Kenya Journal of Science and Technology (A) (1980) 1: 43–52

Atmospheric pollution potentials over Africa

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SUMMARY

In the present study the maximum mixing heights and ventilation factors for 48 radiosonde stations of the African continent and adjoining islands are determined on a monthly and annual basis using the upper air data for a period of 12 years, and climatic surface maximum temperature normals. The method used for the estimation is similar to that of Holzworth (1964a, 1964b). A correction to the estimated values is suggested to compensate for errors due to higher temperatures of pollutants.

The maximum mixing heights and ventilation factors for the African continent and adjoining islands are in general higher than those found over the USA and India; the seasonal variability of these pollution potential parameters are less pronounced.

INTRODUCTION

The air pollution concentration depends not only on the amount of the pollutants that are put into the atmosphere by the generating agency but also on the rate of dispersion and diffusion properties of the atmosphere. The basic meteorological factors that determine the dilution ability of the atmosphere, particularly in the lower layers, are wind speed and atmospheric stability. Higher wind speeds remove the effluents faster from the source area; higher mixing heights and turbulence enhance vertical mixing of pollutants in the atmosphere and hence lower potential for high concentrations. Other factors like inversions, anticyclones and other atmospheric aspects are not considered in the present study. The various factors that are involved in the atmospheric dilution process are described in the National Air Pollution Potential forecasting programme of the USA (1967) and by Dicke (1975). The atmospheric pollution potential is generally described by mixing heights and ventilation factor. These terms effectively describe the dilution capacity of the atmosphere at a given place.

The maximum mixing height (depth) is defined as the maximum beight above the surface under which relatively vigorous vertical mixing occurs. The ventilation factor is the product of mixing height to mean wind speed within the height. Estimation of dilution capacity of the atmosphere with the help of temperature profiles for vertical mixing and wind speed for horizontal mixing was attempted by Holzworth (1964a). He estimated the mean maximum mixing depths for 45 stations in the contiguous United States of America (Holzworth 1964b) using mean radiosonde observations and mean maximum surface temperatures and also the assumption of a dry adiabatic lapse rate. The influence of large-scale weather features such as cyclones and anticyclones that are typically associated with relatively rapid and slow atmospheric dispersions respectively were also examined by Holzworth (1969).The mixing heights and wind speeds for the USA were also estimated by Holzworth (1972) who made

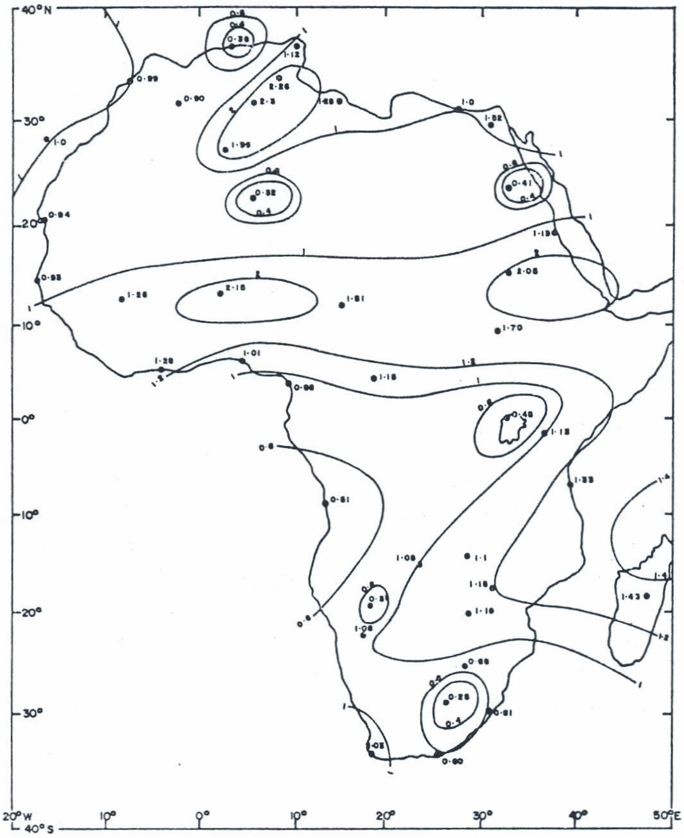

Figure 1. Annual maximum mixing heights.

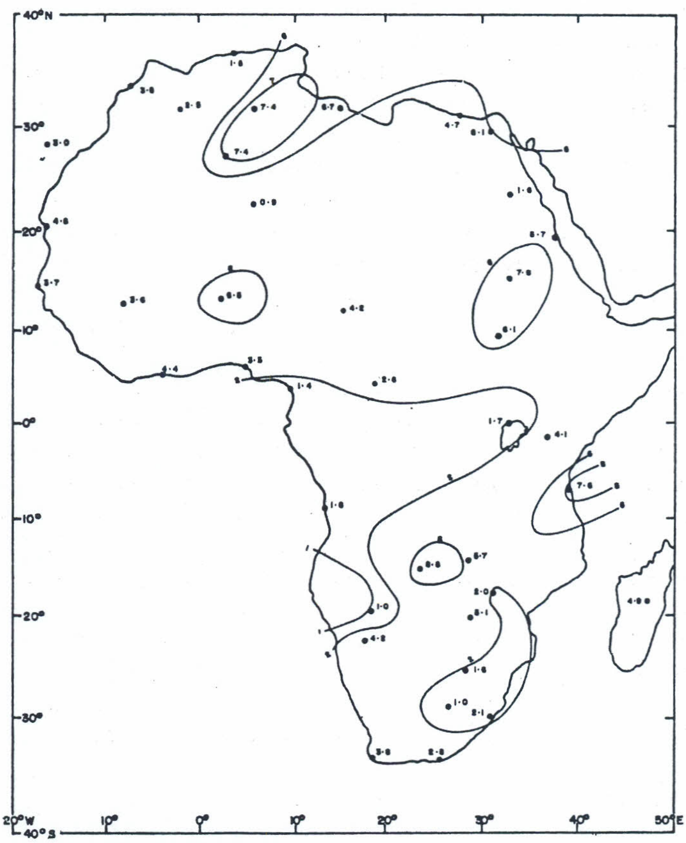

Figure 2. Annual ventilation factor.

