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DEW AND RAIN WATER POTENTIAL IN NORTH MATABELELAND (ZIMBABWE)

Vodni potencijal rose i kiše u sjevernom Matabelelandu (Zimbabve)

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Abstract: Matabeleland North is, during the dry season (April–Sept.), one of the driest regions in Zimbabwe. However, the relative air humidity remains large, which makes dew an interesting potential supplementary source of water. In this paper, one reports an estimation of dew over one year i.e. between 29 May 2020 and 28 May 2021 by using an energy equation and meteorological data extrapolated from the Joshua Mqabuko airport. The calculation was validated by measurements between 1 June 2020 and 21 July 2020 performed on cars used as standard dew condensers. Rain is also considered to determine the dew/rain ratio. It follows from this study that during the dry season, dew is relatively abundant (8.66 mm) and amounts to nearly 40% of rain (22.6 mm). However, dew becomes rare at the end of the dry season (Aug.–Sept.). Dew events are frequent (dry season, typically 1.4 days without dew events; rainy season, 2 days), in contrast to rainfall (dry season, typically 32 days without rain events and erratic; rainy season, 4.1 days). Dew can thus provide a noticeable and reliable supplementary source of water during most of the dry season.

Key words: dew water, rain water, dew/rain ratio, North Matabeleland (Zimbabwe), dry season

Sažetak: Tijekom suhe sezone (travanj – rujan) sjeverni Matabeleland jedna je od najsušnijih regija u Zimbabveu. Međutim, relativna vlažnost zraka ostaje visoka, zbog čega je rosa zanimljiv potencijal dopunskog izvora vode. U radu se prikazuje procjena rose tijekom jedne godine, to jest između 29. svibnja 2020. i 28. svibnja 2021., pomoću energetske jednadžbe i ekstrapoliranih meteoroloških podataka zračne luke Joshua Mqabuko. Izračun je potvrđen na mjerenjima iz razdoblja 1. lipnja 2020. – 21. srpnja 2020. obavljenim na automobilima koji se upotrebljavaju kao standardni kolektori rose. Kiša se također razmatra za određivanje omjera rosa/kiša. Iz ovog istraživanja proizlazi da je tijekom suhe sezone rosa relativno obilna (8,66 mm) i iznosi gotovo 40 % kiše (22,6 mm). Međutim, rosa postaje rijetka pojava krajem suhe sezone (kolovoz – rujan). Za razliku od kiše (suha sezona, uglavnom 32 dana bez kiše, neredovita kiša; kišna sezona 4,1 dan) pojava rose jest česta (suha sezona, uglavnom 1,4 dana bez pojave rose; kišna sezona 2 dana). Rosa stoga može osigurati primjetan i pouzdan dopunski izvor vode tijekom većeg dijela suhe sezone.

Ključne riječi: voda od rose, kišnica, omjer rosa/kiša, sjeverni Matabeleland (Zimbabve), suha sezona

1. INTRODUCTION

The global community is presently seeking ways to mitigate the scale and impact of climate change. While Africa has the world's lowest greenhouse gas emissions per capita, it is one of the continents which is the toughest hit by the impacts of climate change. The poorest communities of Africa are often powerless to face extreme weather events such as droughts, with catastrophic repercussions like famine and livelihood insecurity (Muzerengi and Tirivangasi, 2019). Zimbabwe declared a state of emergency in 2016 because of a drought that produced crop failures (Tirivangasi, 2018). Food production in Zimbabwe is very sensitive to temperature and precipitation changes (Zimbabwe Human Development Report, 2017). The fact that maize is approximately 80%–90% of the food production renders the country vulnerable to climate, especially the region of Matabeleland. In this region there is usually very small amount of rain during the dry season (Apr.–Sept.), on average 63 mm (Weather and climate, 2023).

In this context, dew water, which has been ignored for a long time as a potential source of fresh water, could be of help to the communities. Dew is indeed a natural phenomenon which corresponds to the condensation of water vapor in the atmosphere under passive radiative cooling. Dew forms when the relative air humidity is high (larger than 70%–80%) to find the dew point located within only a few degrees below the air temperature. In addition, the sky should be clear and the wind not too strong to ensure efficient cooling. As the relative humidity in Matabeleland is high in most of the months (World data, 2023) and since the weather is characterized by a large number of clear, sunny days, dew should be frequent.

There is a long history of dew water collection for drinking or agricultural use, mainly coming from legends or oral traditions. For example, it is said that Bedouins in the deserts collected dew water for centuries for drinking purposes. But the oldest documented written report seems presently to be from the alchemists in the Mutus liber (1677) who collected dew for their manipulations. Other achievements are noted in Crimea at the beginning of the 20th century, dealing with dew condensing by thermal inertia on massive structures (Zibold, 1905; Nikolayev et al., 1996), then in USSR and France in the 1930's (Mylymuk-Melnytchouk and Beysens, 2016; Knapen, 1929; Chaptal, 1932). Large modern structures that use radiative cooling have been erected in Israel by Gindel (1965), in France by Muselli et al. (2002; 2006), in Morocco by Clus et al. (2013) and in NW India by Sharan et al. (2011, 2017). One notes that dew harvesting could fulfil 75–95% of the water needs during the 2nd harvest of maize in North Benin (Koto N'Gobi, 2014; Koto N'-Gobi et al. 2018). The dew yield is limited to the available radiative energy, on order of 60–100 Wm^{-2}. This value limits the yield of passive radiative condensers to about 0.7 Lm^{-2}. The actual yield is, nevertheless, often much higher because the technologies used permit weak precipitation (rain, fog), usually lost, to be also recuperated.

Dew is also naturally used by plants and small animals (Tomaszkiewicz et al., 2015; Beysens, 2018). It is sometimes a critical source of water in desert environments when it governs the sustainability of sand to stabilize planted vegetation (Zhuang and Zhao, 2017). In semi-arid regions, dew can contribute with fog and rain to the growth of cyanobacteria in the biocrust (Kidron, 2019). The contribution of dew can be vital for some plants and animals, during drought episodes in humid areas and in semiarid and arid regions (Jacobs et al., 1999; Uclés et al., 2014; Wang et al., 2017; Charnès et al., 1978; Beysens, 2018). Dew gives nightly moisture to plants (Steinberger et al., 1989; Dou et al., 2021). Water is absorbed by leaves through stomata or special physical features as for instance in aerial vegetation (Monteith and Unsworth, 2013; Gerlein-Safdi et al., 2018). Dew increases photosynthesis (Zhuang and Ratcliffe, 2012) and improves the efficiency of water used by plants (Monteith and Unsworth, 2013; Ben-Asher et al., 2010).

