Dew variability within a small arid drainage basin in the Negev Highlands, Israel

By GIORA J. KIDRON*, AARON YAIR and AVINOAM DANIN
The Hebrew University, Israel
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SUMMARY
Dew variability during the autumn dewy season within a small arid drainage basin in the Negev Highlands, Israel, is studied. Dew measurements were carried out at 18 stations on four exposures, using the Cloth-Plate Method (CPM) and Duvedvani dew gauges. The study also included periodical wind and substrate temperature measurements.

Dew variability within the drainage basin was high. Average daily dew values obtained by the CPM were between 0.07 and 0.31 mm, whereas dew duration ranged between 1.6 and 4.1 hours per dewy morning. Dew amounts monitored by the Duvedvani gauges were lower, between 0.09 and 0.20 mm. Both methods show, however, consistent variability and correspond to a similar pattern. Whereas near-ground dew measurements were the highest at the hilltops and at the bottom of the sun-shaded northern and western exposures, wadi bed stations and, especially, the south facing midslope station obtained the lowest dew quantities.

The near-surface dew patterns are not in agreement with the classical model of both Geiger and Oke, which predicts high dew quantities at the wadi beds (due to nocturnal down-slope wind) and at the lee side of the prevailing wind, i.e. the south-facing midslope station. The low quantities at the south-facing midslope station is explained by the paramount role of surface temperatures, whereas variability in radiational cooling is seen as responsible for the high near-ground dew quantities at the hilltops and the low quantities at the wadis.

This conclusion is supported by dew measurements at 40 cm above ground. Dew measurements at 40 cm above ground at the south-facing midslope station and at both wadi beds were significantly higher (p < 0.05) than at 0.7 cm above ground. Facilitating an efficient radiational cooling, and beyond the impact of the surface temperatures, dew measurements at this height correspond to the classical model, highlighting the important impact of surface temperatures and ventilation upon near-ground dew condensation in an arid drainage basin.

KEYWORDS: Dew Drainage basin Fog Negev Desert Temperature Wind velocity

1. INTRODUCTION

The importance of dew for plant and animal life in arid zones has been extensively documented (see Stone (1957) and Wallin (1967) for reviews). Dew was found to be an important source of water for lichens (Lange et al. 1970; Friedmann and Galun 1974; Danin and Garty 1983), arthropods and mollusks (Hamilton and Seely 1976; Broza 1979; Shachak et al. 1987), thus being an important source of moisture for the primary food chain in arid and semi-arid zones (Shachak and Steinberger 1980). However, despite its importance and wide occurrence, information regarding dew precipitation in arid and semi-arid zones is scarce (Goudie 1989; Zangvil 1996). Long-term measurements are almost non-existent. The only published long-term dew measurements were carried out in the Negev Desert Highlands, at Avdat and Sede Boqer. Based on 17 years of measurements, an average annual amount of 33 mm of dew was recorded at Avdat with 195 dewy nights per year (Evenari 1981). Recently, a six-year record from Sede Boqer was published (Zangvil 1996). The data indicate that dewfall in the Negev Desert may exceed rain precipitation during extreme droughts and may provide a consistent moisture supplement for some organisms throughout the whole year (Evenari et al. 1971).

Although important, dew measurements were usually confined to a single station, apart from Lloyd (1961), Kappen et al. (1980) and Danin and Garty (1983). Within a drainage basin, dew variability is expected to follow a general model inferred from temperature and relative humidity measurements at cooler climates (Geiger 1966; Oke

* Corresponding author, present address: Department of Agronomy and Horticulture, New Mexico State University, PO Box 30003, Las Cruces, New Mexico 88003-8003, USA, e-mail: gkiddon@nmsu.edu

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According to this model, high dew quantities were expected to be condensed at the wadi bottom, due to nocturnal cooling and the resultant downslope wind flow (katabatic wind). High dew quantities were also expected to be condensed at the leeward slope, due to higher relative humidity at the wind-sheltered location (Geiger 1966; Oke 1978).

No attempts were thus far made to monitor dew quantities within a single arid drainage basin and, thus, information concerning dew distribution within an entire drainage basin was not available. The aim of the present research was, therefore, to study the dew distribution within a small drainage basin, and to identify the main factors affecting its variability.