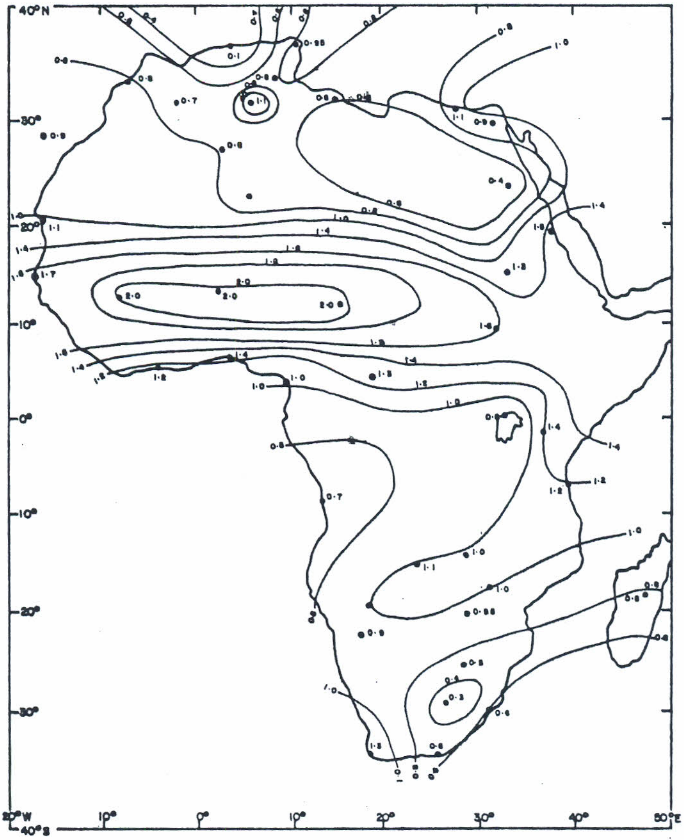

Figure 3. January maximum mixing heights.

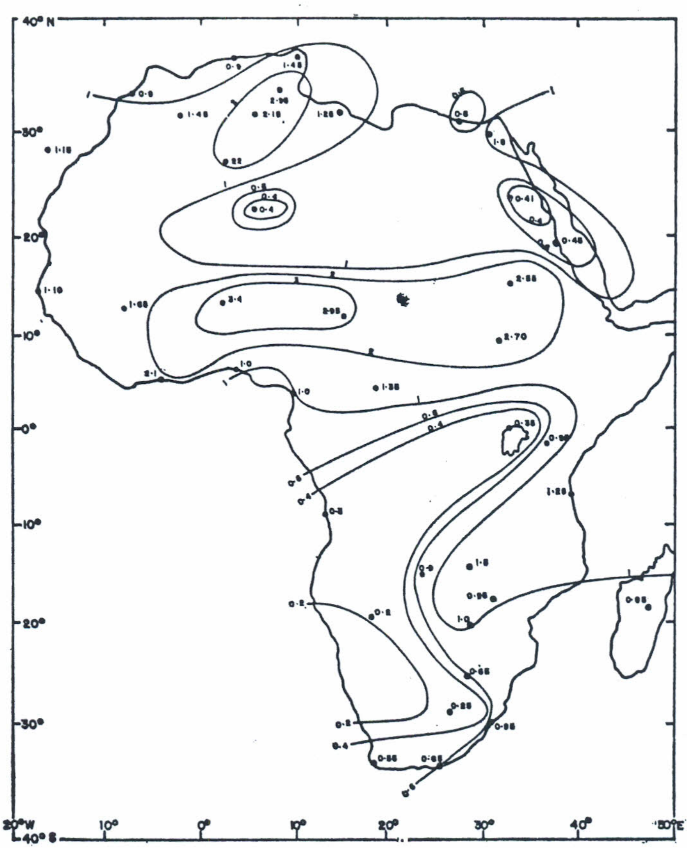

Figure 4. April maximum mixing heights.