The goal of this work is then to estimate the potential of dew and rain to generate fresh water. The time duration of the study is one year (from May 29, 2020 to May 28, 2021) to account for seasonal variations. The paper is organized as follows. The first section deals with the characteristics of the region. Then the methods used to estimate dew and rain are exposed. The next section is devoted to the results obtained on dew, the conditions of its formation and the number of consecutive days without events. Another section is concerned with rain. The last section is involved with the contribution of dew to the total precipitation.

2. MEASUREMENTS AND METHODS

2.1. The studied sites

Matabeleland North is located south west of Zimbabwe (Fig. 1). The mean elevation is 996 m asl. The climate is subtropical steppe climate (Köppen Classification: BSh). The area is one of the warmest regions in Zimbabwe with an average air temperature of 31°C during the day. It is warm or hot throughout the year. The mean annual temperature is 24.52°C and it is 1.79% larger than the Zimbabwe average. The country experiences its rainy season with relatively high temperatures from October to March and it encounters dry seasons with low temperatures from April to September. The annual precipitation amount is 1142 mm, which mainly falls during the rainy season (1079 mm), while the precipitation amount is very low during the dry season (63 mm) (Weather and climate, 2023).

The dew yields are measured on two cars parked during the night near Bulawayo by an observation technique developed by Beysens et al. (2016) and Muselli et al. (2022a) (see section 3.3). The first car (called #1) is located at lat. 20.15°S, lon. 28.62°E, alt. 1341 m asl and the second car (#2) at lat. 20.17°S, lon. 28.60°E, alt. 1369 m asl. Both of these sites are distant to about 15 km and 17 km respectively to the Joshua Mqabuko Nkomo international airport (lat. 20°01'1.65" S; long. 28°37'2.59" E; alt. 1369 m asl) where the meteorological data are collected. The distance between the measurement sites #1 and #2 is 2.7 km.

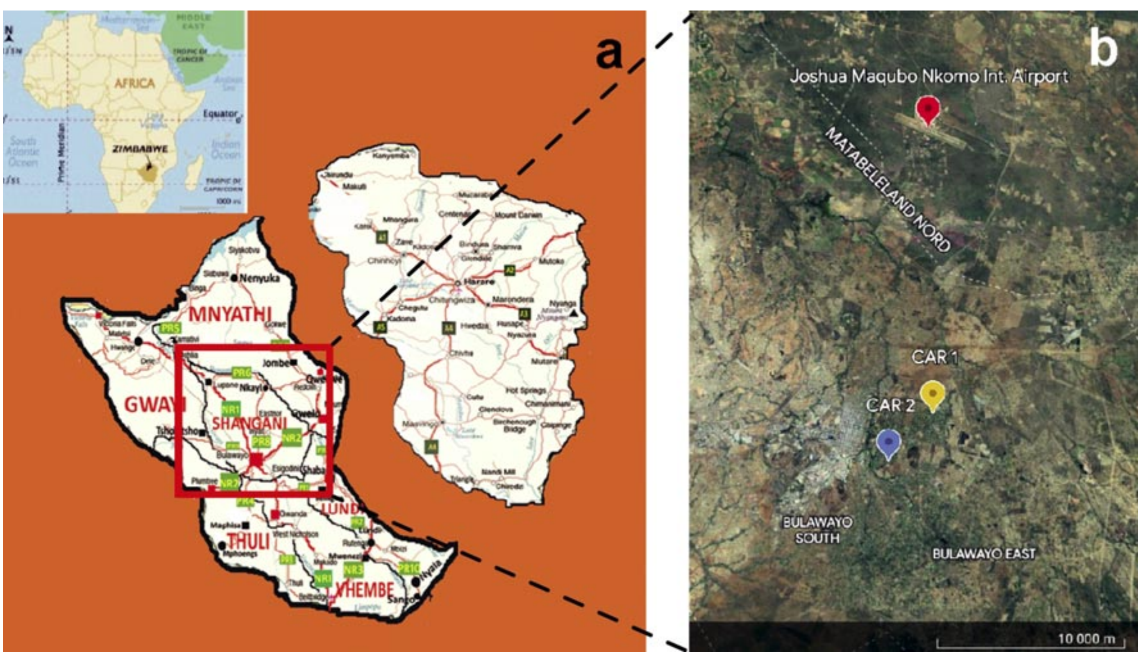


Figure 1. Location of Zimbabwe in Africa and the region of Matabeleland, located on the left, and the rest of Zimbabwe on the right (a) (author: Mcebisi Ndebele Ka Jesu). The region where evaluations are carried out is highlighted in with the Joshua Mqabuko Nkomo International Airport (b) top) and the two sites of dew measurements car 1 and car 2 (b) bottom) (Satellite photo from Google map).

Slika 1. Položaj Zimbabvea u Africi i regije Matabeleland (a) lijevo) i ostatak Zimbabvea (a) desno) (autor Mcebisi Ndebele Ka Jesu). Regija gdje su izvedene procjene posebno je istaknuta međunarodnim aerodromom Joshua Mqabuko Nkomo (b) gore) i dvama mjestima mjerenja rose automobilom 1 i automobilom 2 (b) dolje) (satelitska slika s Google mapa).

2.2. Collection of meteorological data

There are unfortunately only a few meteorological measurement sites in Zimbabwe. The Weather Underground hourly data base (Weather Underground, 2023) nevertheless provides meteorological data from Matabeleland North (lat. 19°S, lon. 27.5°E). Air temperature T_a (°C), dew point temperature T_d (°C), wind speed at 10 m height V (kmh^{-1}), wind direction (deg.) and sky conditions are extracted from the database. However, only hourly interpolated predictions from gridded points are available (time in Zimbabwe is UTC+2). The predicted meteorological data were thus recorded at 21:00 for the next 24h. The cloud cover in oktas, N, is determined from the sky conditions according to standard descriptions of the local meteorology. Recent works have verified and implemented simple correlation between the sky conditions and N in oktas (Muselli et al., 2020; Muselli et al., 2022b). The studied period is one year from May 29, 2020 to May 28, 2021; 12 days (2.7% of whole data) are missing. Unfortunately, numerous hourly data are missing, in an erratic way, causing large errors in the dew calculation and leading to underestimated values. One thus considered only the data obtained at 05:00, before sunrise. Daily rainfall data (mmday^{-1}) were extracted from the Worldweatheronline database (Worldweather online, 2022).

