Linke turbidity factors for several sites in Africa

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LINKE TURBIDITY FACTORS FOR SEVERAL SITES IN AFRICA

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ABSTRACT

The Linke turbidity factor (TL) has been estimated at sixteen locations in Africa (9 stations in Egypt, 2 in Mozambique and Zimbabwe, 1 in Algeria, Tunisia and Zambia). An appropriate processing of time-series of measurements of daily sums of solar global radiation spanning several years provides mean values of TL for each month with a sufficient accuracy. Though limited to the Mediterranean area, Egypt and sub-tropical Southeastern part, this work greatly extends the knowledge on the clearness of the atmosphere in Africa, an area not much addressed in the literature. The relationship between TL and the climate is evidenced. TL is almost constant throughout the year close to the Mediterranean basin with values around 3.5. Stations located in the sub-tropical Southeastern part exhibit large variations of TL.

Keywords: turbidity, atmosphere optics, radiation

1. Nomenclature

γ_s	the solar altitude angle
γ_{snoon}	the solar altitude angle at local noon
p	the air pressure at the geographical site
p_0	the air pressure at sea level
$m(\gamma_S)$	the relative optical air mass
TL	the Linke turbidity factor for an air mass equal to 2
TL_m	long-term monthly average of the Linke turbidity factor for an air mass equal to 2
G_{0d}	the extraterrestrial daily irradiation on the horizontal plane
G_d	the daily irradiation (daily sum of irradiance) received by a horizontal plan.

KT_d	the clearness index for a day, that is the ratio of the daily irradiation to the extraterrestrial daily irradiation G_{0d}
k_h	the minimum sun angle corrected clearness index for each hour
k_{hmean}	the average value of k_h for all hours of a day

2. Introduction

The Linke turbidity factor (TL, for an air mass equal to 2) is a very convenient approximation to model the atmospheric absorption and scattering of the solar radiation under clear skies. It describes the optical thickness of the atmosphere due to both the absorption by the water vapor and the absorption and scattering by the aerosol particles relative to a dry and clean atmosphere (WMO, 1981; Kasten, 1996). The larger TL, the larger the attenuation of the radiation by the clear sky atmosphere. It is a convenient parameter to summarize the turbidity of the atmosphere and is often used by engineers and consultants. It is a key input to several models assessing the downwelling irradiance under clear skies that are used by several communities in the fields of renewable energies, climatology, agro-meteorology, and atmospheric pollution. These issues are of importance in Africa and are evidenced by regional policies and international projects (e.g., Agrhymet or ACMAD).

TL can be obtained directly from observations performed during very clear sky periods, but this kind of experimental data is rarely available, thus TL is generally an estimated parameter. Also, time series of radiation data are generally too short to allow estimation on a daily basis. Fortunately, long-term monthly average values, TL_m, are sufficient for most applications. Several methods for estimating TL_m values can be found in the literature: for example from time series of daily global horizontal irradiation (Aguiar, in ESRA 2000), monthly Angström sum (Page, 1986), aerosol properties and water vapor content (Gueymard 1994) or subjective assessments of the type of atmospheric conditions prevailing in the region of interest (linear regression with latitude and with the Atmospheric Turbidity Index, Dogniaux and Lemoine, 1983).

There is only a few sites in Africa where TL_m is known. We have identified only four sites for which TL_m values are found in the literature: Northeast of Morocco (Diouri *et al*. 2000), Ile-Ife in Nigeria (Adeyefa *et al*. 1991), Cairo in Egypt (El-Hussainy, Omran 1998; Mosalam Shaltou *et al.* 1996) and El-Menia in Egypt (Mosalam Shaltou *et al.* 2001). To these, should be added the ten sites for Morocco and three for the former Spanish Sahara that can be found in the Web site www.helioclim.net and computed from monthly Angström sums found in the ESRA (2000) (Angles *et al.* 1998, 1999). Morocco is well-covered but there is no assessment or so for the remaining of the continent.

The purpose of the study is to palliate this shortcoming and to increase the knowledge on TL_m in Africa. To reach that goal, time-series of daily sums of global radiation were collected and analyzed for sixteen sites.

2. Data

In order to find out a significant mean value of the Linke factor, only stations having data measurements spanning several years were processed in this study. On the basis of this criteria, we selected stations among those proposed by the World Radiation Data Center (WRDC) at its Web site. These stations are listed in Table 1. Period is 1994-1999. We found only sixteen stations, when excluding Morocco. Nine are in Egypt. Two are in the Mediterranean area (Algeria and Tunisia). The other stations are in the Southeastern sub-tropical area (Mozambique, Zimbabwe and Zambia). The data are composed of time-series of daily sums of global radiation (daily irradiation). At the time of the data collection, it was only possible to display the data on the computer screen; the data were then manually digitized at UFAE, with possible typing errors.

The quality of the ground data measurements of the global irradiation was controlled by the means of the Web tool described by Geiger *et al.* (2002). The objective of this quality control is not to perform a precise and fine control, an objective out reach without details on the site and instruments used for measurements, but to flag the data that are obviously questionable. The aim of these procedures are to perform a likelihood control of the data and to check the plausibility of the measurements. The controlled time-series served as a basis for the present work but were also used in the framework of the project SoDa (Wald 2000; Wald *et al.* 2002), to validate the new method Heliosat-II (Lefèvre *et al.* 2002; Rigollier *et al.* 2003) and to prepare worldwide maps of the TL_m (Remund *et al.* 2003).