Table 1: Monthly mean maximum mixing heights (MMH in km),

	January			February			March			April			May			June		
	MMH	VF	FF	MMH	VF	FF	MMH	VF	FF	MMH	VF	FF	MMH	VF	FF	MMH	VF	FF
Kentra	0.8	6.4	8.0	2.8	10.64	3.8	0.7	2.80	4.0	0.90	3.42	3.8	0.10	0.20	2.0	1.75	12.25	7.0
Santa Cruz	0.9	4.05	4.5	1.2	2.4	2	0.9	2.7	3.0	1.15	4.5	5.2	1.25	4.4	3.5	0.95	3.3	3.5
Dar El Beida	0.1	0.2	2.0	0.6	3.0	5	0.25	1.25	5.0	0.90	3.6	4.0	0.15	0.90	6.0	0.45	1.6	3.5
Bechar	0.7	1.4	2.0	0.7	1.75	2.5	0.6	1.2	2.0	1.45	5.8	4.0	1.05	3.15	3.0	1.15	2.9	2.5
Quagla	1.1	3.3	3.0	1.0	3.0	3	1.3	3.25	2.5	2.15	6.45	3.0	2.3	4.6	2.0	3.15	18.9	6.0
In Salah	0.8	2.4	3.0	0.6	2.1	3.5	1.25	4.4	3.5	2.2	11.0	5.0	2.2	11.0	5.0	3.0	10.5	3.5
Tammanrasset	0.15	0.15	1.0	0.1	0.2	2	0.25	0.63	2.5	0.4	1.2	3.0	0.7	1.75	2.5	—	—	—
Tunis Cathage	0.95	—	—	0.6	—	—	0.9	—	—	1.45	—	—	1.2	—	—	1.55	—	—
Tozeur	0.8	—	—	0.9	—	—	2.2	—	—	2.95	—	—	3.15	—	—	2.50	—	—
Tripoli	0.6	5.4	9.0	1.6	12.8	8.0	1.4	11.2	8.0	1.28	7.7	6.0	1.28	6.4	5.0	1.28	6.7	5.2
Mersa Matruh	1.1	6.6	6.0	0.9	5.0	5.5	1.05	5.3	5	0.5	2.0	4.0	0.55	2.2	4.0	0.55	3.0	5.5
Helwan	0.9	3.2	3.5	1.5	6.0	4.0	1.65	5.8	5.0	1.80	9.0	5.0	2.2	8.6	4.0	1.9	1.3	5.0
Asswan	0.4	1.6	4.0	0.3	1.1	3.5	0.4	1.2	3.0	0.4	1.2	4.0	0.4	1.6	3.9	0.4	2.1	5.0
Khartoum	1.3	6.5	5.0	1.7	10.2	6.0	1.7	8.5	5.0	2.6	10.2	4.0	2.5	5.0	2.0	2.9	8.6	3.0
Port Sudan	1.5	6.3	4.5	1.3	5.9	4.5	0.7	3.9	5.5	0.5	2.3	5.0	0.3	1.7	5.5	0.5	2.0	4.5
Malakal	1.6	9.6	6.0	2.4	12.0	5.0	2.4	9.4	4.0	2.7	8.1	3.0	2.0	5.9	3.0	1.7	3.4	2.0
Novadhibou	1.1	13.2	12.0	1.1	3.3	3.0	1.4	4.1	3.0	—	—	—	1.1	5.3	5.0	0.5	2.5	5.0
Dakar	1.7	6.8	4.0	0.8	3.6	4.5	1.1	4.7	4.5	1.1	4.4	4.0	0.6	2.7	4.5	0.7	3.2	4.3
Bamako	2.0	6.0	3.0	1.1	4.4	4.0	1.5	4.4	3.0	1.7	5.0	3.0	1.3	3.1	2.5	1.0	2.0	2.0
Niamey	2.0	6.0	3.0	2.2	6.5	3.0	3.1	12.4	4.0	3.4	6.8	2.0	2.8	8.4	3.1	1.8	3.1	2.0
Abidjan	1.2	3.6	3.0	1.2	4.2	3.5	1.7	5.8	3.5	2.1	12.6	6.0	0.7	2.0	3.0	1.2	3.6	3.0
Lagos	1.4	4.2	3.0	2.1	10.5	5.0	0.7	1.7	2.5	1.0	3.0	3.0	1.1	2.6	2.5	0.9	3.0	3.3
Douala	1.0	1.0	1.0	1.1	2.2	2.0	0.9	1.4	1.5	1.0	1.5	1.5	1.0	1.6	1.6	0.7	1.4	2.0
Bangui	1.3	1.3	1.0	1.3	2.0	1.5	1.2	3.5	3.0	1.4	3.4	2.5	1.1	3.2	3.0	1.0	4.0	4.0
Port-Lamy	2.0	7.0	3.5	1.5	6.0	4.0	1.7	6.6	4.0	3.0	8.9	3.0	2.2	6.5	3.0	1.5	2.2	1.5
Entebbe	0.8	3.2	4.0	0.6	2.1	3.5	0.4	1.2	3.5	0.4	1.2	3.5	0.3	1.1	4.5	0.6	2.4	4.0
Nairobi	1.4	6.3	4.5	1.7	8.5	5.0	1.7	8.5	5.0	1.0	3.8	4.0	0.9	2.7	3.0	0.8	1.6	2.0
Dar Es Salaam	1.2	6.6	5.5	0.9	4.5	5.0	1.1	3.7	3.5	1.3	5.6	4.5	1.4	9.8	7.0	1.4	7.7	5.5
Bulawayo	1.0	3.8	4.0	1.2	5.4	4.5	1.0	5.2	5.5	1.0	5.0	5.0	0.9	4.1	4.5	—	—	—
Salisbury	1.0	1.0	1.0	1.3	0.7	0.5	0.9	0.9	1.0	1.0	1.0	1.0	1.3	2.5	2.0	1.2	2.3	2.0
Broken Hill	1.0	2.0	2.0	1.2	3.0	2.5	0.9	4.7	5.5	1.5	9.8	6.5	1.2	6.9	6.0	1.1	5.5	5.2
Mongu	1.1	6.6	6.0	1.3	6.5	5.0	0.9	7.7	9.0	0.9	0.9	1.0	1.1	10.5	10.0	1.1	9.5	9.0
Luanda	0.7	2.5	3.5	1.0	3.0	3.0	1.2	3.5	3.0	0.3	1.4	4.5	0.3	1.4	5.5	1.0	0.2	4.0
Tananarive	0.8	1.6	2.0	0.9	2.7	3.0	1.0	2.9	3.0	0.9	2.6	3.0	5.2	20.8	4.0	1.0	3.8	4.0
Diego Garcia	—	—	—	—	—	7.0	—	—	6.0	—	—	2.0	—	—	4.0	—	—	5.0
Vacoas	1.7	9.4	5.5	1.3	5.9	4.5	1.1	3.2	3.0	1.2	3.5	3.0	2.3	10.1	4.5	1.4	6.3	4.5
Ile Nouvelle	—	—	—	—	—	6.0	—	—	6.0	—	—	7.0	—	—	—	—	—	—
Port Aux France	0.5	7.0	14.0	—	—	3	0.4	2.5	7.0	0.2	2.6	17.0	0.2	2.8	14.0	0.4	5.2	13.0
Groot Fontein	0.2	0.6	3.0	0.4	1.6	4.0	0.2	0.8	4.0	0.2	0.8	4.0	0.4	1.4	4.0	0.3	1.0	4.0
J. G. Strijdom	0.9	3.6	4.0	1.0	3.0	3.0	—	—	—	—	—	—	0.9	4.3	5.0	1.0	4.3	5.0
Pretoria	0.5	1.5	3.0	0.5	1.0	2.0	0.4	0.8	2.0	0.7	1.6	2.5	0.8	1.1	1.5	0.9	1.3	1.5
Bloemfontein	0.3	1.2	4.0	0.3	0.9	3.0	0.1	0.2	3.0	0.3	0.8	3.0	0.1	0.3	3.0	0.5	1.5	3.0
Alexanderbay	—	—	—	—	—	6.0	—	—	7.0	—	—	4.0	—	—	3.0	—	—	1.0
Cape Town	1.3	5.2	4.0	1.1	3.9	4.0	0.9	2.6	3.0	0.6	1.7	3.0	0.9	4.3	5.0	1.3	6.5	5.0
Port Elizabeth	0.6	3.6	6.0	0.5	2.0	4.0	0.5	1.1	2.5	0.7	2.9	4.5	0.8	3.2	4.0	0.9	4.3	5.0
Durban	0.6	1.2	2.0	0.8	2.1	3.0	0.7	2.1	3.0	1.0	2.4	2.5	0.9	2.1	2.5	1.0	2.0	2.0
Gough Island	—	—	4.4	—	—	5.0	—	—	5.0	—	—	3.0	—	—	5.0	—	—	6.0
Morion Island	—	—	5.1	—	—	4.0	—	—	6.0	—	—	5.0	—	—	5.0	—	—	2.0