2.3. Dew calculation

In order to estimate the dew potential, Beysens (2016) developed an energy balance model that uses only a few classical meteorological data: cloud cover (N, oktas), wind speed (V, ms^{-1}), air temperature (T_a, °C), relative air humidity (RH, %) and dew point temperature (T_d, °C).

Using a time step of 12 hours, the daily dew yields h_d (mmhour^{-1}) can be calculated using the airport data from the following formulation:

$$h_d = (HL + RE) \tag{1}$$

The data for $h_d > 0$ correspond to condensation and $h_d < 0$ to evaporation, which are rejected. The quantity HL represents the convective heat losses between air and condenser, with a cut-off for wind speed $V>V_0$ = 4.4 ms^{-1} where condensation vanishes:

$$HL = \begin{cases} 0.06(T_d - T_a) & if\ V < V_0 \\ -10^6 & if\ V > V_0 \end{cases} \tag{2}$$

It means that when $V>V_0$ the negative contribution of heat losses is so important that the dew yield becomes negative and are discarded.

The quantity RE is the available radiative energy, which depends on air water content (measured by T_d, °C), site elevation H (in km) and cloud cover N (in oktas):

$$RE = 0.37 \times (1 + 0.204323H - 0.0238893H^2 - (18.0132 - 1.04963H + 0.2189H^2) \times 10^{-3}T_d)((T_d + 273.15)/285)^4 \left(1 - \frac{N}{g}\right) \tag{3}$$

The cumulative daily yields (mm) can be estimated by filtering the rain or fog events and integrating the time series on a daily timestep corresponding to $h_d > 0$. Rain and fog events are based on the observations at the airport at each time step.

2.4. Dew measurements

Two sites of measurements are considered in this study (see Fig.1 and section 2) to compare with calculations. The measured period is June 1, 2020 to July 21, 2020 corresponding to 23 daily observations. There was some (rare) unavailability of measurements on site. Dew observations are carried out by observing whether dew forms on three different parts of a car (rooftop, windshield and lateral windows). An indicator, n, is used to quantify the observations (Beysens et al., 2016; Muselli et al., 2022a): $n = 0$, no dew everywhere; $n = 1$, dew only on the car rooftop; $n = 2$, dew on rooftop and windshield; $n = 3$, dew on rooftop, windshield and lateral windows. Figure 2 shows dew forming on lateral windows and windshield. Cars were randomly observed at each location.

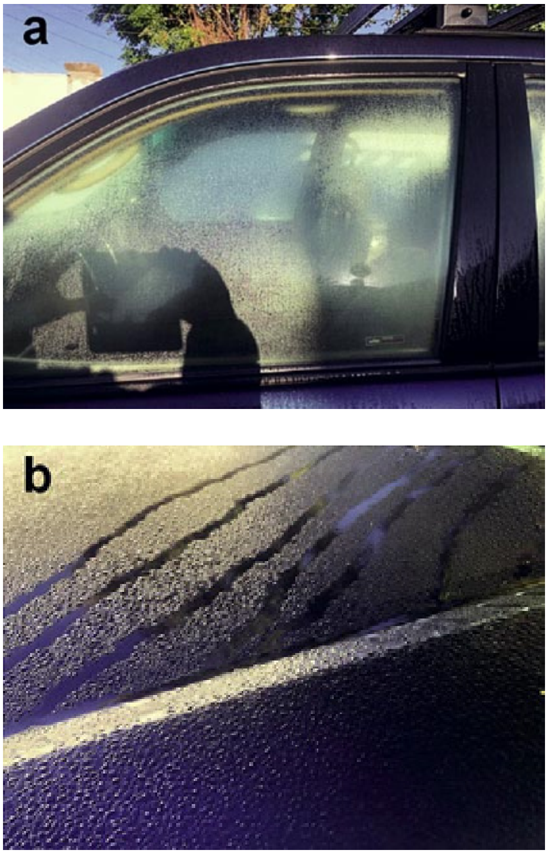


Figure 2. Dew formed on a car during the night on a lateral window (a) and the windshield (b).

Slika 2. Rosa nastala na automobilu tijekom noći na bočnim prozorima (a) i na vjetrobranskom staklu (b).

3. RESULTS

3.1. Dew

3.1.1. Comparison between calculation and measurements

Figure 3 presents a correlation between the cumulative indicators as measured on the cars and the daily dew yields (mmday^{-1}) calculated with the energy model. Only the days corresponding to dew observations on cars are presented in order to compare curves on the same time basis.

The daily accumulation of dew yields calculated by the model follows the evolution of the accumulation of observations, *sum*(h_d). However, the observed law of proportionality has a coefficient close to 0.05 instead of the expected value 0.067 (Beysens et al., 2016; Muselli et al., 2022a). The same value (n/h_d =0.052±0.01 dmm^{-1}) is obtained with the daily data (inset in Fig. 3). This low value may be due to an underestimation of the indicator *n* at the time of the morning reading on the cars or to a late reading when the action of the sun has already led to partly evaporate the dew.

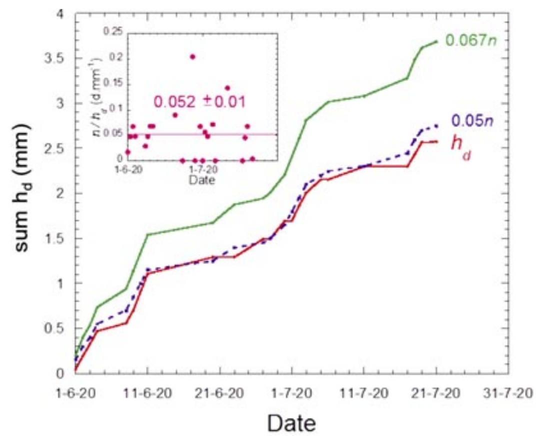


Figure 3. Correlation between the cumulative daily dew yields *sum*(h_d) (mm) obtained during two months of the dry season from Eq.1 with the corresponding cumulative values of the indicator *n* used to estimate dew on cars (Beysens et al., 2016; Muselli et al., 2022a). Inset: Daily ratio n/h_d (dmm^{-1}). The line is a fit to the data giving $\overline{(n/h_d)}$ = 0.052±0.01dmm^{-1}.