2. The Research Site

The research site is located at Sede Boqer, at the Haluqim ridge in the Negev Desert Highlands, Israel (Fig. 1). The Haluqim ridge is mainly composed of flat and rounded hilltops, rising to 500–600 m above mean sea level (m.s.l.), and forming, for the most part, a uniform skyline (Fig. 2). Rain precipitation at the site is limited to the winter months (November–April) with an average annual precipitation of 93 mm (Yair and Shachak 1987). The mean monthly temperatures vary from 9 °C in January to 25 °C in August (Rosenan and Gilad 1985). Potential evaporation as measured by a class
A evaporation pan at the Avdat farm, 10 km south of Sede Boqer, is approximately 2600 mm (Evenari 1981).

A second-order drainage basin with relatively steep slopes was chosen. The drainage basin bedrock consists of Turonian limestone of three formations: Netzer, Shivta and Drorim, which occupy the upper, mid and lower sections of the slopes, respectively (Arkin and Braun 1965). Both Netzer and Drorim formations are strongly jointed limestone, characterized by patches of soil, while massive and continuous bedrock characterize the Shivta formation at the midslopes. Abundant pebbles, cobbles and stones, usually up to 15 cm high, characterize the Netzer and Drorim formations, while less abundant at the Shivta formation. The climate and rock formations dictate the shallow soil and the sparse vegetation cover (usually between 5–15%), height (usually up to 40 cm) and distribution (Danin et al. 1975; Yair and Danin 1980; Wieder et al. 1985). Whereas Artemisia sieberi and Gymnocarpos decander characterize the shrub-steppe of the north- and west-facing slopes, Zygophyllum dumosum and Artemisia sieberi dominate the south- and east-facing slopes and Retama raetam and Haloxylon scoparium characterize the wadis. Lichens and cyanobacteria inhabit rocks and soil patches. Cyanobacteria characterize the Shivta formation at the southern and eastern exposures, while lichens characterize all other locations, covering more than 95% of all rock and rock fragment surfaces (Danin and Garty 1983).

3. Methodology

Dew measurements were carried out periodically during the autumns of 1987–1989. Eighteen stations, 2.5 × 2.5 m each, were demarcated (with paint) along the northern,
southern, eastern and western exposures and at the wadi bottoms (Fig. 3). The stations were demarcated at places with low vegetal cover (usually ≤5%). Elevation, slope angle and rock cover are shown in Table 1. A schematic topographical cross-section of the drainage basin is shown in Fig. 4.

Dewfall was measured by Duvedvani dew gauges and the Cloth-Plate Method (CPM). The gauge and plates were placed at the centre of each station (Fig. 5). Both methods were able to detect dew and fog precipitation. Whereas dew is defined as atmospheric moisture condensation at the substrate surface, once the substrate temperature falls below the dew-point temperature (due to radiational cooling), fog precipitation occurs as a result of air cooling below the dew-point. Consequently, fine water droplets are formed due to vapour condensation. Fog is generated when these water droplets remain in suspension and reduce visibility to less than 1 km (Fairbridge 1967). In the Negev, fogs vary temporally and spatially (Levi 1967), and tend to be carried by light winds during the night and early morning. Since fog precipitation will usually occur concurrently with dew precipitation, it was not always possible to distinguish between them. Consequently, both dew and fog precipitation will be regarded in this paper as dewfall.

The Duvedvani dew gauges are specially treated and painted wooden blocks measuring $32 \times 5 \times 2.5$ cm, placed 4.5 cm above ground. Dew is condensed on the surface in different drop sizes which are compared to a photo atlas depicting known dew quantities (Duvedvani 1947). As dew duration cannot be determined by Duvedvani gauges,
the CPM was used. Each afternoon, cloths (6 × 6 × 0.15 cm) were attached to the centre of eight to twelve 10 × 10 × 0.2 cm glass plates, overlying 10 × 10 × 0.5 cm plywood plates to create an isolated and homogenous substratum (Kidron 1998). The plates within each station were placed horizontally, adjacent to one another. The cloths attached to the plates were collected throughout the morning hours into preweighed flasks which were immediately sealed and later weighed for their dew quantity. The consecutive measurements within each station were used for plotting the dew condensation and evaporation graph throughout the morning hours, which later served to determine the dew duration at each station.