ventilation factors (HV in km/sec) and wind speeds (FF in km/sec)

July			August			September			October			November			December			Annual		
MMH	VF	FF	MMH	VF	FF	MMH	VF	FF	MMH	VF	FF	MMH	VF	FF	MMH	VF	FF	MMH	VF	FF
0.99	0.99	1.0	0.35	1.40	4.0	0.99	0.99	1.0	0.6	1.2	2.0	0.75	37.5	5.0	1.1	4.0	4.4	0.99	3.8	3.8
0.6	1.2	2.0	0.75	1.88	2.5	1.05	3.15	3.0	—	—	—	1.45	2.5	3.6	0.8	1.9	2.5	1.0	3.0	3.0
0.25	0.88	3.5	0.25	1.0	4.0	0.4	1.05	3.0	0.4	1.2	3.0	0.3	1.65	5.5	0.55	4.0	2.2	0.4	1.5	4.0
1.05	5.8	5.5	0.8	2.8	3.5	0.95	2.85	3.0	0.9	2.25	2.5	0.55	0.83	1.5	0.8	1.6	2.0	0.9	2.5	2.8
3.5	10.5	3.0	3.0	6.0	2.0	2.7	7.95	3.0	1.85	9.25	5.0	1.1	2.2	2.0	1.2	4.2	3.5	2.3	7.4	3.2
3.7	18.5	5.0	3.1	15.5	5.0	2.9	14.5	5.0	2.3	11.5	5.0	0.55	2.48	4.5	0.9	3.6	4.0	1.9	7.4	4.3
0.3	1.5	5.0	0.35	1.58	4.5	0.4	1.22	3.5	0.3	0.75	2.5	0.3	0.6	2.0	0.3	0.6	2.0	0.3	0.9	2.8
1.4	—	—	—	—	—	1.85	—	—	1.5	—	—	1.05	—	—	0.95	—	—	1.12	—	—
2.45	—	—	3.7	—	—	3.6	—	—	2.55	—	—	1.35	—	—	1.0	—	—	2.26	—	—
1.28	2.6	2	1.28	3.84	3.0	1.45	4.35	3.0	2.0	6.0	3.0	1.45	7.54	5.2	0.45	2.3	5.0	1.28	6.65	5.2
0.55	3.3	6.0	0.6	3.0	5.0	1.8	6.1	3.5	1.7	6.0	3.5	1.6	4.7	3.0	1.2	5.5	6.6	1.0	4.7	4.7
1.5	6.1	4.0	1.4	5.6	4.0	1.3	3.9	3.0	1.8	7.9	4.5	1.5	4.4	3.0	0.9	3.8	4.0	1.52	6.1	4.0
0.4	2.1	5.0	0.4	1.6	4.0	0.4	2.1	5.0	0.3	0.75	3.0	0.5	1.8	3.5	0.6	1.5	2.5	0.4	1.6	3.9
2.4	7.1	3.0	1.7	6.8	4.0	1.4	2.9	2.0	3.0	12.0	4.0	1.7	6.8	4.0	1.9	6.5	3.5	2.1	7.8	3.8
1.8	7.9	4.5	2.5	10.0	4.0	0.9	4.5	5.0	1.4	7.4	5.5	1.5	7.5	5.0	1.6	6.2	4.0	1.2	5.7	4.8
1.0	3.3	3.5	0.5	1.0	2.0	0.9	2.3	2.5	1.5	2.3	1.5	1.9	9.5	5.0	1.9	11.1	6.0	1.7	6.1	3.6
0.5	2.5	5.0	0.6	4.4	8.0	1.0	4.3	4.5	0.8	4.0	5.0	1.5	2.9	2.0	1.0	2.9	3.0	0.9	4.8	5.1
0.9	3.6	4.0	1.0	3.5	3.5	1.2	4.0	3.5	0.7	2.8	4.0	0.7	2.6	4.0	0.8	2.3	3.0	0.9	3.7	4.0
0.9	1.7	2.0	1.2	1.7	1.5	1.0	5.0	5.0	1.3	3.8	1.3	1.3	2.6	2.0	1.3	4.6	3.5	1.3	3.7	2.9
1.4	2.7	2.0	0.7	1.1	1.5	0.9	2.1	2.5	3.0	12.0	4.0	3.1	12.4	4.0	1.5	6.0	4.0	2.2	6.5	3.0
1.4	3.5	2.5	1.3	3.1	2.5	1.2	2.9	2.5	1.3	4.4	3.5	1.3	5.6	4.5	1.1	3.9	3.5	1.3	4.4	3.4
1.0	3.8	4.0	0.9	3.6	4.0	—	—	—	—	—	—	1.0	3.5	3.5	0.2	0.5	2.5	1.0	3.3	3.3