Slika 3. Korelacija između kumulativne dnevne količine rose *sum*(h_d) (mm) dobivena tijekom dva mjeseca sušne sezone iz jednadžbe 1 s odgovarajućim kumulativnim vrijednostima indikatora *n* korištenom za procjenu rose na automobilima (Beysens i sur., 2016; Muselli i sur., 2022a). Umetnuto: Dnevni omjer n/h_d (dmm^{-1}). Linija odgovara danim podacima $\overline{(n/h_d)}$ = 0.052±0.01dmm^{-1}.

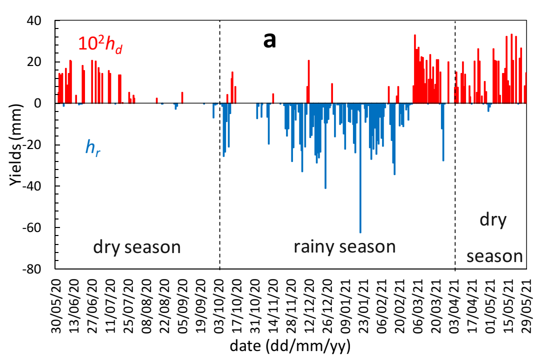
3.1.2. Dew evolution and yield

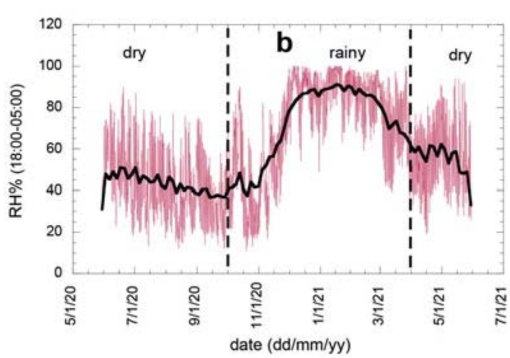
Figure 4a shows the daily evolution of dew and rain yields (negative values). For better visibility, the dew yields are presented with a multiplicative factor (×10^2). One clearly sees the two seasons, dry between April and September and rainy between October and March. One also observes that dew forms regularly when the sky is clear (rain is not present) and the relative humidity is large enough during the night (Fig. 4b). Relative air humidity (RH) was averaged during the night, which does not vary much in the year. RH data were thus averaged between the constant times

18:00 and 05:00, except for 12 nights where the data were not available at 05:00 and replaced by values at 04:00 or 06:00. There is indeed always a strong correlation between the dew yield and RH, as verified in Fig. 7a.

The statistics of these time series are presented in Table 1. One notes a complementarity between the water inputs in winter with rainfall and in summer with dew. Over the dry period April–September, one observes 62 dew days and 20 rainy events while in the rainy period October–March, one sees 32 dew days and 112 rainy days. Thus, the whole year exhibits 94 dew days (26.6%) and 132 rainy days (42.8%). On a monthly basis, the dew yield <h_d> = (1.13±1.32) mm per month (min: 0 mm in Jan. 2021; max: 3.86 mm in March 2021), with a large dispersion according to the seasons.

The cumulative dew values are shown in Fig.4c. Between June 2020 and the end of September 2020, dew is the only available source of atmospheric water (cumulative 330 mm).





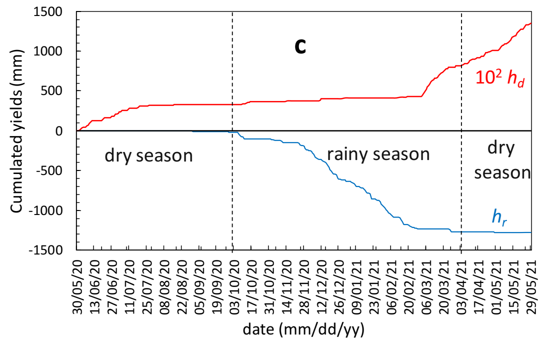


Figure 4. Evolution of dew yields in units of 10^2 mm per day ($\times 10^2$ mmd^{-1}, red bars) and rain yields in mm per day (mmd^{-1}, displayed as negative blue bars) (a). The studied period corresponds to 94 dew events and 132 rain events. Dew yields are computed from Eq. 1. Relative air humidity RH (%) averaged during the night (18:00–05:00 o'clock) (b). The black curve is a smoothing of the data. Cumulated dew (red data) and rain (blue data) in mm units (c). Dry and rainy seasons are delimited by black interrupted lines.

Slika 4. Razdioba količine rose u jedinicama od 10^2 mm po danu (x10^2 mmd^{-1}, crveni stupci) i količine kiše u mm po danu (mmd^{-1}, prikazane kao negativni plavi stupci) (a). Razmatranom razdoblju korespondiraju 94 pojave rose i 132 pojave kiše. Količina rose se izračunava iz jednadžbe 1. Relativna vlažnost zraka RH (%) osrednjena tijekom noći (18:00–05:00 sati) (b). Crna krivulja je izglađivanje podataka. Kumulativna količina rose (crveno) i kiše (plavo) u milimetrima (c). Sušne i kišne sezone su razgraničene crnim isprekidanim linijama.

3.1.3. Dew frequency with respect to meteorological parameters

The histograms of dew events during the dry and rainy seasons are represented in Figure 5. They are similar. One sees that dew yields are important since, for dry and rainy season 40.3% and 50% of events, respectively, have a yield greater than 0.15 mm. Only 14.5% and 9.4% of events are lower than 0.05 mm for the dry and rainy season, respectively. The no-dew days during dry and rainy season represent respectively 64.7% (114 nights) and 81.9% (145 nights) of the events.

The correlation between dew yields and the important meteorological parameters for dew formation (wind speed, relative air humidity and cloud cover) is presented in the following.