3. Method used to estimate TL_m

Cucumo *et al.* (2000) propose a method for calculating TL_m from a time series of daily irradiation. This method is based on i) the computation of the direct and diffuse components by the means of the Collares-Pereira and Rabl correlation, ii) the modeling of each component as an analytical function of TL_m and iii) the inversion of these models. The method was applied to several sites in Italy. For these sites, the authors used the maximum daily irradiation values read per month in the ESRA (1984). These maxima are those found in the time-series of daily irradiation spanning the period 1966-1975.

Walkenhorst *et al.* (2002) processed time-series of hourly means of beam irradiance. The Linke turbidity factor was calculated for the four hours around noon for each day by inverting the ESRA formula for the clear sky beam irradiance (ESRA 2000; Rigollier *et al.* 2002). From the resulting calculated set of TL for each month, the smallest three are averaged and this mean serves as an approximation for TL_m.

The approach used here is based on that proposed by Aguiar in 1995, reported in the ESRA (2000). It is easier to implement and operated than that of Cucumo *et al*. It does not require the analytical inversion of the clear-sky model. Given a time-series of daily sums spanning several years, the maximum daily irradiation is retained for each year of the period and each month at each site. Here, five years are available and thus five maxima are extracted for each month. In order to avoid cloudy days, these daily irradiations must satisfy the following criteria based on the daily clearness index, KT_d:

$$KT_d = G_d / G_{0d} \qquad (1)$$

where G_d is the daily irradiation and G_{0d} the extraterrestrial daily irradiation. Define γ_{snoon} as the solar altitude angle at local noon. Let define also k_h for each hour as the minimum sun angle corrected clearness index (Pedros *et al.* 1999):

$$k_h = 0.7 / [1.031 \exp-(1.4/(0.9+9.4/(m\ p / p_0))) + 0.1] \qquad (2)$$

where m is the air mass, defined in the clear sky model (Geiger *et al.* 2002; Remund *et al.* 2003):

$$m(\gamma_S) = 1 / [\ \sin \gamma_S + 0.50572\ (\gamma_S + 6.07995)^{-1.6364}] \qquad (3)$$

Let define k_{hmean} as the average value of k_h for all hours of the day. The conditions to be filled by the daily clearness index KT_d are (Remund *et al.* 2003):

If $\gamma_{snoon} > 30°$, KT_d should be greater than $0.8\ k_{hmean}$, otherwise reject data

If $30° \geq \gamma_{snoon} > 15°$, KT_d should be greater than $0.6\ k_{hmean}$, otherwise reject data

If $15° \geq \gamma_{snoon} > 4°$, KT_d should be greater than $0.4\ k_{hmean}$, otherwise reject data

If $4° \geq \gamma_{snoon}$, reject data

To further filter cloudy days, only are kept the three greatest values for each month. They are averaged and this forms the clear sky daily irradiation characterizing the site under concern. No processing was done if the number of years was less than 5. In these cases it was believed that no reliable estimate of TL_m can be obtained.

For each site and each month, TL_m is varied from 2 to 8 by step of 0.1 until the output of the clear sky model corresponds to this clear sky daily irradiation. In that way, twelve values of TL_m are obtained for a given site, one per month.

The clear sky model used is that of the ESRA (2000), detailed and validated by Rigollier *et al.* (2000), including the corrections described in Remund and Page (2002) and Page (submitted for publication), already used and reported by Geiger *et al.* (2002) and Remund *et al.* (in press). In the original model, the formula for the Rayleigh optical thickness behaves incorrectly with terrain altitude. This was not evidenced in the paper of Rigollier *et al.* because the sites used for validation have altitudes less than 500 m. Also the TL value in the diffuse transmittance should be corrected by a multiplying factor p/p_0, where p_0 is the air pressure at sea level and p that at the site. The model was developed by the means of data acquired in Europe. The tests made by Rigollier *et al.* spanned several latitudes and climates in Europe and included the station of Sede Boquer in Israel. There is no indice that indicates that the model behaves incorrectly for other climates, especially in Africa.

The whole approach was tested by using several groups of sites for which TL_m was estimated in an independent way. In the first of the four tests, TL_m was estimated by the means of the measurements of the water vapor pressure and aerosol optical depth at 440 and 1020 nm performed in the AERONET network (Holben *et al.* 2001) following the work of Gueymard (1994) (Remund *et al.* 2003). Two other stations (Patras and Toledo) were added for which TL_m is considered known (Table 2). Nine surrounding stations are available with long-term time-series of daily irradiation and located within 1° of arc angle of one of the seven stations of reference with a difference in altitudes less than 200 m. The periods of measurements are not the same for these nine stations and differ from those of the seven stations. For these nine stations, TL_m was assessed as explained above. Those estimates were compared to the known values (Table 2). The bias is –0.1 and the root mean square difference (RMSD) is 0.9 (Table 5). One may note in Table 2 the large fluctuations that can be observed between estimates at three different sites and known values for the station Ispra. The bias is very different and this tells us how cautious we should be in using such references.

In the three other tests, sites are used for which time-series of daily beam irradiation are available. From these time-series, TL_m is computed in an analytical way by inverting the equations for the beam component in the clear sky model (Remund *et al.* 2003). The minimum value is retained as TL_m. In the second test, six stations are used (five in Europe, one in Alaska, Table 3). Thirteen surrounding stations (same conditions as above) were found for which TL_m is derived by the explained approach from time-series of global irradiation. The periods of measurements are not the same. The bias is 0.1 and the RMSD is 0.8 (Table 5).

