/1990 set of data, (R^2) was 0.72 and the slope was 0.56 mm/$^o{}_C$ similar to its group. Figures 1a to 1f show the Piche evaporation.

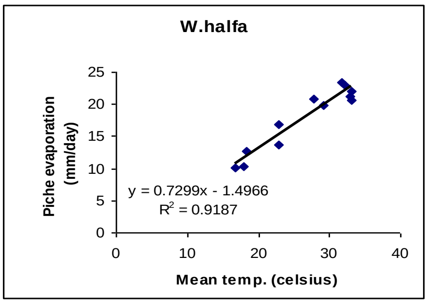

Fig-1a: Piche evaporation *vs.* mean temp for W.halfa

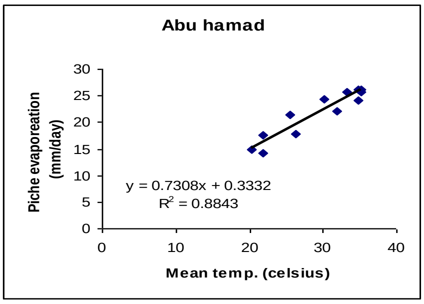

Fig-1b: Piche evaporation *vs.* mean temp for Abu hamad

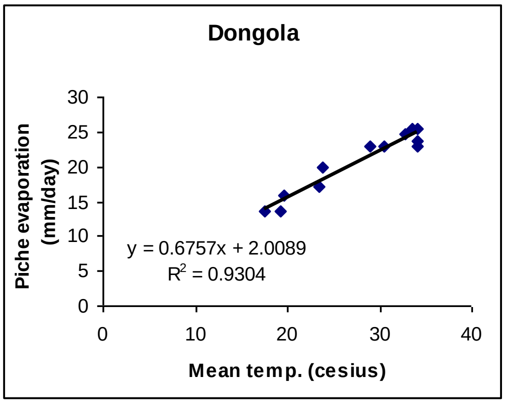

Fig-1c: Piche evaporation *vs.* mean temp for Dongola

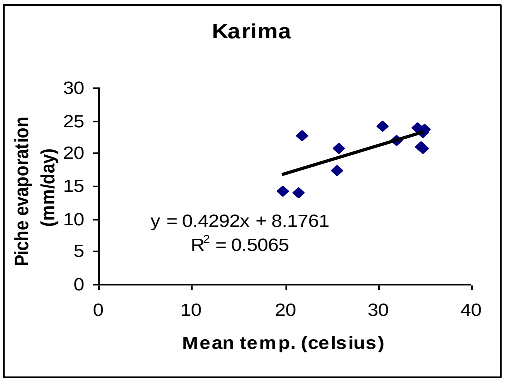

Fig-1d: Piche evaporation *vs.* mean temp for Karima

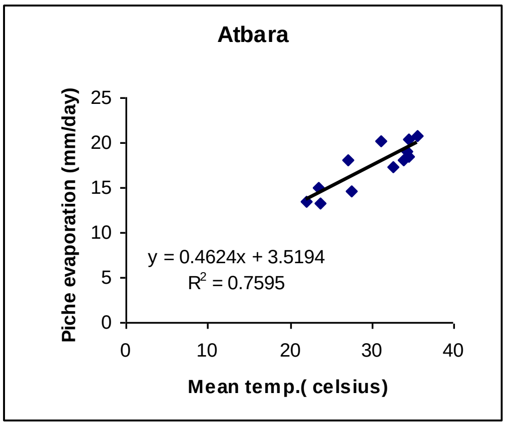

Fig-1e: Piche evaporation *vs.* mean temp for Atbara

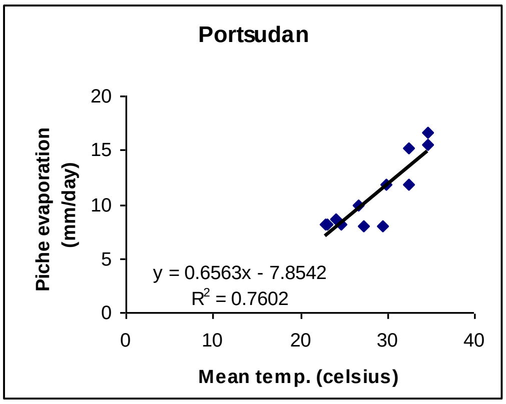

Fig-1f: Piche evaporation *vs.* mean temp for Portsudan

The second group includes eight stations that showed on average weak association with mean air temperature where (R^2) varied between 0.003 and 0.33. However, these stations showed two trends rather than one and each trend represented a linear correlation. The two trends may have resulted in response to interference of another factor like % relative humidity, slightly modifying the temperature effects. In some stations Piche evaporation in winter and autumn is represented by a trend while that in summer and transitional months is represented by another trend. These stations with few exceptions generally found north of Nyala (12.05°N). This region comprises arid and semi arid stations [8]. For most stations in this group the slope was positive and the average slope for the eight stations was about 0.28 mm/^{o}$_C$. Figures 2a to 2h show the Piche evaporation *vs.* mean air temperature for the eight stations

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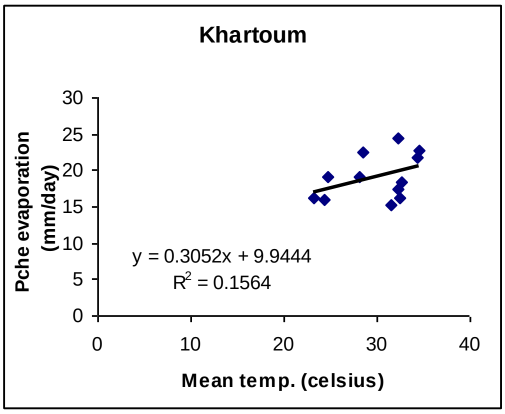