Figure 6 is concerned with the influence of wind. Dew yields with respect to wind speed (at 10 m height, in ms^{-1}) are reported in Figure 6a and the influence of wind direction (at 10 m, in sectors) is drawn in Figure 6b. One clearly observes that dew does not form when $V \geq 3.5$ ms^{-1}. This value is below the cut-off imposed in the model $V_0 = 4.4$ ms^{-1} and thus not correlated. The dominant wind directions during the nightly dew formation and for the whole day are the same: east/southeast, corresponding respectively to more than 25% and 30% of the events.

Dew begins to form when RH>60%. However, if one ignores three very low dew events, dew forms only when RH>70%. The highest dew yields, between 0.3 and 0.4 mmd^{-1}, can be reached only when RH>90%.

Concerning cloud cover (Fig.7b), one notes the presence of a threshold at N=6. Above this value the dew yields become zero. In order to fit the envelope of the data one defines a linear variation similar to Eq. 4:

$$h_d = a'_d N + b'_d \quad (5)$$

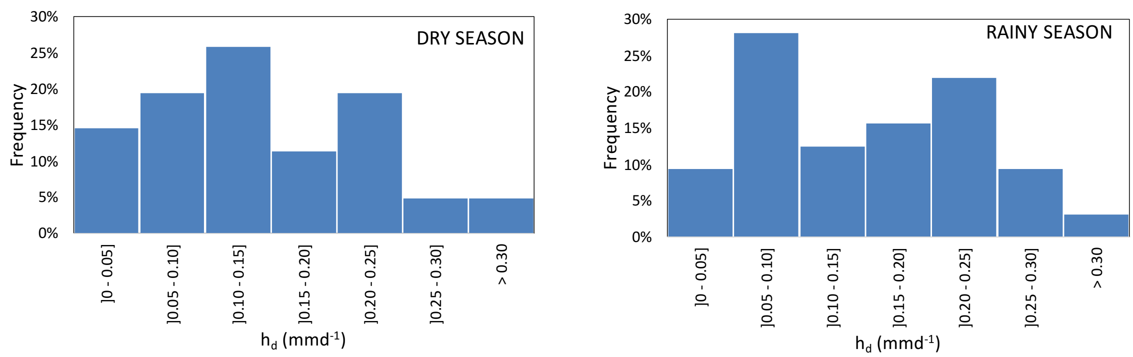


Figure 5. Dew event relative frequencies (94 events) for dry and rainy season.

Slika 5. Relativna čestina pojave rose (94 događaja) za suhu i kišnu sezonu.

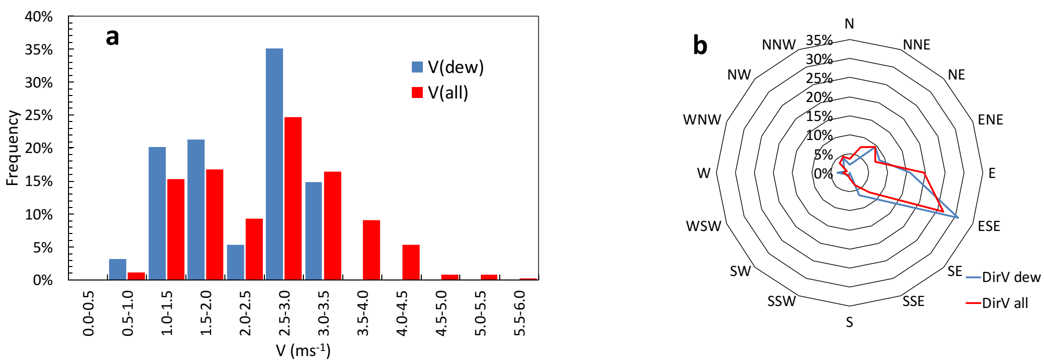


Figure 6. Wind speed (ms^{-1}) at 10 m height (a) and wind direction (sectors) (at 05:00 a.m.) (b). Blue data: dew days; red data: all days.

Slika 6. Brzina vjetra (ms^{-1}) na 10 m visine (a) i smjer vjetra (sektori) (u 05:00 sati) (b). Plavo: dani s rosom; crveno: svi dani.

As can be seen in Figure 7, relative air humidity (RH, %) and cloud cover (N, oktas) have a strong influence on the dew yields. Concerning *RH*, the envelope of the data can be fitted with the following linear regression:

$$h_d = a_d RH + b_d \quad (4)$$

Considering the upper points, the best parameters are $a_d = 0.01$ ($mmd^{-1}\%^{-1}$) and $b_d = -0.6$ mmd^{-1}.

Considering the upper points one finds $a'_d = -0.057$ ($mmd^{-1}oktas^{-1}$) and $b'_d = 0.4$ mmd^{-1}, corresponding to a maximum cloud cover $N_{max} = 7$ for dew to form. These results compare well with previous data such as those collected in Ajaccio (Corsica island, France) giving $N_{max} \approx 7$ (Muselli et al., 2002).

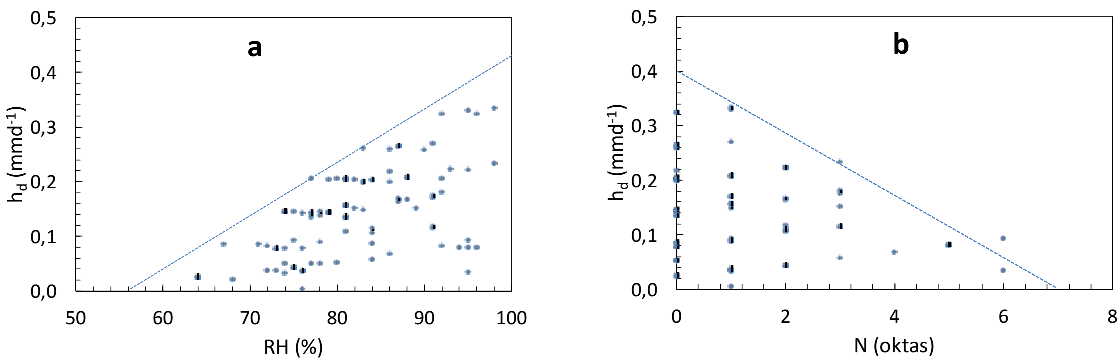


Figure 7. Daily dew yields (at 05:00 a.m.) versus a) relative humidity RH and b) cloud cover N.