In the third test, twenty-two stations are used for which time-series of daily global and beam irradiation are available but for different periods (Table 4). The bias is –0.3 and the RMSD is 0.6. The fourth test is performed with a sub-set of these stations for which the time-series are available simultaneously for the period 1981-1990 (ESRA 2000). The six stations under concern are Uccle, Hamburg, Braunschweig, Dresden, Trier, Würzburg and Weihenstephan. The bias is –0.5 and the RMSD is 0.6 (Table 5).

From these tests, one obtains hints of the uncertainties attached to the assessments of TL_m based on time-series of global irradiation. It can be concluded that the uncertainty is ± 0.6-0.9. This is fairly large but in any case less than the day-to-day variations of TL.

4. Results and discussions

The series of TL_m obtained are reported in Table 6 for the sixteen stations. Six groups of stations were identified according to the values of TL_m and their variations during the year. These groups have links to climate zones:

- sub-tropical humid climate in the South of Africa, at sea level (Fig. 1),
- sub-tropical humid climate in the South of Africa, high elevation plateaus (Fig. 2),
- Sahara climate at high elevation (Fig. 3),
- industrialized areas in semi-arid climate (Fig. 4),
- desert Nile climate (Fig. 5),
- Mediterranean climate (Fig. 6).

The intra-group variations are large and once the uncertainty in the assessment of TL_m taken into account, the number of groups may differ. The first four groups will remain as they exhibit very different features but the two last groups: desert Nile climate and Mediterranean climate, may be aggregated.

There are five stations located in the South of Africa, in a sub-tropical humid climate. Two of them, Maputo and Tete (both in Mozambique) are located either at the ocean shoreline (Maputo) or along the Zambeze River at low elevation (Fig. 1). The TL_m values for both sites follow the same trend; they fluctuate around 3.5 ranging between 3 and 4 throughout the year. The lowest values are found in March-May and the highest in September-November. In Figure 1, one may note two outliers, one for Tete in September, the other for Maputo in October. The causes are unknown. They may result from bad quality or inappropriate data sets.

The TL_m values differ for the three other stations that have higher elevation. The stations in Zambia and Zimbabwe are on high plateaus, with elevations close to or higher than 1300 m (Fig. 2). TL_m offers a large range of values (2.5 to 7) and exhibits the same dynamics: the values decrease from January (around 6) to May (approx. 3.5), are more or less constant till July and then increase with a maximum attained in October-December. These three periods may be related to the local climate that is hot and humid in January (austral summer), dry and cool during the austral winter (low TL_m), then hot but still dry with increasing aerosol loading due to wind carrying dust (Trewartha 1954).

The Tamanrasset station is single in the Sahara climate group (Fig. 3). This station has a high elevation (1377 m). This property may prevent this station to be used as a representative for the Sahara desert. TL_m reaches its lowest in February (2.6), then increases fairly regularly up to 4.7 in October, which is its maximum.

The industrialized areas in semi-arid climate group (Fig. 4) comprises the stations Tahrir, Bahtim and Cairo, located in Egypt. These stations are characterized by a semi-arid climate that differs from that of the Mediterranean shoreline and they are close to or within the large cities of Cairo and Alexandria. Cairo is one of the largest cities in Africa (approximately 13 million of inhabitants); Alexandria comprises approximately 3 million inhabitants. Both cities are the seat of industries and the traffic of vehicles is large. The TL_m values are large compared to those of the Mediterranean group and range between 4 and 6. The group is heterogeneous. The station Cairo HQ exhibits the extreme values of this group, with low values in winter and high values in spring and summer, in agreement with the previous work of El-Hussainy, Omran (1998) on Cairo and to a lesser extent with that of Mosalam Shaltout *et al.* (1996) for the city of Helwan, in the suburb of Cairo, who processed only one year of data. These agreements sustain the validity of our method.

The stations of Asyut, El Arish and Aswan compose the desert Nile climate group (Fig. 5). They are located along the Nile River in the desert. The values are quasi-constant from January to June, around 3.5, with a minimum in February-March. Then, the values increase up to 4.5 in August and decrease till February. Mosalam Shaltout *et al.* (2001) analysed hourly irradiation data for the year 1997 for the city of Menia, approximately 200 km North of Asyut. They reported a similar behavior with minima in winter and maxima in summer, the latter being due to dust and partly to the local industry.

The Mediterranean climate group (Fig. 6) comprises the stations located close to the Mediterranean Sea: one in Tunisia (Sidi Bou Said) and three in Egypt (Sidi Barrani, Rafah and Mersa Matruh). TL_m is almost constant all along the year and fluctuates around 4 with low values in winter (3.5) and largest values (4.5) in August-September. One may notice the case of Mersa Matruh. This station has the same latitude than Sidi Barrani and is located approximately 200 km to the East. It exhibits extreme values for most of the months compared to the others and the fluctuations are more pronounced. This may be explained either by the quality of the data or by local orographic effects but we cannot go further with our set of data.