Fig-2a: Piche evaporation *vs.* mean temp for Khartoum

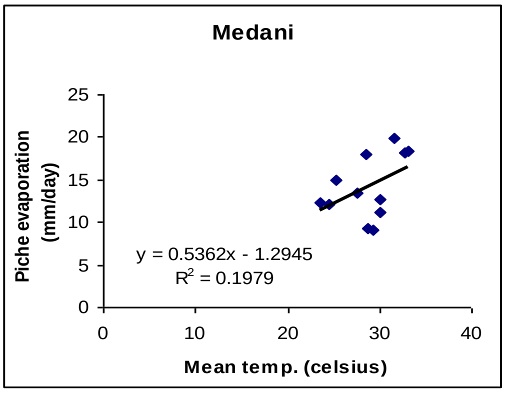

Fig-2b: Piche evaporation *vs.* mean temp for Medani

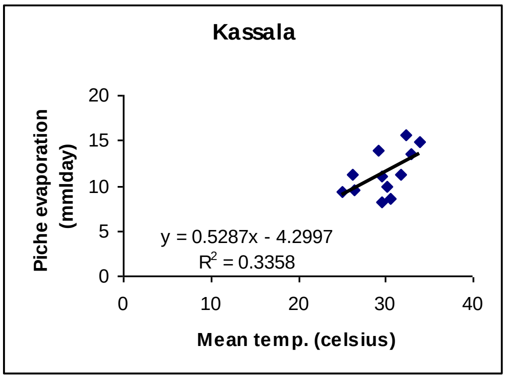

Fig-2c: Piche evaporation *vs.* mean temp for Kassala

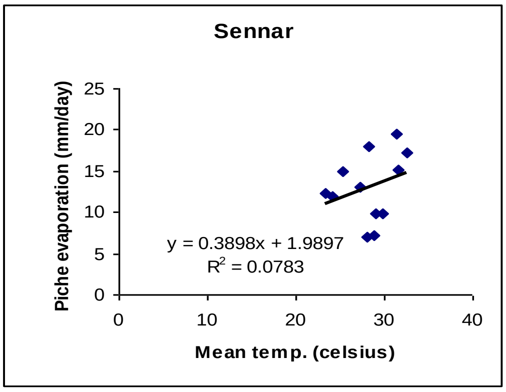

Fig-2d: Piche evaporation *vs.* mean temp for Sennar

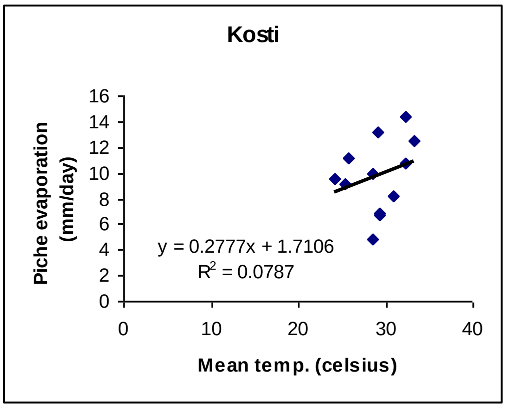

Fig-2e: Piche evaporation *vs.* mean temp for Kosti

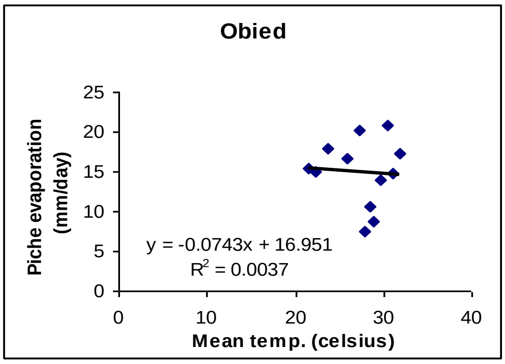

Fig-2f: Piche evaporation *vs.* mean temp for Obied

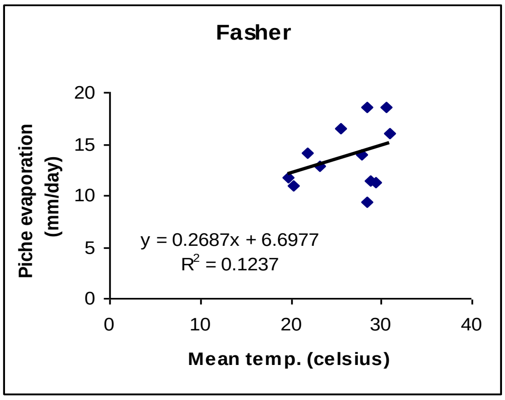

Fig-2g: Piche evaporation *vs.* mean temp for Fasher

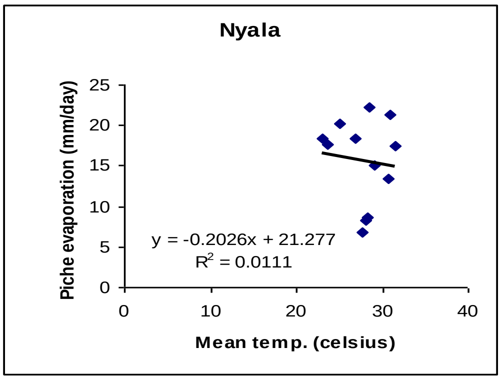

Fig-2h: Piche evaporation *vs.* mean temp for Nyala

The third group includes Damazine and the three stations south of it in addition to Gedarif which lays to the east of Damazine, not too far from the Ethiopian high lands. These stations showed almost single trends, but with rather high spread and low correlations, except for Juba which showed strong correlation. The stations also showed high slope that varied between 0.91 and 1.96 mm/ºC with an average of about 1.47 mm/ºC. Figures 3a to 3e show the trends for these stations. These stations are in the sub humid and humid regions.