Slika 7. Dnevna količina rose (u 05:00 sati) u odnosu na: a) relativnu vlažnost zraka RH i b) naoblaku N.

3.1.4. Number of consecutive days without dew

The distribution of the number of consecutive days without dew (Fig. 8) obeys an exponential decay. With f the frequency number of events showing N_c consecutive days without events, one can write:

$$f = f_0 exp\left[-\frac{N_c}{N_{c0}}\right] \quad (6)$$

Here f_0 is an amplitude and N_{c0} is the typical number of consecutive days without events. The distribution show similar exponential behaviors both in the dry season (N_{c0} = 1.4 ± 0.4 days) and in the rainy season (N_{c0} = 2 ± 0.8 days). It appears that in the dry season 74.1% of the events are between 1 and 3 days without dew and in the rainy season 73.9% of the events without dew are between 1 and 3 days. 92.6% (dry season) and 87% (rainy season) of the events correspond to sequences without dew and without rain of less than 6 days (for rain see Fig. 12).

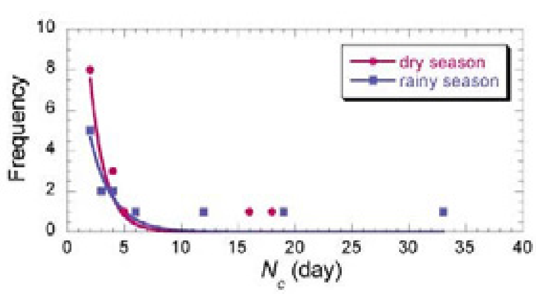


Figure 8. Frequency distribution of consecutive days without dew events, N_c, in the studied period.

Slika 8. Razdioba čestine uzastopnih dana bez rose, N_c, u razmatranom razdoblju.

3.2. Rain

3.2.1. Frequency

The evolution of daily rain is shown in Figure 4a. The annual mean value is $<h_r>$ = (107±136) mm (min: 0.1 mm in July 2020; max: 381.4 mm in December 2020), showing a large dispersion in amplitudes. The cumulative rainfall amount is shown in Figure 4c. The rainy period between October 2020 and March 2021 certainly brings water (more than 1200 mm), however the difficulty for the population lies in the ability to store it for the next dry season. No rainy days during dry and rainy seasons represent respectively 88.8% (158 days) and 36.7% (65 nights) of the events.

The frequency distribution of daily rainfall amount (Fig. 9) is very different from that of dew (Fig. 5) and strongly contrasts in the dry and rainy seasons. Concerning the dry season (Fig. 9a), all events have amount less than 10 mm. In the rainy season (Fig. 9b), more than 60% of the annual rainfall amount is less than 10 mm, 36.6% of the rainfall events have an amount between 11 and 30 mm and only one event is measured at more than 60 mm. With 132 rain events over the one-year period, for a total of 1278 mm, the mean rainfall amount is less than 10 mm. However, it has to be noted that rain events are mostly confined in the rainy season and almost absent the rest of the year.

3.2.2. Rain with respect to meteorological data

Unlike dew, which forms at low wind speeds, during rain events, the wind velocity can reach up to 5.5 to 6 ms^{-1} at 10 m height (Fig. 10a). The average wind speed value in rain events is

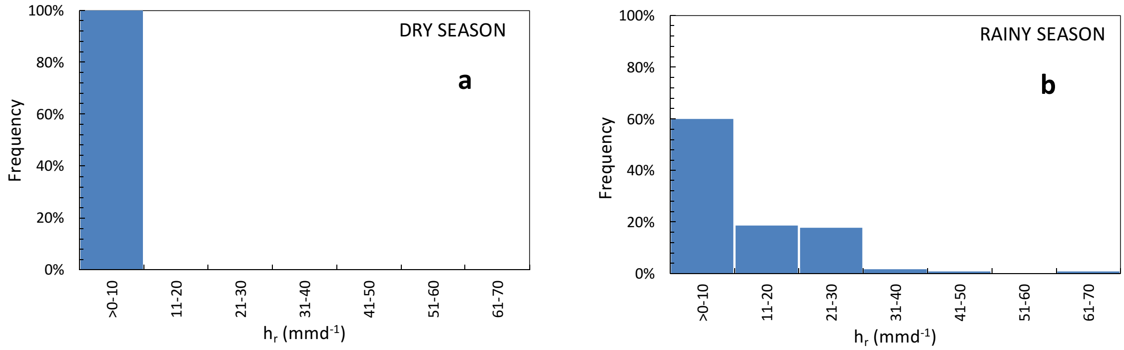


Figure 9. Rainfall amount (mmd^{-1}) frequency in the studied period (one year) in dry (a) and rainy (b) season.

Slika 9. Razdioba čestina količine kiše (mmd^{-1}) u razmatranom razdoblju (jedna godina) za suhu sezonu (a) i kišnu sezonu (b).

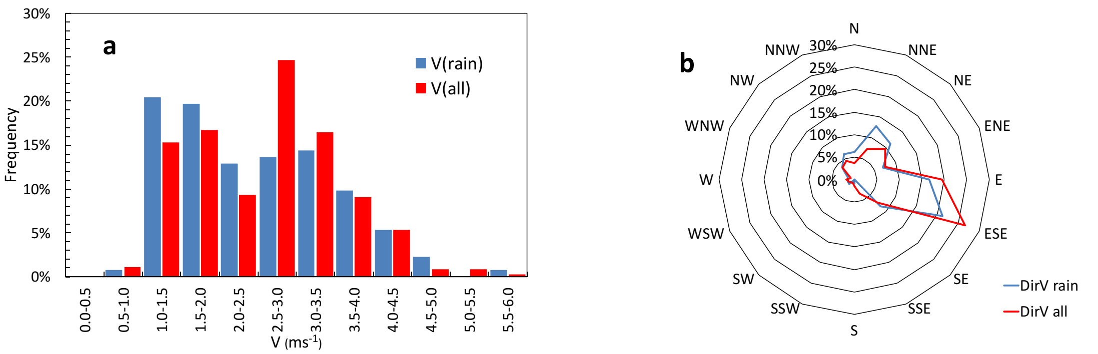


Figure 10. Wind speed (ms^{-1}) at 10 m height (a) and wind direction at 05:00 a.m. (b). Blue: rainy days; red: all days.