In the graph are reported three time-series of TL_m obtained for the stations of Al Hoceima, Tetouan and Nador, located on the Mediterranean coast of Morocco. These values are derived by the means of the Page formula (1986) applied to the monthly Angström sum found in the ESRA (2000). One sees that these values are in fairly agreement with the four others. However, one may note that this group is very heterogenous. The behaviour for all stations is not the same. The stations for Morocco have a very similar behaviour but differ from the others. This may be explained either by the way TL_m has been derived for these stations or by the hypothesis that there is not an unique optical climate for the African Mediterranean area. More studies are needed for this area.

5. Conclusion

This work provides estimates of long-term monthly average values of the Linke turbidity factor TL_m for sixteen stations in Africa. Agreement with previous works made on coincident stations or areas in Egypt show that the approach is valuable for Africa. These results strongly increase the sparse knowledge available in Africa on this parameter. The analysis of the values of TL_m, the range and the behavior throughout the year, demonstrates that TL_m is related to the climate, a unsurprising result.

The values obtained by this study have been used by the project SoDa for the creation of world-wide maps of the Linke turbidity factor for each month (Remund *et al.* 2003; Lefèvre *et al.* 2003). The method for assessing TL_m can be re-used on other time-series of daily sums of global radiation spanning several years. Tests made with other sites in the world demonstrate an uncertainty in the assessment of 0.6-0.9.

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Station Name	Latitude (°)	Longitude (°)	Elevation (m)	Period of Measurement	WMO-Nr
Tamanrasset (Algeria)	22.78	5.52	1377	1995-1999	60680
Sidi Barrani (Egypt)	31.63	25.85	26	1994-1998	62301
Mersa Matruh (Egypt)	31.33	27.22	38	1995-1998	62306
Rafah (Egypt)	31.22	34.22	73	1994-1998	62335
El Arish (Egypt)	31.12	33.75	32	1994-1998	62337
Tahrir (Egypt)	30.65	30.70	19	1994-1998	62345
Bahtim (Egypt)	30.15	31.25	17	1994-1998	62369
Cairo HQ (Egypt)	30.08	31.28	36	1994-1998	62371
Asyut (Egypt)	27.20	31.50	52	1994-1998	62392
Aswan (Egypt)	23.97	32.78	192	1994-1998	62414
Tete (Mozambique)	-16.18	33.58	123	1994-1998	67261
Maputo (Mozambique)	-25.97	32.60	70	1994-1998	67341
Lusaka (Zambia)	-15.42	28.32	1280	1994-1998	67666
Harare (Zimbabwe)	-17.83	31.02	1471	1994-1998	67774
Bulawayo (Zimbabwe)	-20.15	28.62	1343	1994-1998	67964
Sidi Bou Said (Tunisia)	36.87	10.23	127	1994-1998	No index

Table 1. *Description of the stations and data used to calculate the Linke turbidity factor. They are ranked by WMO identifying number*

Station. Estimated	Lat (°)	Lon (°)	Elev. [m]	Period	Station. Measured	Lat (°)	Lon (°)	Elev. [m]	Period	Bias	RMSD
Magadino	46.16	8.94	200	1995-99	Ispra*	45.80	8.62	235	1997-98	-1.05	1.24
Locarno-Monti	46.17	8.78	366	1981-90	Ispra*	45.80	8.62	235	1997-98	-0.60	0.66
Lugano	46.00	8.97	273	1987-96	Ispra*	45.80	8.62	235	1997-98	0.12	0.69
Trappes	48.77	2.02	168	1981-90	Palaiseau*	48.70	2.20	156	1999-2000	0.94	1.09
Carpentras	44.08	5.05	99	1971-80	Avignon*	43.92	4.87	32	1999-2001	0.32	1.09
Artaa	39.17	21.00	10	1981-90	Patras	38.38	21.78	64	1973-76	-0.08	0.33
Fairbanks	64.82	-147.87	138	1961-90	Bonanza*	64.73	-148.30	150	1995-2000	0.69	0.81
Toledo	41.6	-83.8	211	1961-90	Toledo	41.6	-83.8	211	1971-85	-0.13	0.36
Honolulu	21.33	-157.92	5	1961-90	Lanai*	20.82	-156.98	80	1995-99	1.15	1.24

*AERONET (= measured Water vapor pressure, aot440,1020)

Table 2. Comparison between measured values of TL and estimates (first test). RMSD means root mean square difference.

Station. Global	**Lat (°)**	**Lon (°)**	**Elev. (m)**	**Period**	**Station. Beam**	**Lat (°)**	**Lon (°)**	**Elev. (m)**	**Period**	**Bias**	**RMSD**
Broom's Barn	52.27	0.57	75	1981-90	Garston	51.71	-0.37	80	1992	-0.54	1.05
London	51.52	-.12	77	1981-90	Garston	51.71	-0.37	80	1992	-0.25	0.75
Payerne	46.82	6.95	490	1987-96	Payerne	46.82	6.95	491	1998	0.93	0.99
Luzern	47.48	8.53	436	1981-90	Reckenholz	47.43	8.52	443	1990-91	0.61	0.86
Zuerich-Kloten	47.03	8.30	456	1987-96	Reckenholz	47.43	8.52	443	1990-91	0.06	0.32
Haerkingen	47.31	7.82	420	1995-99	Payerne	46.82	6.95	491	1998	-0.04	0.26
Geneva	46.25	6.12	420	1981-90	Payerne	46.82	6.95	491	1998	0.82	0.86
Sion	46.22	7.33	482	1987-96	Payerne	46.82	6.95	491	1998	0.06	0.52
Schleswig	54.53	9.55	59	1981-90	Hamburg	53.65	10.12	49	1981-90	-1.17	1.21
Freiburg	48.00	7.82	308	1981-90	Reckenholz	47.43	8.52	443	1990-91	0.67	4.36
Wien H. Warte	48.12	16.57	203	1981-90	Bratislava	48.17	17.08	195	1994	0.30	0.60
Bratislava	48.17	17.12	292	1981-90	Bratislava	48.17	17.08	195	1994	-0.88	0.99
Barrow	71.3	-156.78	4	1961-90	Barrow	71.32	-156.61	8	1992	-0.73	1.14