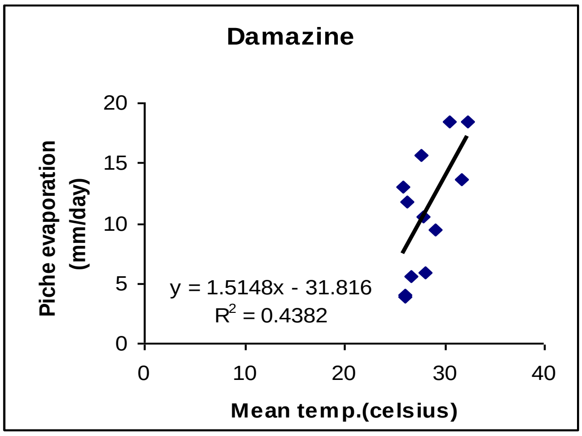

Fig-3a: Piche evaporation *vs.* mean temp for Damazine

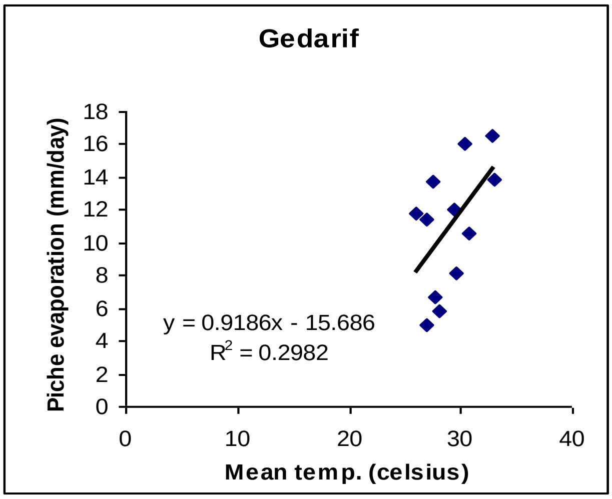

Fig-3b: Piche evaporation *vs.* mean temp for Gedarif

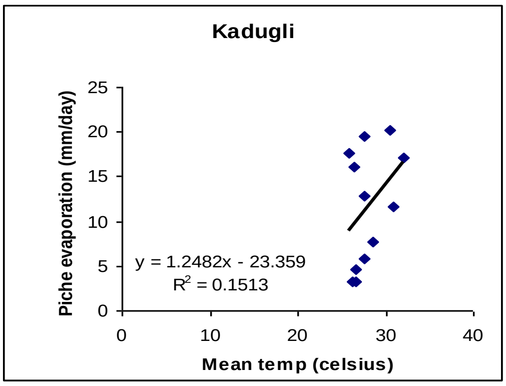

Fig-3c: Piche evaporation *vs.* mean temp for Kadugli

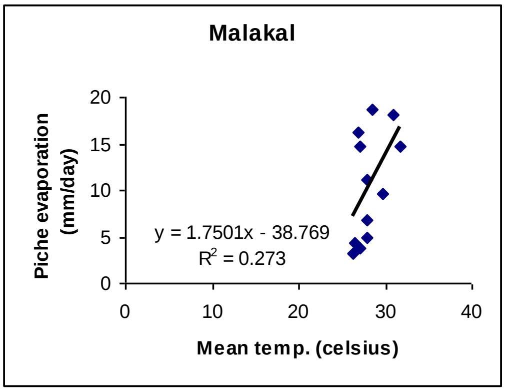

Fig-3d: Piche evaporation *vs.* mean temp for Malakal

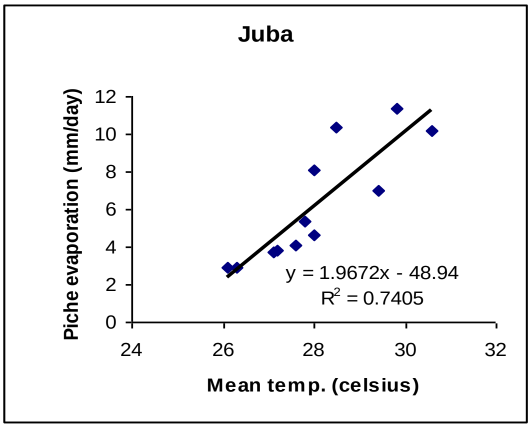

Fig-3e: Piche evaporation *vs.* mean temp for Juba

Effects of Relative Humidity % on Piche Evaporation

With the exception of Fasher which showed rather low (R^2) for the correlation between Piche evaporation and % relative humidity (%RH), almost all correlations (R^2) were high or very high reaching 98% for some stations like Malakal and Juba. In all cases, the Piche evaporation rate decreased as % relative humidity increased. According to the magnitude of the effect of %relative humidity on Piche evaporation, stations can be classified into three groups; a hyper-arid group in which four stations showed the highest mean negative slope of about - 0.62 mm/ unit % RH and an average (R^2) of about 0.85. These stations include Karima and stations north of it. Figures 4a to 4d show the Piche evaporation *vs.* the % relative humidity for the four hyper-arid stations. The second group includes four stations that varied in their negative slopes between -0.15 and -0.34 mm/ %RH with a mean of -0.23 mm/%RH and an average (R^2) of about 0.58. These are mainly arid and semi arid stations and represented by figures 5a to 5d. The third group includes eleven stations, mainly sub humid and humid stations. Their slope varied between -0.34 and -0.17mm/ %RH and their average (R^2) was about 0.92, with some correlations as high as 0.98. Their trends are highly linear. Although the drop in Piche evaporation as % relative humidity increased was almost similar for the stations in the arid, semi-arid, sub-humid and humid regions of the Sudan and South Sudan, the correlations showed more variability. Figures 6a to 6k show the Piche evaporation *vs.* the % relative humidity for the remaining 11 stations. The very high linearity in many stations shows the possibility of estimating Piche evaporation from humidity measurements for these stations or their localities any time during the year.