Previous findings indicate that dew precipitation patterns during the early morning follow a typical condensation and evaporation curve. The curve shows continuous condensation during the first 1–2 hours after dawn, which was explained as resulting from slight turbulence during the early morning hours (Fig. 6; Kidron 1998; see also Kappen et al. (1979)). Whereas high evaporation rates characterize the dew pattern 3–4 hours after dawn, a sharp decline in the evaporation rate occurs thereafter, at low water levels of 0.02–0.03 mm of dew. A quantity of 0.03 mm of dew, which marks the onset of the transition between the parabolic and asymptotic pattern of the evaporation phase, was thus taken as a threshold for the presence of dew, marking also the threshold for dew duration (Fig. 6). At this quantity, utilization of dew by organisms is drastically impeded (Lange 1969; Kappen et al. 1979).
Figure 4. A schematic topographical cross-section of the drainage basin showing positions of stations 1–18; (a) south–north and (b) east–west exposure.
In addition to the dew measurements, occasional temperature and wind measurements were made. Temperature measurements were carried out manually, within the different station limits, using flat thermistors with a precision of $+/−0.05$ degC (Yellow Instruments, USA). When measurements were conducted, the thermistors were shielded from radiation and ventilation. Most of the measurements were carried out during the early morning, although some were also carried out during the night. Temperature measurements included rock and soil surfaces as well as the glass-plate surfaces. Wind velocity was measured with a Woelfle anemograph (Lambrecht, Germany) placed on top of a flat mountain ridge, at 3.5 m above ground. The anemograph was located at a similar elevation to the surrounding hilltops, at 540 m above m.s.l., and thus was believed to represent the wind regime at the top of the HaUjin ridge. In addition, portable anemometers (Fuess, Germany) were occasionally used for measuring wind velocity at certain stations. These anemometers were placed within station limits at 50 cm above ground. The wind velocity was manually recorded at set intervals.

Paired $t$-test examinations ($p$) were executed in order to determine possible significant differences between dew values.
4. RESULTS

(a) Near-ground dew amounts and duration

A total of 35 and 31 dewfall mornings were recorded with the CPM and Duvdevani dew gauges respectively, both at northern and southern exposures. A total of 18 and 23 mornings were recorded using the CPM and Duvdevani dew gauges respectively, at all four exposures (north, east, south and west).

Variability in dew amounts at the different stations disclosed similar patterns along two (north and south) and four (north, south, west and east) exposures using both methods (Fig. 7; Kidron 1988). However, higher differences in dew amounts between the stations were obtained using the CPM. The average dew quantity obtained at all stations using the CPM was 0.23 mm, with extreme values of 0.07 and 0.31 mm. The average dew amount obtained using the Duvdevani dew gauges was 0.17 mm, with extreme values of 0.09 and 0.20 mm (Fig. 7).

Both methods exhibited similar patterns. While top and upslope stations, together with stations shaded from the early sun beams during the early morning (i.e. at the bottom of the northern and western exposures), exhibited high dew amounts, wadi bed stations and, especially, the midslope south-facing station exhibited low dew amounts, significantly different ($p < 0.01$) from all other stations (Tables 1 and 2 and Fig. 7). Slightly low dew amounts also characterized the remaining midslope stations, being lower at stations with a high rock-to-soil ratio (Tables 1 and 2 and Fig. 7).