Table 3. Comparison between two sets of values of TL estimated from global and beam radiation (second test). RMSD means root mean square difference.

Name	Latitude (°)	Longitude (°)	Elevation (m)	Period -beam	Period - global	WMO-Nr
Uccle	50.80	4.35	100	1981-90	1981-90	6447
Hamburg	53.65	10.12	49	1981-90	1981-90	10141
Braunschweig	52.30	10.45	83	1981-90	1981-90	10348
Dresden-Wahnsdorf	51.12	13.68	246	1981-90	1981-90	10486
Trier	49.75	6.67	278	1981-90	1981-90	10609
Wuerzburg	49.77	9.97	275	1981-90	1981-90	10655
Weihenstephan	48.40	11.70	472	1981-90	1981-90	10863
Payerne	46.82	6.95	491	1998	1987-96	6610
Barrow	71.32	-156.61	8	1992	1961-90	70026
Miami	25.80	-80.27	2	1978-85	1961-90	72202
Brownsville	25.90	-97.43	6	1978-84, 88	1961-90	72250
El Paso	31.80	-106.40	1194	1988-90	1961-90	72270
Los Angeles	33.93	-118.40	32	1978-80	1961-90	72295
Raleigh	35.87	-78.78	134	1988-90	1961-90	72306
Fresno	36.77	-119.72	100	1978-80	1961-90	72389
Dodge City	37.77	-99.97	787	1978-80, 88-90	1961-90	72451
Salt Lake City	40.77	-111.97	1288	1988-90	1961-90	72572
Eugene	44.12	-123.22	109	1988-90	1961-90	72693
Caribou	46.87	-68.02	190	1978-85, 88, 90	1961-90	72712
Great Falls	47.48	-111.37	1116	1988-90	1961-90	72775
Seattle	47.45	-122.30	122	1978-80, 88-90	1961-90	72793
San Juan	18.43	-66.00	19	1979-80	1961-90	78526

Table 4. List of the stations used in the third test

Test Properties	Bias	RMSD
Nine stations. Seven "reference" stations. Measured values of TL and estimates. Different periods and stations	-0.1	0.9
Thirteen stations. Six "reference" stations. TL assessed by beam and global radiation. Different periods and stations	0.1	0.8
Twenty-two stations. TL assessed by beam and global radiation. Different periods. Same stations	-0.3	0.6
Eight stations. TL assessed by beam and global radiation. Same periods and stations	-0.5	0.6

Table 5. Summary of the tests. RMSD means root mean square difference.

Station Name	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
Tamanrasset (Algeria)	2.7	2.6	3.2	3.3	3.2	3.9	4.0	4.4	4.5	4.7	3.5	3.7
Sidi Barrani (Egypt)	3.4	-	4.0	-	4.1	-	4.2	-	-	4.5	-	4.1
Mersa Matruh (Egypt)	2.6	4.3	-	-	4.4	4.3	-	4.9	4.5	3.0	-	-
Rafah (Egypt)	4.2	3.8	-	3.9	4.2	3.9	4.2	4.6	4.4	-	-	4.0
El Arish (Egypt)	4.5	3.8	2.9	4.0	3.9	3.7	3.4	4.2	4.1	4.6	4.3	4.3
Tahrir (Egypt)	-	4.5	4.5	-	4.0	4.2	-	4.7	4.7	5.0	5.2	4.3
Bahtim (Egypt)	-	4.6	4.5	4.9	5.2	4.3	4.6	4.9	5.3	5.2	5.4	-
Cairo HQ (Egypt)	-	3.9	4.7	4.8	5.3	-	5.4	5.9	5.6	5.3	5.6	-
Asyut (Egypt)	3.8	3.4	3.2	3.7	3.7	3.6	4.0	4.6	4.2	4.6	4.4	4.3
Aswan (Egypt)	3.5	3.3	3.9	3.9	-	4.0	4.3	4.4	4.3	-	3.7	3.6
Tete (Mozambique)	3.8	3.3	2.9	2.8	2.8	3.0	3.3	3.7	5.3	4.1	4.3	3.0
Maputo (Mozambique)	3.7	3.8	3.3	3.5	3.0	3.1	3.1	3.0	4.0	2.9	3.5	3.2
Lusaka (Zambia)	6.3	-	6.3	5.0	2.5	3.1	2.7	3.6	4.9	7.0	5.8	4.4
Harare (Zimbabwe)	6.3	5.7	-	-	-	-	4.4	3.9	-	4.5	6.1	6.6
Bulawayo (Zimbabwe)	5.0	4.9	4.7	4.8	3.8	3.7	3.7	3.9	4.6	5.5	5.4	5.5
Sidi Bou Said (Tunisia)	3.8	3.7	3.5	4.3	4.2	4.1	4.5	3.6	4.4	3.6	3.6	3.1