0.7	1.0	1.5	0.7	1.1	1.5	0.8	1.6	2.0	0.9	1.7	2.0	1.0	1.6	1.6	0.7	0.7	1.0	0.9	1.4	1.6
1.0	1.4	1.5	1.1	1.7	1.5	—	—	—	—	—	—	—	—	—	—	—	—	1.2	1.6	2.3
1.2	1.7	1.5	0.9	1.4	1.5	1.2	2.9	2.5	1.3	3.2	2.5	0.8	2.4	3.0	1.3	3.8	3.0	1.5	4.2	2.8
0.4	1.6	4.0	0.5	1.8	3.5	0.4	1.2	3.5	0.3	1.1	3.5	—	—	—	—	—	—	0.5	1.7	3.8
0.9	1.3	1.5	1.1	2.6	2.5	1.3	2.5	2.0	1.2	4.2	3.5	1.0	5.2	5.5	0.9	4.1	4.5	1.1	4.1	3.6
1.7	13.6	8.0	1.7	9.9	6.0	1.6	9.3	6.0	1.4	8.4	6.0	1.2	5.4	4.5	1.3	8.8	7.0	1.3	7.6	5.7
1.2	5.8	5.0	1.1	5.3	5.0	1.3	3.8	3.0	1.3	6.9	5.5	1.3	5.6	4.5	1.2	4.6	4.0	1.1	5.1	4.6
1.3	2.5	2.0	1.2	2.3	2.0	1.3	2.5	2.0	1.3	3.9	3.0	—	—	—	—	—	—	1.2	2.0	1.7
1.2	8.6	7.5	0.7	5.3	7.5	1.2	8.6	7.5	1.2	7.8	6.5	1.1	3.7	3.5	1.0	2.5	2.5	1.1	5.7	5.2
1.1	8.4	8.0	1.0	9.5	10.0	1.3	13.8	11.0	1.3	10.4	8.0	1.3	7.5	6.0	0.9	4.3	5.0	1.1	8.7	8.1
0.2	0.5	3.4	0.9	3.0	3.5	0.2	0.6	3.0	0.1	0.4	4.0	0.5	1.6	3.5	1.0	2.9	3.0	0.5	1.8	3.4
1.0	4.8	5.0	1.1	4.4	4.0	1.2	4.8	4.0	1.9	3.0	5.7	1.4	4.1	3.0	1.2	2.3	2.0	1.4	4.9	5.4
—	—	5.0	—	—	5.0	—	—	4.0	—	—	3.0	—	—	2.0	—	—	5.0	—	—	4.4
1.4	9.1	6.5	1.5	9.4	6.5	1.6	7.0	4.5	1.5	4.8	4.0	1.6	3.0	4.7	1.7	5.0	3.0	1.5	6.6	4.4
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	6.3
0.3	2.7	9.0	—	—	—	0.6	8.3	15.0	0.4	4.6	13.0	0.5	7.5	15.0	2.7	34.5	13.0	0.6	7.3	12.1
0.4	1.8	5.0	0.4	1.6	4.0	0.4	1.2	3.0	0.4	0.8	2.0	0.3	0.8	3.0	0.4	0.7	2.0	0.3	1.0	3.3
0.9	4.5	5.0	1.0	5.0	5.0	1.1	4.4	4.0	1.2	3.6	3.0	1.5	3.0	2.0	1.2	3.5	3.0	1.1	4.2	3.9
0.8	1.1	1.5	0.8	1.1	1.5	0.8	1.9	2.5	0.9	2.7	3.0	0.7	2.8	4.0	0.7	1.0	2.5	0.7	1.6	2.3
0.3	0.9	3.5	0.3	1.2	4.0	0.1	0.4	4.0	0.4	1.6	5.0	0.2	1.1	7.0	0.3	1.2	4.0	0.3	1.0	3.9
—	—	1.0	—	—	3.5	—	—	5.0	—	—	7.0	—	—	7.0	—	—	10.0	—	—	4.7
1.1	4.2	4.0	1.2	5.8	5.0	1.0	2.4	2.5	1.1	3.3	3.0	1.0	2.5	2.5	1.1	4.4	4.0	1.0	3.8	3.7
0.8	6.5	4.9	0.3	1.4	5.5	0.9	4.3	5.0	0.7	3.6	5.5	0.6	2.2	4.0	0.3	1.2	4.0	0.6	2.8	4.7
0.9	2.3	2.5	0.8	1.9	2.5	0.8	2.3	3.0	1.0	3.0	3.0	0.7	1.8	2.5	0.8	2.4	3.0	0.8	2.1	2.6
—	—	4.0	—	—	4.0	—	—	4.0	—	—	4.0	—	—	4.0	—	—	4.0	—	—	4.4
—	—	6.0	—	—	5.0	—	—	7.0	—	—	5.0	—	—	6.0	—	—	5.0	—	—	5.1