Slika 10. Brzina vjetra (ms^{-1}) na 10 m visine (a) i smjer vjetra u 05:00 sati (b). Plavo: kišni dani; Crveno: svi dani.

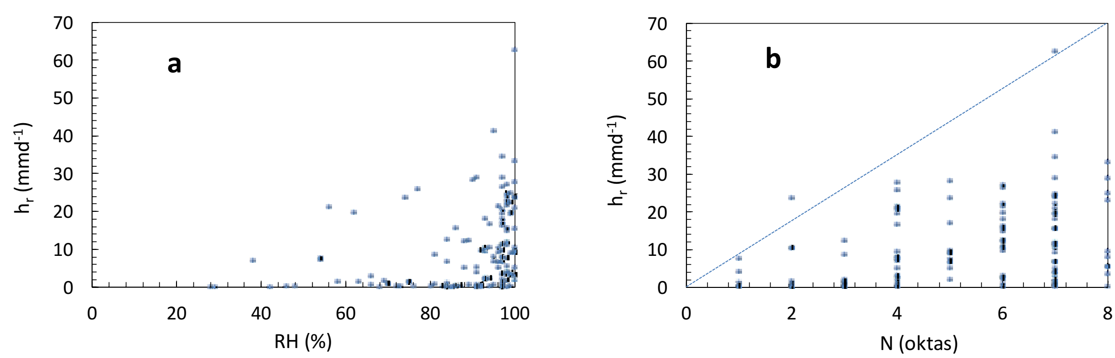


Figure 11. Daily rain yields (at 05:00 a.m.) versus (a) relative humidity RH and (b) cloud cover N.

Slika 11. Dnevna količina kiše (u 05:00 sati) u odnosu na (a) relativnu vlažnost zraka RH i (b) naoblaku N.

$<V_{rain}> = (2.5\pm1.0)$ ms^{-1} close to the mean annual wind speed $<V> = 2.8\pm1.1$ (min: 0.6 ms^{-1}; max: 8.3 ms^{-1}). The directions of the wind during the rainy episodes are similar to those of dew. The east/southeast sector is the most represented with frequencies greater than 20% for rain events and more than 25% for all events (Fig. 10b). The reason why wind blows mostly from east/southeast comes from the special wind regime prevailing in Zimbabwe. The most important winds are the southeast trade winds that blow from the Indian Ocean. The southeast trade winds bring drizzle and light showers and cause cloudy conditions in winter and clear sky conditions in summer. To a lesser extent, the seasonal northeast monsoons blow during summer and bring rainfall in North Zimbabwe during the months of December and January (about 13% in our case study). Due to the proximity to the ocean, and the fact that the ocean has a greater specific heat capacity when compared to land, most of the prevailing winds affecting Zimbabwe have thus an easterly direction (Fig. 10b).

Unsurprisingly, the relative air humidity during rain events is close to 100% (Fig. 11a) and cloud cover is high, although the sky can be not fully covered (Fig. 11b). One can describe the envelope of the data by a linear regression with cloud cover N, starting from zero:

$$h_r = a_r N \tag{7}$$

One finds a_r = 8.75 (mmd^{-1}oktas^{-1}). Also not surprisingly, the larger the cloud cover, the higher the rain volume.

3.2.3. Number of consecutive days without rain

In the rainy season, the frequency distribution of consecutive days without rain (Fig. 12) can be described, as for dew (section 3.1.4), by an

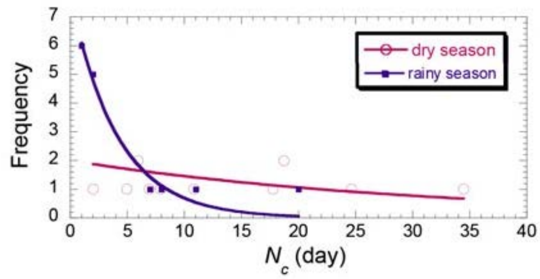


Figure 12. Frequency distribution of consecutive days without rain events, N_c, in the studied period.

Slika 12. Razdioba čestine uzastopnih dana bez kiše, N_c, u razmatranom razdoblju.

Table 1. Statistics of dew water contribution to the dew/rain ratio for different months in both dry and rainy season.

Tablica 1. Statistika doprinosa vode od rose omjeru rosa/kiša za različite mjesece u suhoj i kišnoj sezoni.

	No. of missing days	h_d (mm)	No, of dew days and (%)	h_r (mm)	No. of rainy days and (%)	τ_m (%)	Season	Dew (mm)	Rain (mm)	τ_s (%)	No, of dew days and (%)	No, of rainy days and (%)
April 2021	0	1.89	16 (53.3%)	4.5	4 (13.3%)	42.00	Dry	8.66	22.6	20.8	62 (33.9%)	20 (10.9%)
May 2021	5	3.46	18 (58.1%)	2.2	3 (9.7%)	157.27						
June 2020	0	2.06	14 (46.7%)	3	4 (13.3%)	68.67						
July 2020	0	1.17	12 (38.7%)	0.1	1 (3.2%)	1170.00						
August 2020	1	0.03	1 (3.2%)	3.4	4 (12.9%)	0.88						
September 2020	1	0.05	1 (3.3%)	9.4	4 (13.3%)	0.53						
October 2020	0	0.39	4 (12.9%)	87.1	9 (21.0%)	0.45	Rainy	4.86	1255.4	0.41	32 (17.6%)	112 (61.5%)
November 2020	2	0.04	1 (3.3%)	136.6	16 (53.3%)	0.03						
December 2020	1	0.38	3 (9.7%)	381.4	27 (87.1%)	0.10						
January 2021	1	0.0	0 (0%)	337.2	29 (93.5%)	0.00						
February 2021	0	0.19	3 (10.7%)	271.9	24 (85.7%)	0.07						
March 2021	1	3.86	21 (67.7%)	41.2	7 (22.6%)	9.37						
SUM	12	13.5	94 (26.6%)	1278	132 (42.8%)			13.5	1278		94 (26.6%)	132 (42.8%)

exponential distribution (Eq. 6) with typical time 4.1 ± 0.8 days. During the rainy season, events are mainly concentrated on one or two consecutive days (73.3%, to be compared with 8.3% in the dry season).