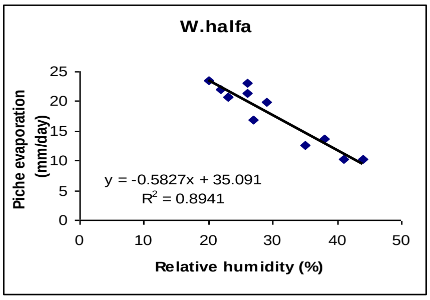

Fig-4a: Piche evaporation *vs.* % relative humidity for W.halfa

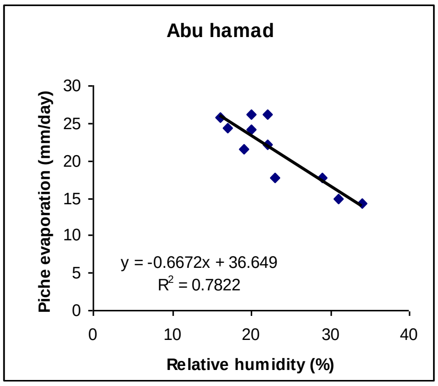

Fig-4b: Piche evaporation *vs.* % relative humidity for Abu hamad

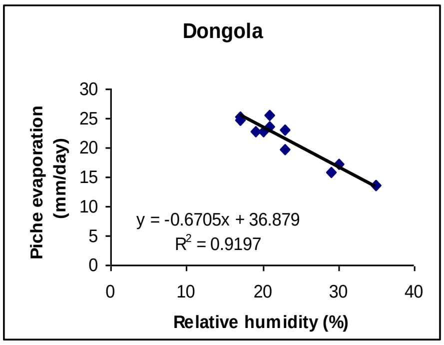

Fig-4c: Piche evaporation *vs.* % relative humidity for Dongola

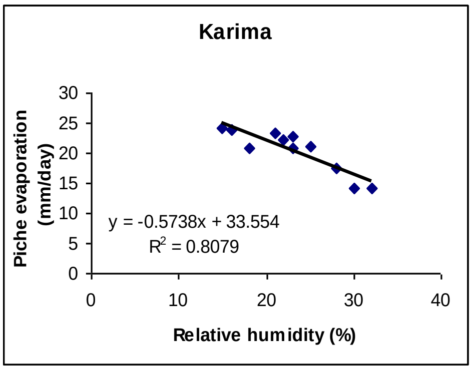

Fig-4d: Piche evaporation *vs.* % relative humidity for Karima

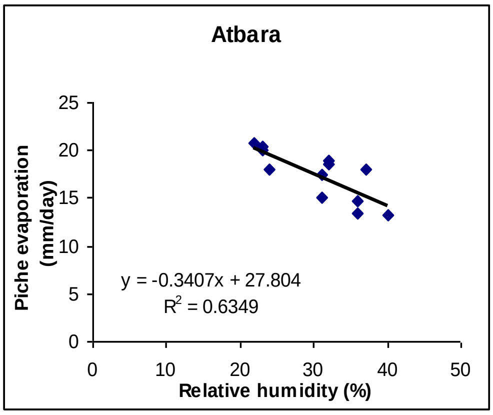

Fig-5a: Piche evaporation *vs.* % relative humidity for Atbara

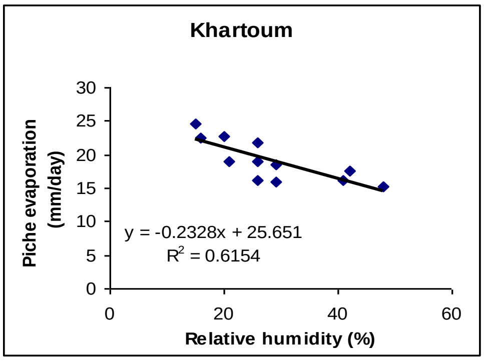

Fig-5b: Piche evaporation *vs.* % relative humidity for Khartoum

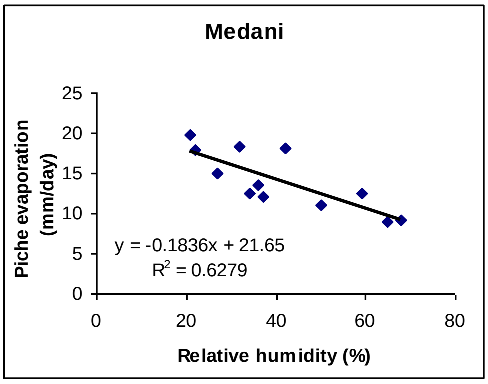

Fig-5c: Piche evaporation *vs.* % relative humidity for Medani

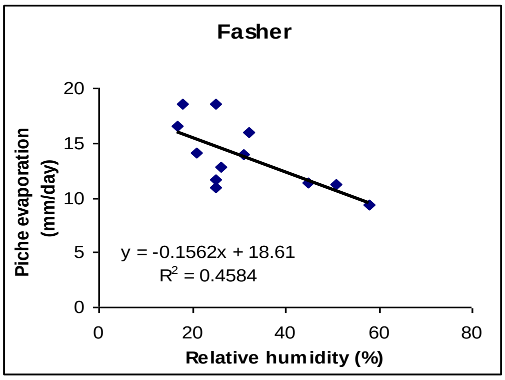

Fig-5d: Piche evaporation *vs.* % relative humidity for Fasher

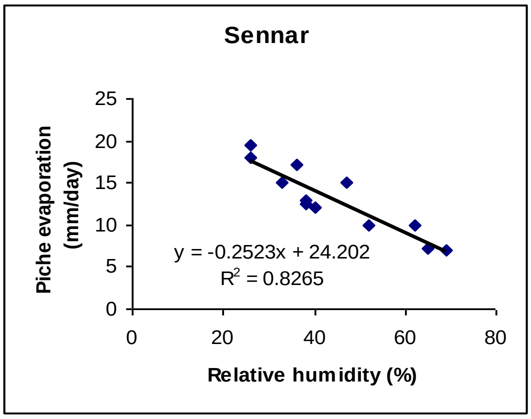

Fig-6a: Piche evaporation *vs.* % relative humidity for Sennar

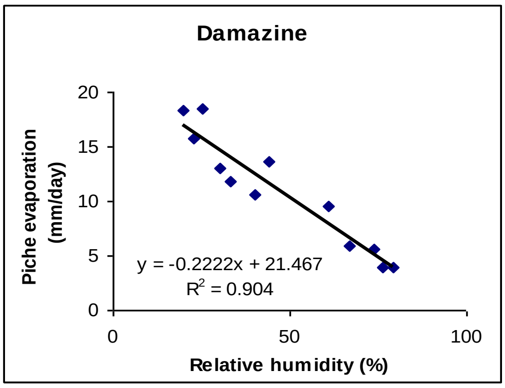

Fig-6b: Piche evaporation *vs.* % relative humidity for Damazine

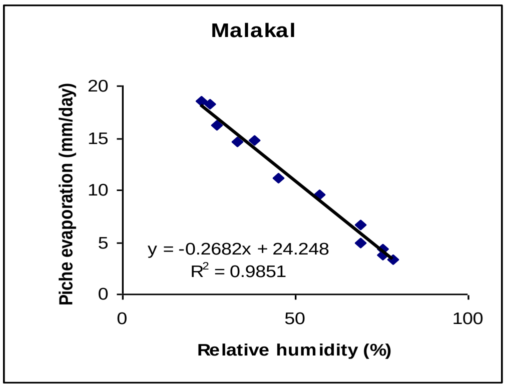

Fig-6c: Piche evaporation *vs.*% relative humidity for Malakal

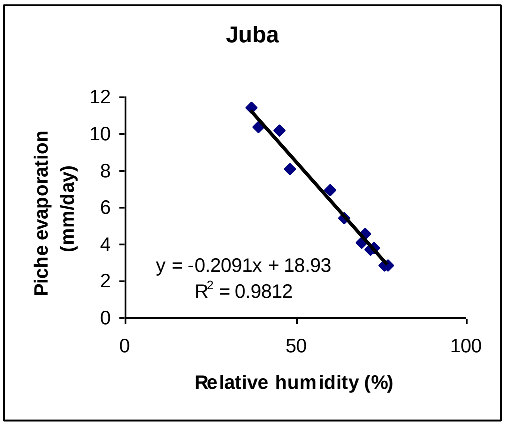

Fig-6d: Piche evaporation *vs.* % relative humidity for Juba

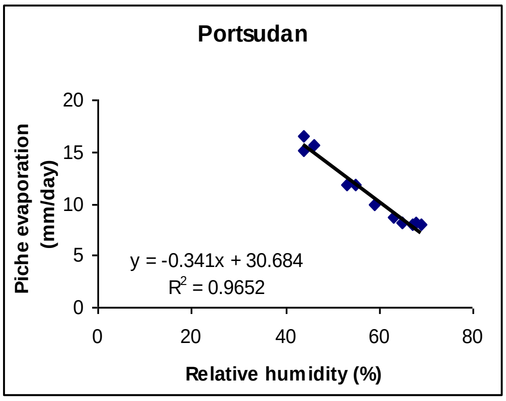

Fig-6e: Piche evaporation *vs.* % relative humidity for Portsudan

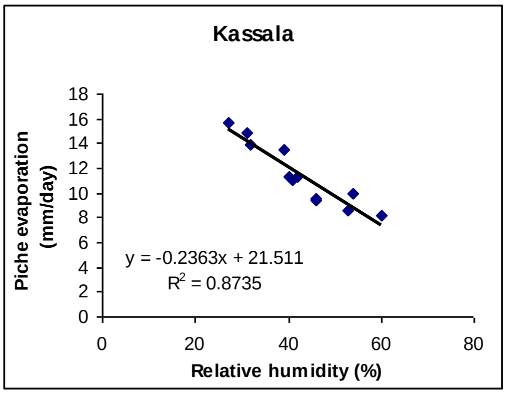

Fig-6f: Piche evaporation *vs.* % relative humidity for Kassala

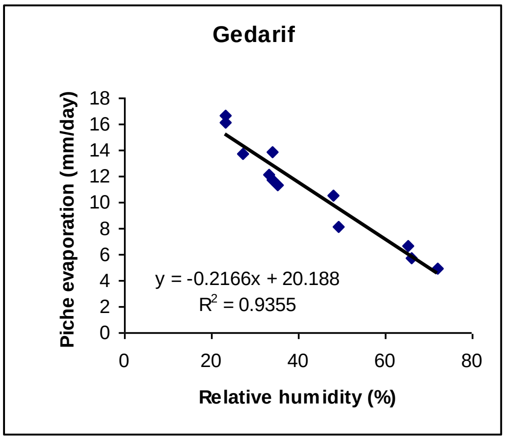

Fig-6g: Piche evaporation *vs.* % relative humidity for Gedarif

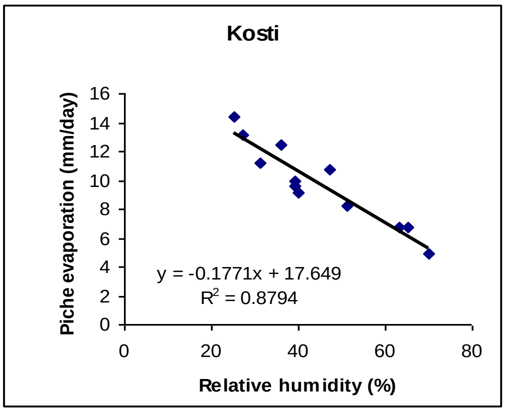

Fig-6h: Piche evaporation *vs.* % relative humidity for Kosti