High variability also characterized the dew duration (Fig. 8). Average dew duration as measured by the CPM at all stations was 3.4 hours with stations showing an average
Figure 7. Dew quantities recorded on the northern and southern exposures by (a) the Cloth-Plate Method (CPM) \((n = 35)\) and (b) the Duvdevani dew gauges \((n = 31)\), and dew quantities recorded on the northern, southern, eastern and western exposures by (c) the CPM \((n = 18)\) and by (d) the Duvdevani dew gauges \((n = 23)\). Bars represent one standard error. For station locations and characteristics see Table 1. \(n\) is the number of dew mornings.

dew duration of 1.6–4.1 hours. While top and upslope stations and especially bottom stations at the shaded northern and western exposures exhibited a long dew duration, wadi bed stations and the south-facing midslope station exhibited short duration (Table 1 and Fig. 8), with dew duration at the south-facing midslope station being significantly shorter \((p < 0.001)\) than all other stations (Table 2). A positive linear correlation obtained between dew amounts and duration (Fig. 9), indicates that the initial dew amount may largely determine the total dew duration within a station.

The low amounts obtained at the wadi beds and especially at the south-facing midslope station are not in agreement with the Geiger (1966) and Oke (1978) model. Due to the fact that the near-ground microclimate may have obscured wind and relative humidity distribution within the drainage basin, dew measurements at 40 cm above ground were carried out at several selected stations.

\(b\) Dew measurements at 40 cm above ground

Dew measurements at 40 cm above ground were carried out during 12 days at the top north and south stations, at the north- and south-facing midslope stations, and at both wadi beds. Whereas significantly lower amounts of dew were obtained at both hilltop stations at 40 cm above ground as compared with near-ground measurements \((p < 0.001)\), measurements at 40 cm above ground at all other stations exhibited significantly higher amounts \((p < 0.05\) for the mid north station and \(p < 0.001\) for the
mid south and both wadi stations) (Fig. 10). Dew quantities at 40 cm above ground at the E/W wadi bed (station 14) were the highest recorded dew values.

(c) Temperature and wind measurements

Similar temperatures characterized the soil surface at the north- and south-facing midslope stations during the night and early morning. This was not the case with bedrock temperatures. Consistently higher temperatures characterized the rock surfaces with south-facing bedrock surfaces exhibiting higher temperatures than the north-facing bedrock. These measurements were consistent throughout the night, with south-facing midslope bedrock being 3–5 degC warmer than north-facing midslope bedrock (Fig. 11). Bedrock temperatures also affected the glass deposition plates. Plates at 0.7 cm above ground in the south-facing midslope station were found to be 0.5–0.9 degC warmer than plates at 40 cm above ground during the early morning hours. Thus, serving as an efficient heat sink, south-facing bedrock apparently retained the higher radiation
Table 2. Relationships between dew amounts and duration at the different stations (see Figs. 3 and 4). Different letters indicate significant differences between dew values, as found by paired t-tests.

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*Similar characters indicate non-significant differences while different characters indicate significant differences between stations (paired t-test; p < 0.05).

Figure 9. The relationship between dew amount and duration as measured by the Cloth-Plate Method.

received by the southern aspect during the day, consequently resulting in higher surface temperatures during the night and early morning. This warm microclimate also affected the near-ground glass plate temperatures and the dew quantities consequently condensed on the plates.
Figure 10. Average dew amounts as measured at stations Top N and Top S (stations 1 and 10), Mid N and Mid S (stations 3 and 7), and Wadi N/S and Wadi E/W (stations 5 and 14) during 12 days of measurements at 0.7 cm and 40 cm above ground. Bars represent one standard error. See Table 1 for details of stations.

Figure 11. Average hourly temperatures of surface bedrock at the midslope north- and south-facing stations during six nights in the autumn of 1987. Arrow indicates time of dawn.

An analysis of wind direction and speed during 40 dewy days of the autumn of 1987 is presented in Fig. 12. The data indicate the predominance of north-westerly winds, which comprise 69.4% of the total winds. The data also point to the remarkable increase in wind speed during the late afternoon; a gradual increase from the early morning until the late afternoon, from less than 2 m s\(^{-1}\) to over 6 m s\(^{-1}\).

A comparison between wind speed at 50 cm above ground at the hilltop (station 1), north- and south-facing midslopes (stations 3 and 7, respectively), and at the N/S wadi
Figure 12. Average hourly wind speed and windrose for 40 days in the autumn of 1987 during which dew measurements were carried out.

bed (station 5) is shown in Fig. 13. A decrease in wind speed from the top station through the north-facing midslope and the wadi bed towards the south-facing midslope station is apparent. This pattern characterized most of the days and nights measured. Occasionally, a sudden shift in wind direction may have taken place, resulting in relatively higher wind speeds at the south-facing midslope station. Such conditions occurred during 27 October 1987 (Fig. 13).