As expected, the distribution in the dry season becomes more widespread. When the data are fitted to an exponential distribution, the typical number of consecutive days without rain is in order 32 ± 12 days.

3.3. Comparison dew-rain

The correlation between dew and rain shows a large variability (Tab. 1). The monthly dew/rain ratio τ_m (%) in the dry months between April and July shows the important contribution of dew water (τ_m = 1170% in July 2020; 157% in May 2021; 69% in June 2020). The contribution is, however, weak in August (0.88%) and September (0.53%) because dew events are rare in these two months. During the whole dry season (June–Sept. 2020 and Apr.–May 2021), the contribution of dew in the water balance is τ_s = 20.8%. During the rainy season (October 2020 to March 2021), dew contributes only within 0.4% to the water balance.

4. DISCUSSION

The particular environmental conditions concerning dew production in Zimbabwe are concerned with cloud cover, wind speed and relative air humidity. These parameters are ruled by the presence of a well-defined rainy season and the occurrence of monsoon. Monsoon is this specific seasonal change in atmospheric circulation and precipitation associated with the annual latitudinal oscillation of the Intertropical Convergence Zone. This zone is located between the north and south of the equator. Monsoons take place mainly in South Asia, Africa, Australia, and the Pacific coast of Central America.

Monsoon affects Zimbabwe (Bailey and Heinrich, 2021). Wind coming off the Indian Ocean blows from ESE during the warmer and rainy months of the year (from October to March). Two distinct periods within the rainy season are, however, observed. From October to December, westerly clouds convey rainfall, while from January to March precipitation is mainly due to the migration of the Intertropical Convergence Zone. This process brings large rainfall to the area during period January–March. One notes that dew is rare because, although the relative humidity is high, cloud cover and wind speeds are quite often large, preventing efficient radiative cooling.

In contrast, during the other months of the year (April–September), precipitations are weak, unreliable and irregular. In this time period, however, dew condenses very regularly thanks to an effective radiative cooling during clear and calm nights, as long as the relative humidity of the atmosphere is high enough. The rainy season is followed by a high air humidity; then RH (and dew yield) decreases with time during the dry season, giving nearly no dew at its termination (see section 3.1.2 and Figs. 4b, c). The correlation dew yield versus RH is indeed quite general and comes from the fact that the radiative deficit cannot cool an open surface more than a few K below the temperature of the adjacent air. It is, however, within these few degrees of cooling that the dew point has to be reached and condensation takes place. It gives a lower limit for RH of about 70–80% for dew condensation to occur (e.g. Beysens, 2018). During two-thirds of the dry season, however, dew is regularly present and provides a reliable and steady additional moisture resource for plants, and also humans if proper collectors are set up (Beysens, 2018). One should note that dew forming on or close to the ground can be less than at a certain elevation or on artificial surfaces, e.g. dew harvesters, due to the soil heating during the day (Kidron et al., 2023).

The comparison of the present dew yield (13.5 $mmyr^{-1}$) with those found in other places in the world offers some interest despite the large differences found in radiation and humidity values according to the locations. A comprehensive review can be found in Tomaszkiewicz et al. (2015) where the present mean annual dew rate (13.5 $mmyr^{-1}$) stays in the average, the lowest reported value of 0.019 $mmyr^{-1}$ (Ye et al., 2007) and the maximum 39 mm (Berkowicz et al., 2007). One can also compare the present data during the April–September dry season (1.44 mm per month) with those obtained in tropical areas. In French Polynesia, a less but close similar value of 1.12 mm per month was obtained by Clus et al. (2008) during the April–October dry season. In SW of Madagascar, Hanisch et al. (2015) measured a larger value of 3.9 mm per month during the May–October dry season. However, contributions from fog and mist added to dew; the dew yield calculation from meteorological data by Rasoafaniry et al. (2023) gives a lower value 1.20 mm per month, which is slightly less than the present data. In Onne (Port Hartcourt, Nigeria), where the climate is also ran by the monsoon, Salau et al. (1986) reported in a short dry season (December to March) a small value of 0.074 mm per month. Raman et al. (1973) carried out a map of the dew yields in India. They measured in the dry season (October to March) values ranging from 5 mm (NE of India) to 0.17 mm (NW of India). Sharan et al. (2007a; 2007b) reported during the dry season 2004–2005 in the Kutch area (NW coastal India) mean values of about 1.7 mm per month.

Dew water exhibits, in general, chemical (and sometimes biological) properties which makes it potable with respect to the World Health Organization requirements (Beysens, 2018). The question whether dew water can be used as drinking water in order to supplement other sources like rain must, however, consider their relative frequency and contributions during the dry season. During this season, rain is erratic and dew is continuous but its yield becomes increasingly small at the end of the season. Rain amounts to 22.6 mm and dew to 8.66 mm, corresponding to a large contribution to the overall water resource of nearly 30%. There is, thus, an obvious interest to collect dew since dew collectors will in addition collect rain and even the often forgotten resources given by light rainfall, mist and fog.

5. CONCLUSION

The study of dew and rain during one year (29 May 2020 – 28 May 2021) allows the contribution of dew to be highlighted during the dry season (April–September). This contribution corresponds to 40%, on average, with peaks in May (157%) and in July (1170%). The months of August and September, however, exhibit very little dew contribution, only 0.88% and 0.53%, respectively.

It has to be noted that, in contrast to rain, dew forms very regularly. There are exceptions, when RH is too low, as in the end of the dry season, or the sky is too cloudy, in most of the rainy season. The mean number of consecutive days without dew is about two days all year, while for rain it is two days in the rainy season and one month in the dry season with a large dispersion. Dew in the dry season, although weak in amplitude when compared to rain in the rainy season, nevertheless appears a reliable source of water, except near the end of the dry season (August and September) due to the low value of atmospheric humidity. Although the average dew in the dry season (8.66 mm) is relatively high as compared with the corresponding rain amount (22.6 mm), it is uncertain that this input can be beneficial to agriculture. However, it could give a significant contribution to the population by harvesting dew water from e.g. roofs.

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