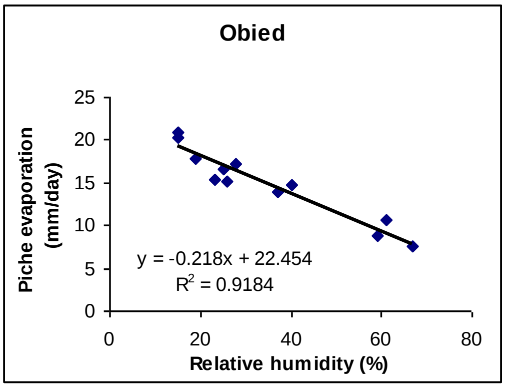

Fig-6i: Piche evaporation *vs.* % relative humidity for Obied

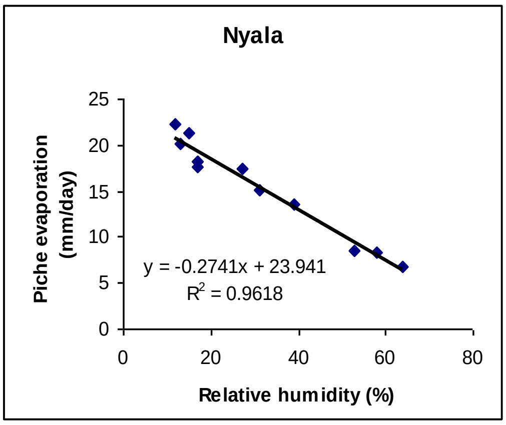

Fig-6j: Piche evaporation *vs.* % relative humidity for Nyala

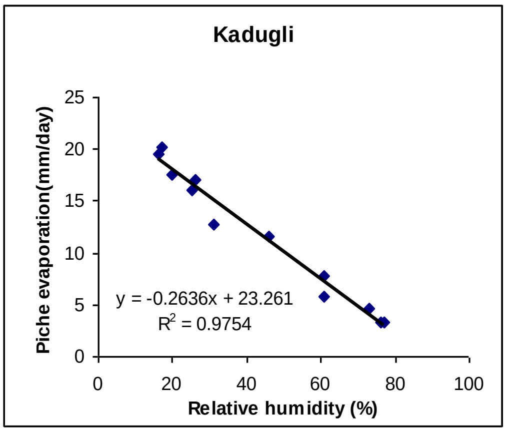

Fig-6k: Piche evaporation *vs.* % relative humidity for Kadugli

Effects of Wind Speed on Piche Evaporation

The effects of wind speed (WS) on Piche evaporation were quite variable between stations. Some stations showed highly linear correlation (R^2) between PE and WS; these include Nyala (0.64), Kadugli, (0.68) and Malakal, (0.79). The slope was positive where PE increased at an average rate of 0.55mm per m/s for the three sub-humid stations. Another group of stations showed positive and weak correlations between PE and WS, and these include Dongola, (0.26); Fasher, (0.15); Obied, (0.1) and Juba, (0.22) with an average slope of 4.67mm per m/s. Three stations showed almost low to moderate correlations and negative trends; these were Portsudan, (0.5); Abuhamad, (0.59); and Atbara, (0.3) with an average slope of 2.9mm per m/s. The remaining nine stations showed on average no specific single linear correlation, but two of the stations; W.halfa and Karima displayed two linear positive trends each rather than one. It can be said that the effect of WS on PE was quite variable depending on the magnitude of the speed itself e.g. for speeds higher than 4.5m/s the effect seems to become negative, and also depending on the proximity of the locations from water bodies e.g big lakes(sennar) and sea coast lines (Portsudan). On the average, and compared to other climatological factors, the lowest determination coefficient was obtained for the effect of wind speed on Piche evaporation.