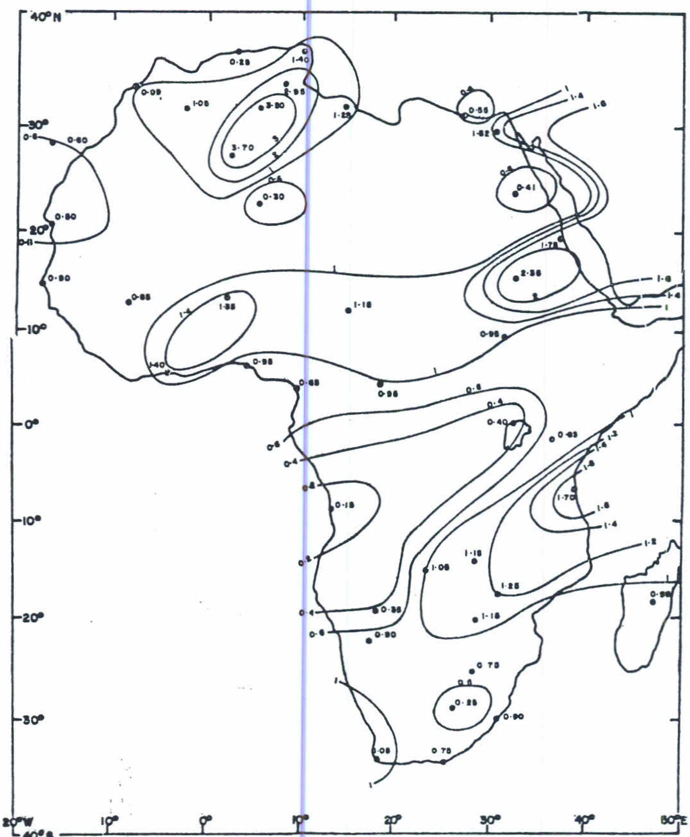

Figure 5. July maximum mixing heights.

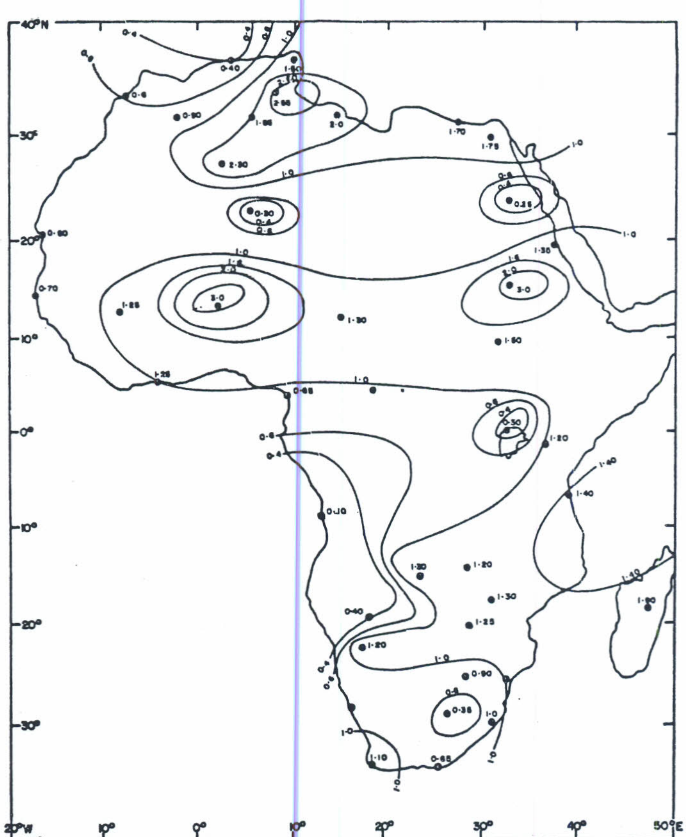

Figure 6. October maximum mixing heights.

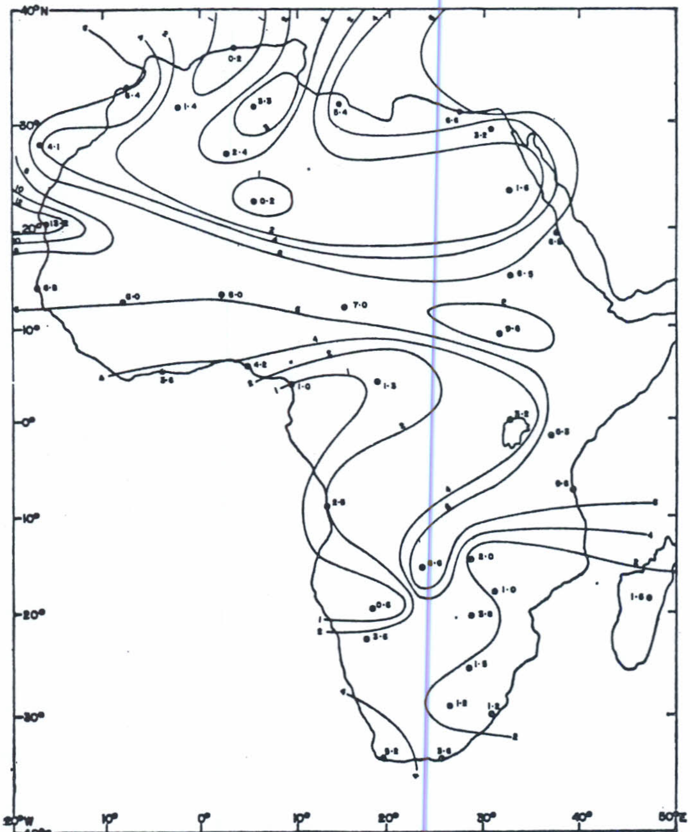

Figure 7. January ventilation factor.