Table 6. *Linke turbidity factor (TL) values for the 16 stations*

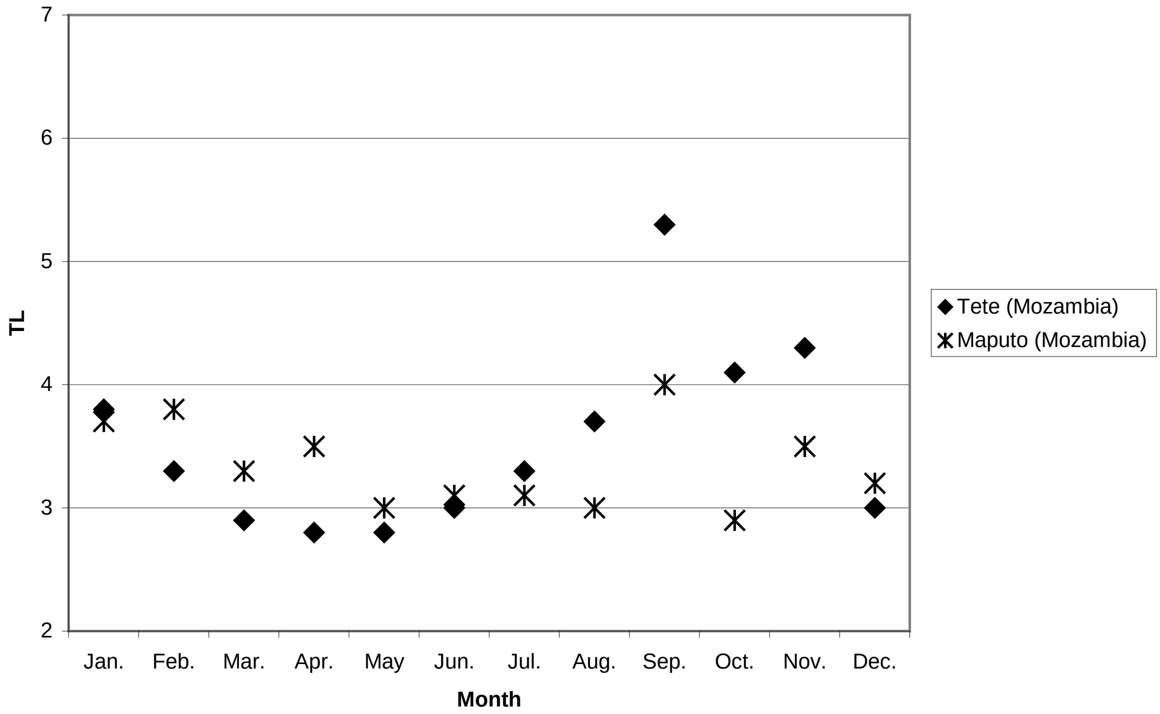

Figure 1: TL_m for stations in Mozambia

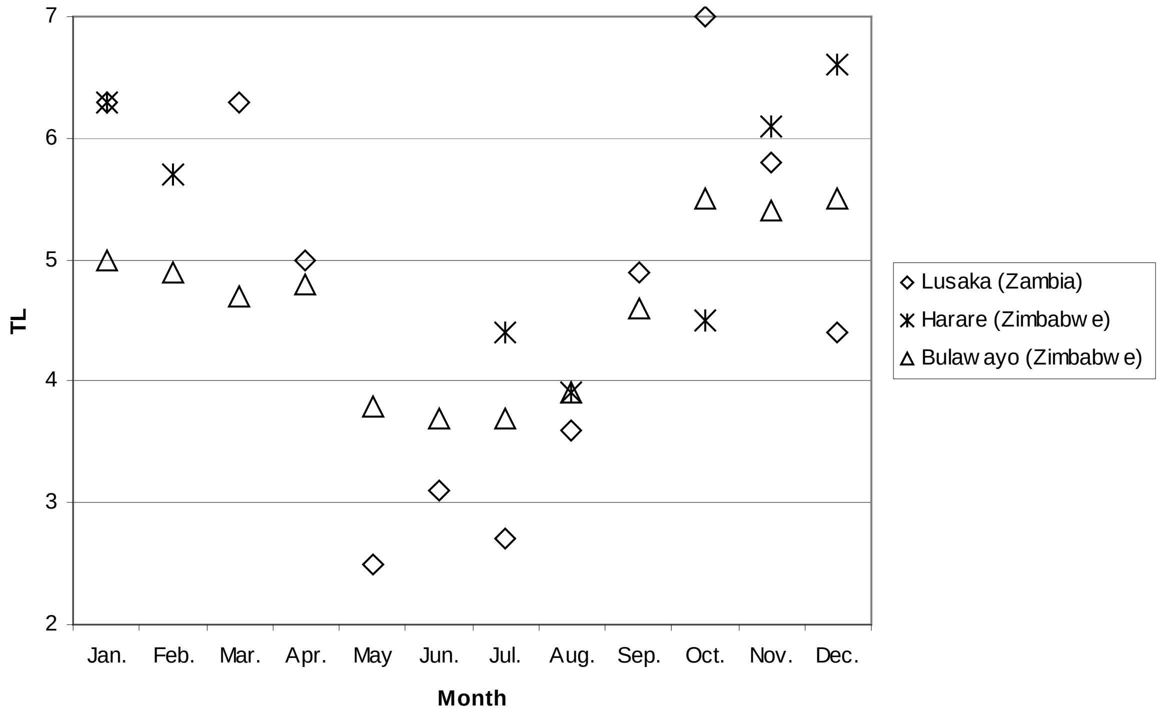

Figure 2: TL_m for stations in Zimbabwe and Zambia