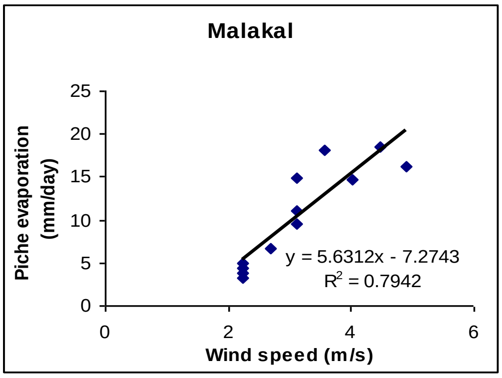

Fig-1a: Piche evaporation *vs.* wind speed for Malakal

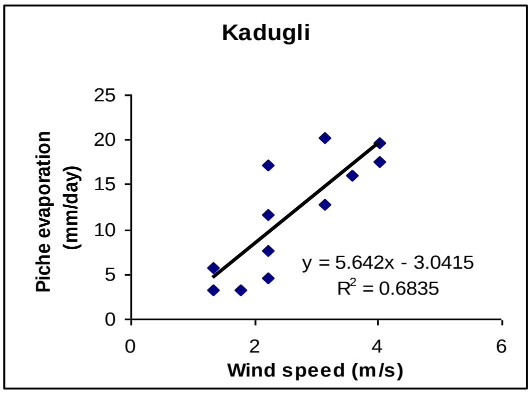

Fig-1b: Piche evaporation *vs.* wind speed for Kadugli

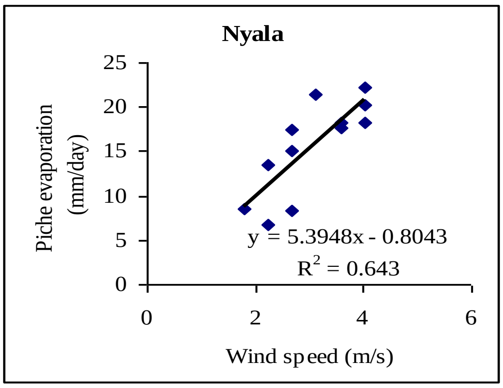

Fig-1c: Piche evaporation *vs.* wind speed for Nyala

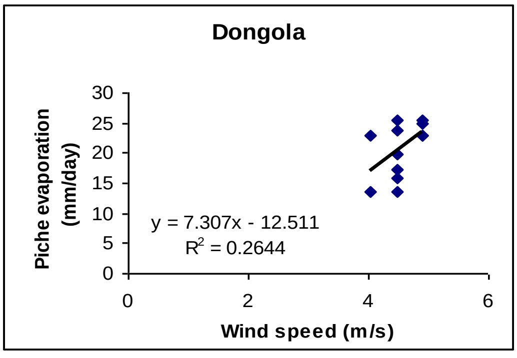

Fig-2a: Piche evaporation *vs.* wind speed for Dongola

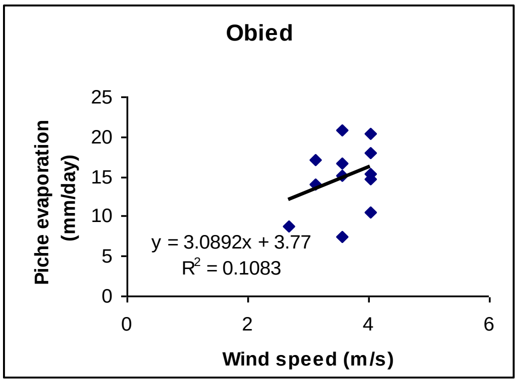

Fig-2b: Piche evaporation *vs*. wind speed for Obied

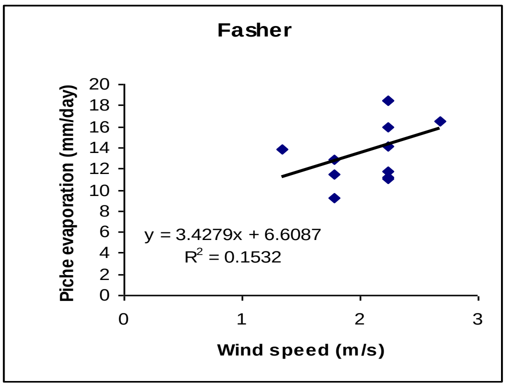

Fig-2c: Piche evaporation *vs*. wind speed for Fasher

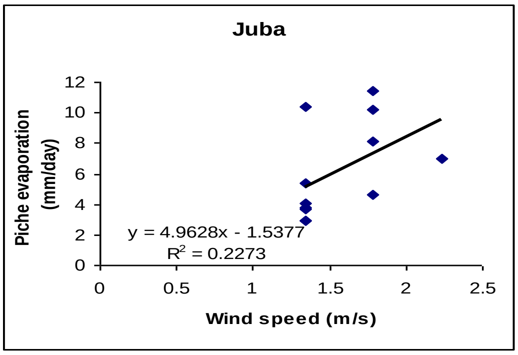

Fig-2d: Piche evaporation *vs.* wind speed for Juba

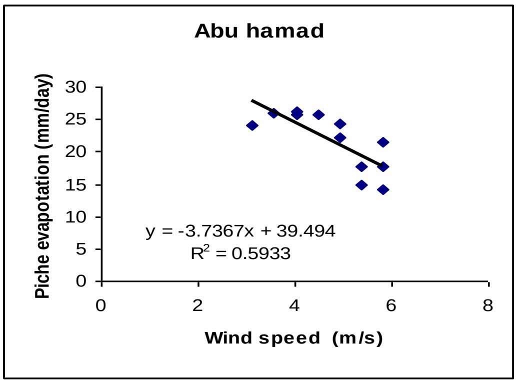

Fig-2a: Piche evaporation *vs.* wind speed for Abuhamad

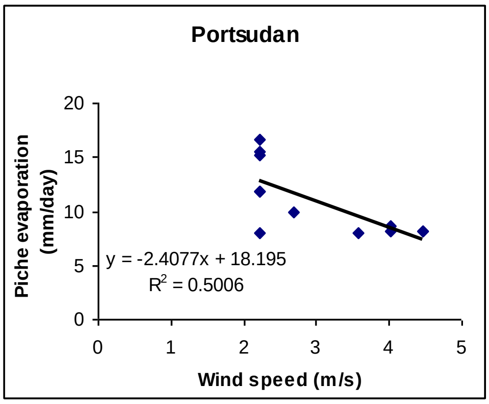

Fig-2b: Piche evaporation *vs.* wind speed for Portsudan

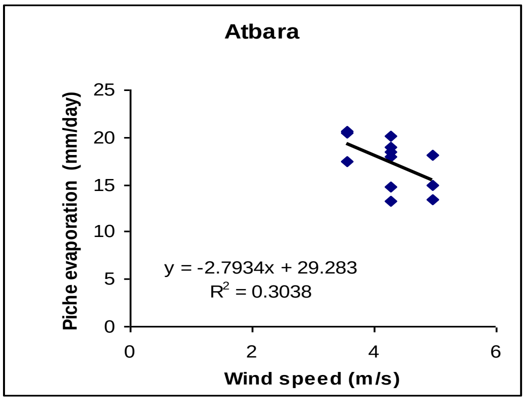

Fig-3c: Piche evaporation *vs.* wind speed for Atbara

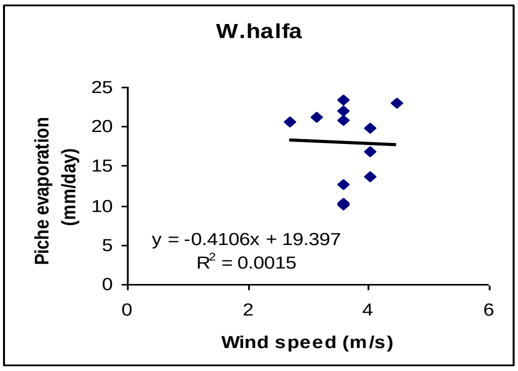

Fig-4a: Piche evaporation *vs.* wind speed for W.halafa

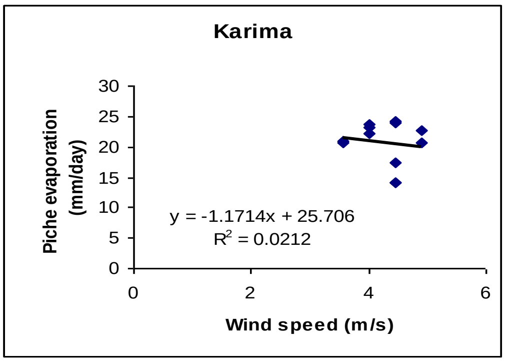

Fig-4b: Piche evaporation *vs.* wind speed for Karima

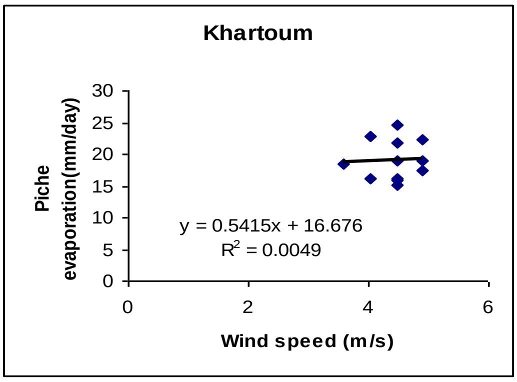

Fig-4c: Piche evaporation *vs.* wind speed for Khartoum

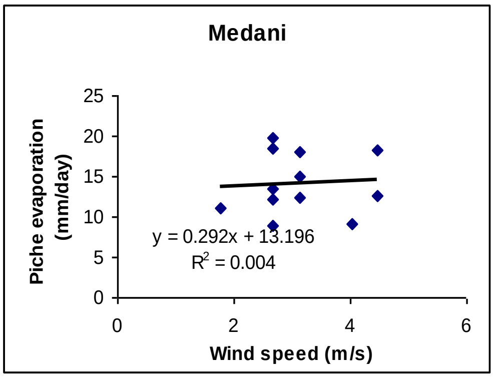

Fig-4d: Piche evaporation *vs.* wind speed for Medani

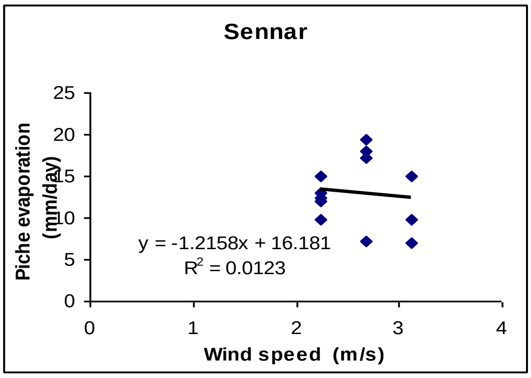

Fig-4f: Piche evaporation *vs.* wind speed for Sennar

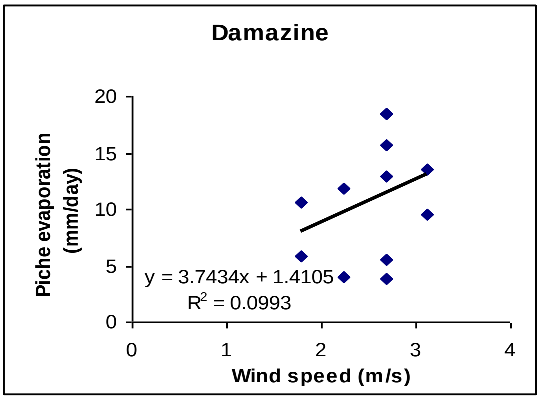

Fig-4g: Piche evaporation *vs.* wind speed for Damazine

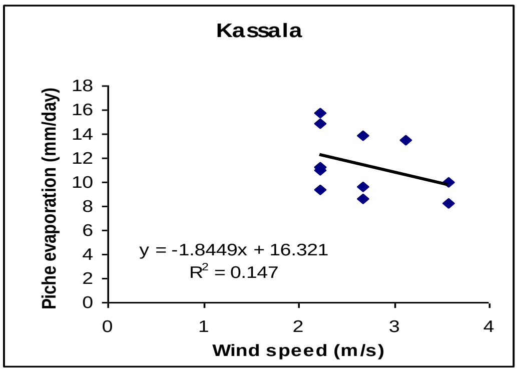

Fig-4h: Piche evaporation *vs.* wind speed for Kassala

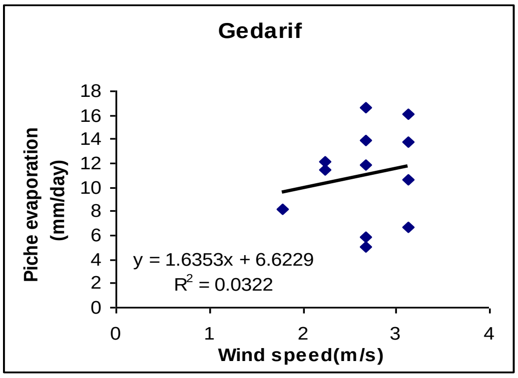