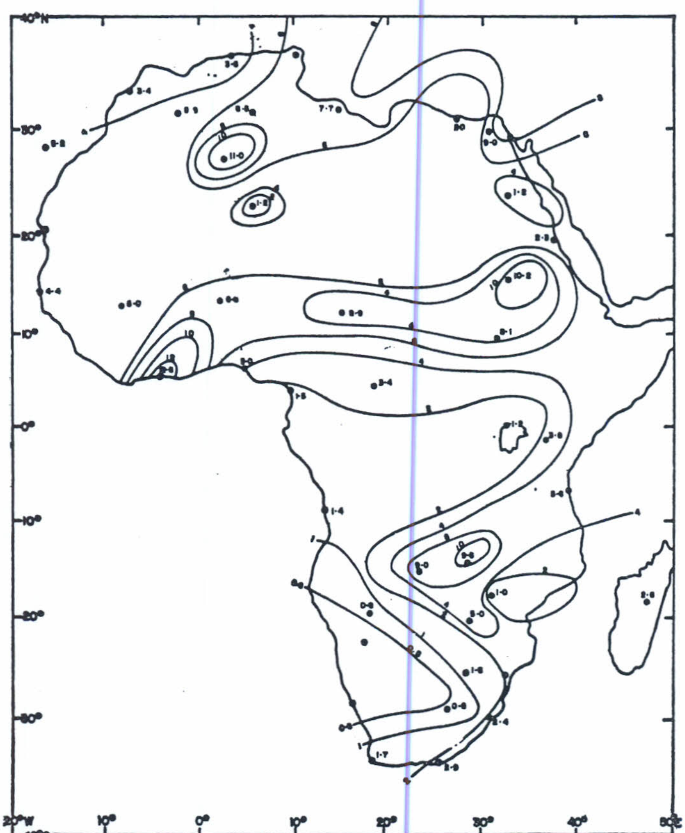

Figure 8. April ventilation factor.

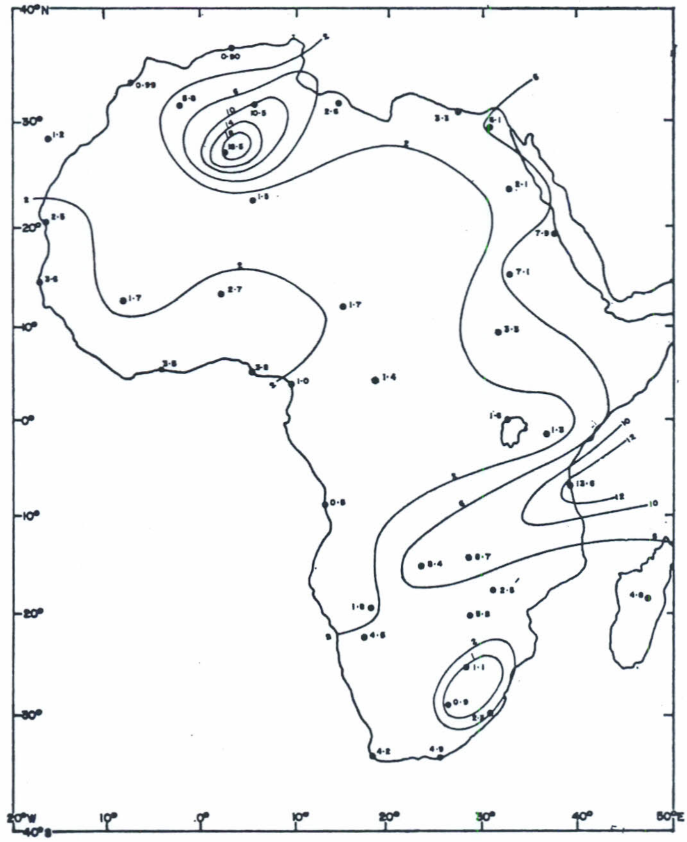

Figure 9. July ventilation factor.