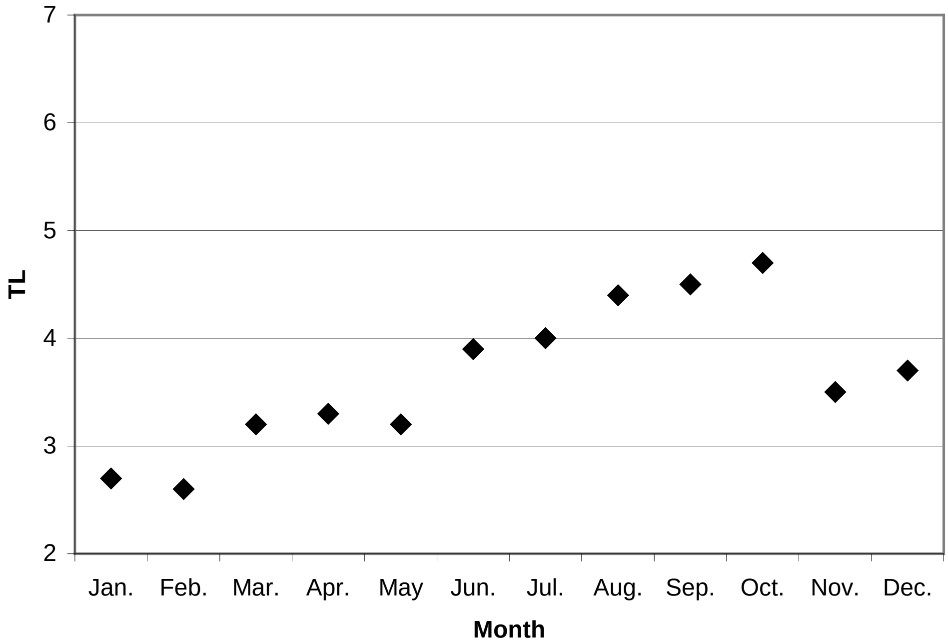

Figure 3: TL_m for Tamanrasset (Algeria) - Sahara zone

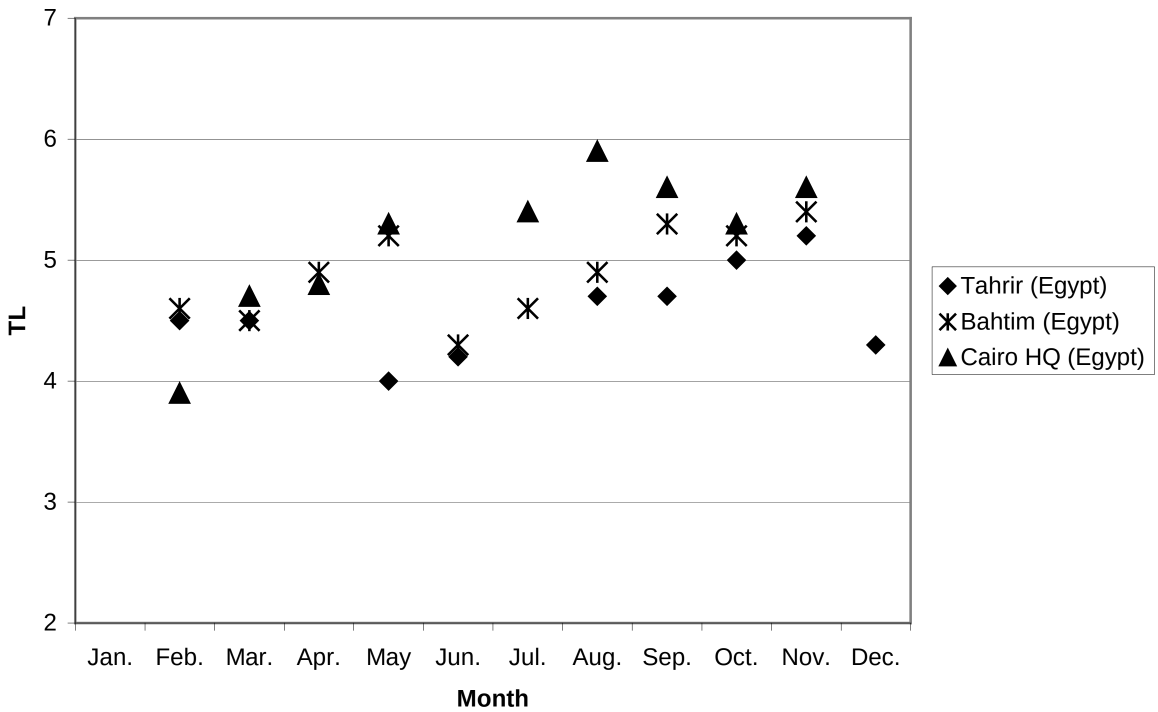

Figure 4: TL_m for stations in industrial areas in semi-desert zone

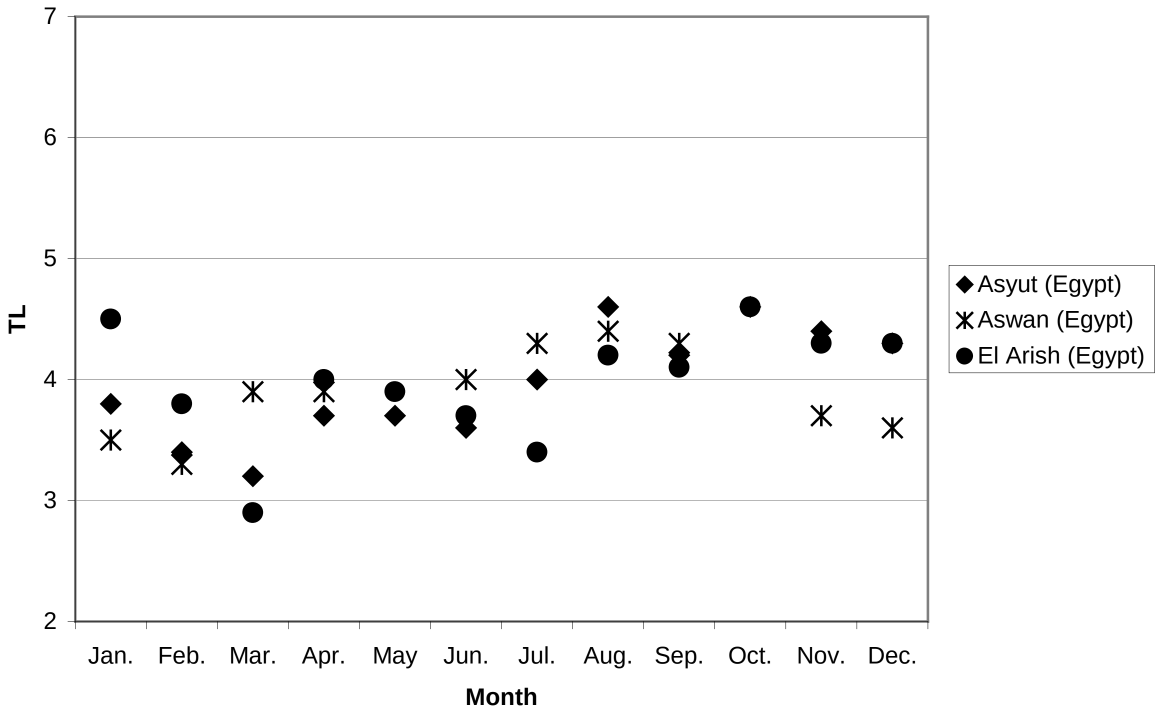