Fig-4i: Piche evaporation *vs.* wind speed for Gedarif

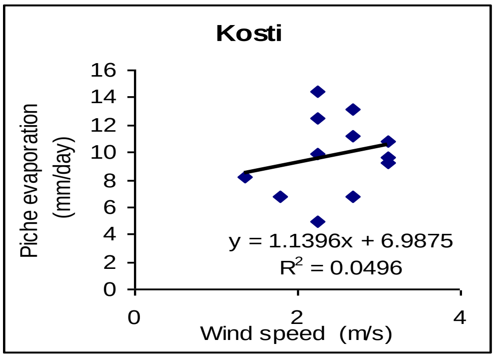

Fig-4j: Piche evaporation *vs.* wind speed for Kosti

Effects of the Combination of Factors on Piche Evaporation

Table-2 shows the 19 stations averages of coefficients of correlation (R), standard errors (SE) and significances (P) for the various factors and their combinations. The mean coefficient of correlation across stations was highest for the combination of all three factors (R=0.98), followed by the combinations of mean temperature and %RH, %RH and WS, %RH alone, mean temperature and WS, mean temperature alone and WS alone which showed the lowest mean correlation coefficient of 0.41. The lowest WS correlation coefficient confirms the finding of Bolgun [7] for Ibadan, Nigeria. For all of the 19 stations, the correlation coefficient for the combination of the three variables ranged between 0.98 and 0.99 and it varied between 0.96 and 0.99 for the combination of mean temperature and %RH. For the combination of %RH and WS, the correlation coefficient varied between 0.68 and 0.99. The linkage between Piche evaporation of the individual stations on the one hand and either of these factors or their combinations on the other hand can be described by equations incorporating one or more variables according to availability of data. Table-3 shows the best across stations equations that relate PE to various individual factors or combination of factors. On average the equations involving the three factors were the best to use for the estimation of PE of the individual stations with the highest accuracy, but other equations can be used with good accuracy in the absence of some data.