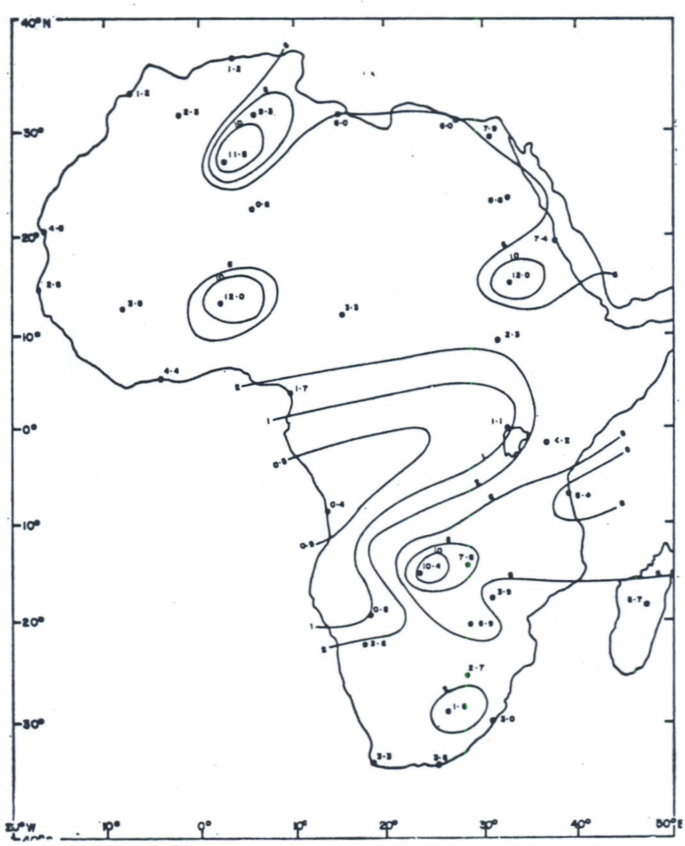

Figure 10. October ventilation factor.

a rough allowance for effects of the urban "heat island". Using a similar procedure, the pollution potential over India was estimated by Patnaik and Satyanarayana (1977). The present work aims at finding out the maximum mixing heights (MMH) and ventilation factor (VF) over Africa.

As there are no highly industrialized and congested urban complexes in Africa, the need for allowance for effects of urban "heat island" is neglected in the present study.

Data and method of computation

The monthly upper air temperature and wind data for 48 radiosonde stations in Africa and surrounding islands were extracted from monthly climatic data for the world, published by the US Department of Commerce. The period of study extends from 1960 to 1971. The mean temperatures and wind speeds for all months of the years considered were obtained for the surface, 850 mb, 700 mb and 500 mb pressure surfaces. The climatic mean maximum surface temperatures for all the stations were extracted from the tables of temperatures supplied by the British Meteorological Office (M.O. 617d, 1964). Vertical profiles of temperature and wind speed were drawn for each of the stations during the 12 months of the year. The altitudes of the stations are neglected. From the point of maximum surface temperature the dry adiabatic lapse rate line (9.8°C/km) was drawn. The altitude of intersection of the temperature curve and the dry adiabatic line was noted for each station. The point of intersection of the temperature curve and the dry adiabatic line gives the maximum mixing height (MMH) or depth. In this study it is expressed in kilometres. The average wind speed through this thickness is also given. In this study the units are metres per second. The wind speeds at different significant levels, starting from the surface through the layer of the atmosphere covered by the maximum mixing height and the wind speed at the significant level above the intersection point of vertical temperature profile and the dry adiabatic line, are added and the average is determined. The average wind speed is taken as the mean wind of the layer. The product of the average wind speed and the maximum mixing height gives the ventilation factor (VF). The units for this parameter is 10^{-3}km/sec. Table 1 gives the values of maximum mixing heights, mean wind speed and the ventilation factors.

The authors are of the opinion that the values of the MMH and VF could be greater than are presented in table 1. The temperatures, particularly at ground level, are measured under the Stevenson's screen conditions (Petterssen 1956), whereas the pollutants are exposed to direct sun and are heated directly. Depending on the heat capacities of the particulate and other aerosol pollutants the temperatures of these may be higher, though there is continuous heat exchange between the pollutants and the ambient atmosphere.

DISCUSSION AND RESULTS

The annual charts of MMH and VF values are shown in figures 1 and 2. The contour patterns follow the general climatic disposition of temperature and winds over the African continent. These annual MMH values are somewhat higher than those prevailing in the USA (Holzworth 1964b) and India (Patnaik and Satyanarayana 1977). This can be attributed to the fact that large portions of the African continent experience relatively warm to hot climates throughout the year (Trewartha 1954).

Over the interior of Africa high MMH values are found over the Sahel region. This zone of high MMH values is confined to between latitudes 15°N and 0°. The MMH values in this zone lie in the range 1.0 to 2.5 km. Low MMH values are found in the interior of the Sahara Desert. This is a manifestation of the high stability associated with the large-scale dynamic descent prevalent in these latitudes. Over the countries along the Mediterranean Sea we find MMH values of the order of 1 to 2 km: this is particularly so over Libya in north Africa.

Also, the countries adjoining the west Indian monsoon zone exhibit MMH values lying in the range 1.0 to 1.5 km.

The annual values of the VF for Africa are shown in figure 2. The configuration of the VF isolines resemble those of the MMH values in figure 1. Particularly high VF values (6 to 8×10^{-3}km^2/sec.) are found over the regions bordering west Indian Ocean. This can be attributed to the existence of high wind speeds associated with the low level jet stream prevalent over the west Indian Ocean during the northern hemisphere summer (Findlater 1969). Generally the Sahel zone of Africa exhibits VF values lying in the range 3 to 8 $\times 10^{-3}$km^2/sec. The seasonal variations of MMH values are given in figures 3 to 6. The distribution of the MMH values during the months of January, April, July and October show that the northern hemisphere portion of Africa has relatively higher values than those over the southern hemisphere. Nonetheless, the spatial distribution appears the same as one moves from one season to another. The characteristic zone of high MMH values across the African Sahel zone is evident during the four months. The centre of this zone with high MMH values is somewhere along the latitude of Bamako, Niamey and Fort Lamy.

The seasonal distribution of VF values over Africa is shown in figures 7 to 10. It is immediately evident from these figures that high values of VF are, as in the case of MMH values, found in the Sahelian zoné of Africa. The months of January and April exhibit relatively larger VF values than during July and October: this is particularly so over the Sahelian region.

ACKNOWLEDGEMENTS

The authors wish to thank Prof. R. Ramanadham and Prof. G. O. P. Obasi for initiating the project and advice at different stages.

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Acceptance date: 3 December 1979.