Figure 5: TL_m in desert zone

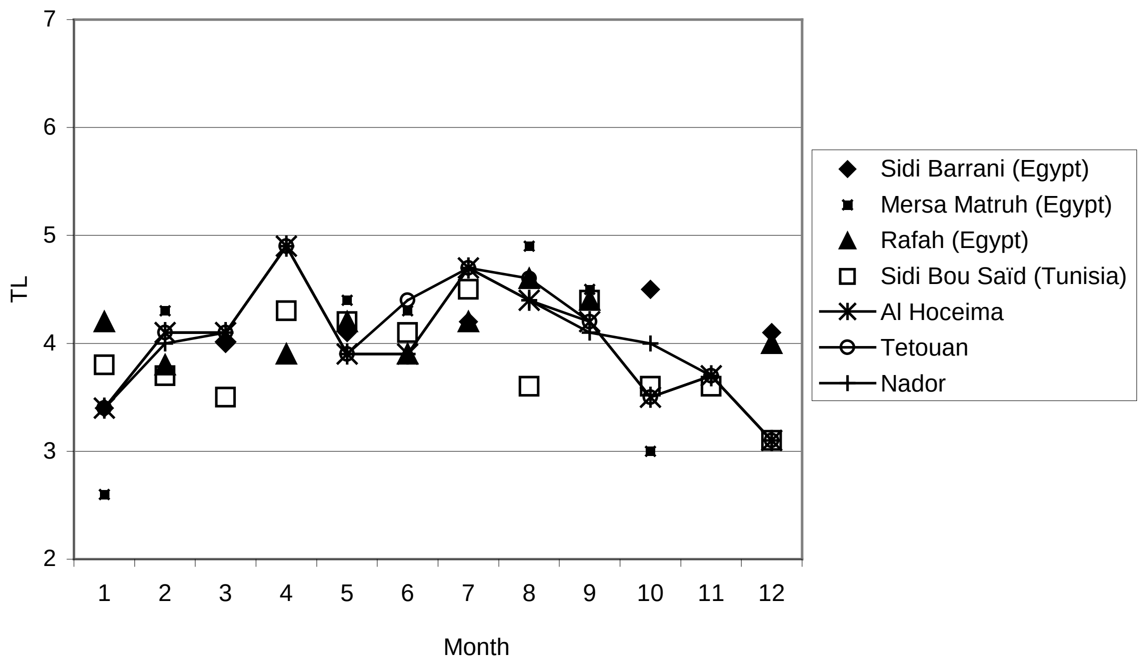

Figure 6: TL_m for stations in Mediterranean zone. Superimposed are TL_m values derived from the ESRA (2000) for 3 sites in Morocco (Al Hoceima, Tetouan, Nador).