Table-2: Averages of parameters of linear regression of PE vs. various factors for the 19 stations

Parameter	R	SE	P
T	0.57	3.08	1.75E-01
%RH	0.90	1.49	8.09E-04
WS	0.41	3.49	0.30
T&%RH	0.97	0.74	7.70E-07
T&WS	0.73	2.43	1.24E-01
%RH&WS	0.93	1.25	3.38E-03
All	0.98	0.50	3.92E-07

Table-3: The best equation amongst the 19 equations that represented each factor or combination of factors

Factor	Station	R	R	SE	P	Equation
T	Dongola	0.96	0.93	1.25	4.13E-07	Pe=0.67T+2.00
RH	Juba	0.99	0.98	0.44	5.90E-10	Pe=18.92-0.20RH
WS	Malak.al	0.89	0.79	2.77	9.98E-05	Pe=5.63WS-7.27
T&RH	Juba	0.99	0.99	0.26	1.06E-10	Pe=4.90+0.43T-0.17RH
T&WS	Dongola	0.98	0.97	0.82	8.97E-08	Pe=-10.67+0.62T+3.10WS
RH&WS	Juba	0.99	0.98	0.38	2.99E-09	Pe = 17.08-0.20RH+0.89WS
All	Medani	0.99	0.99	0.26	4.22E-10	Pe=1.10+0.62T-0.21RH+1.24WS
	Juba	0.99	0.99	0.28	3.30E-09	Pe=5.19+0.41T-0.17RH+0.05WS
	Portsudan	0.99	0.99	0.32	5.40E-09	Pe=14.99+0.33T-0.28RH+0.91WS

CONCLUSIONS

In conclusion the study which was based on reliable normal data for the period 1971/2000 showed that the Piche evaporation over Sudan and South Sudan is driven mainly by the air temperature which provides the necessary energy for the process and the %RH which determines the steep ness of the ladder a long which the water vapor moves. In addition, the study showed that wind speed plays a varying role that depends to great extent on its magnitude, and that role could be negative by as much as it could be positive. The locality seem to play an important role as to what factors play a dominant role compared to others. The Piche evaporation of the individual stations can be estimated to a good accuracy using one, two or three variables equations.

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