5. DISCUSSION

(a) Dew amounts and duration

A high variability of dew amounts and duration was obtained. Whereas the most dewy station received 4.6 times as much dew as the least dewy one (top south station as compared with the midslope south-facing station, as measured by the CPM), longer dew duration, of up to 2.6 times, characterized the bottom north- and west-facing stations in comparison with the midslope south station.

Although similar in their patterns, both methods exhibited differences in their absolute values, with the Duvdevani wooden bars yielding lower amounts than the glass plates. The differences may be explained by the thermal properties of glass and wood which result in higher dew condensation on glass (Oke 1978; Kidron 1998). However, apart from the lower absolute quantities obtained by the Duvdevani dew gauges, the Duvdevani gauges also exhibited moderate differences in dew quantities between stations, with consequently higher amounts recorded at the midslope south-facing station (Fig. 7). This phenomenon is explained by the impact of the bedrock surface temperatures as will be discussed later.

The positive linear correlation between dew amount and duration (Fig. 9) is in accordance with other observations, indicating a positive link between these two factors (Duvdevani 1964; Zangvil 1996). Consequently, hilltop, upslope and bottom north- and west-facing stations exhibited long dew duration which lasted on certain days up to 5.5 hours after dawn. It should, however, be noted that during the present research the dew plates were placed horizontally. Dew precipitation on plates, located parallel to an
inclined slope surface at the bottom north- and west-facing stations, may have lasted up to one hour longer, facilitating prolonged hours of moisture availability for microorganisms, flora and fauna (Kidron 1988).

The patterns of dew variability, as shown in Figs. 7 and 8, were similar under most weather conditions prevailing at the research site during the autumnal morning hours. During autumn, maximal dew amounts are obtained (Evenari et al. 1971) due to astronomical and climatological factors (Monteith 1957; Zangvil and Druian 1980). Furthermore, distillation (condensation of vapour originating from a wet surface) is avoided, before the first rains (Monteith 1957). Thus, the data obtained solely represent vapour originating from the atmosphere, i.e. dew and fog.

During most mornings, near-ground dew measurements at the hilltop and upslope stations and at the bottom northern and western exposures exhibited high values. At the same time, midslope stations and especially the midslope south-facing station, as well as wadi bed stations, exhibited low amounts. The higher dew amounts obtained at the lower flanks of the northern and western exposures are not surprising in light of the location of these two stations, relatively sheltered from the early morning sun rays. However, the variability obtained at the other stations, especially the relatively low amounts at the south-facing midslope and at the wadi beds, called for an explanation. Thus, the lower near-ground dew amounts at the wadi beds were inconsistent with the classical model of dew accumulation, predicting a rather high condensation rate at the lower-slope sections due to cold-air accumulation at the wadi bed (Geiger 1966; Oke 1978). The lower
dew amounts at the midslope south-facing station were also surprising when one takes into account the wind regime, i.e. the leeward location of this station. However, both wadi bed stations and the south-facing midslope station exhibited a completely different trend when dew measurements at 40 cm above ground were made. Higher amounts of dew characterized the 40 cm above ground measurements of the south-facing midslope station in comparison with the north-facing midslope station, ruling out the possibility that dew distribution follows advective condensation with windward stations receiving higher humidity (Kappen et al. 1980).

(b) Effect of wind and temperature

When considering the wind regime, the south-facing midslope station was sheltered from the north-westerly winds prevailing during the autumn (Fig. 12), as also found by Zangvil and Druian (1980) and Zangvil (1996). As wind turbulence inhibits dew accumulation, leeward sites, protected from direct winds, are believed to enjoy a better dew regime (Oke 1978). High dew quantities were, however, only monitored at the south-facing midslope station at 40 cm above ground, whereas near-ground dew measurements at this station were the lowest recorded; thus, while high near-ground dew values characterized the exposed stations, low dew amounts characterized the wind-sheltered stations, such as the midslope south-facing station and the wadi beds.

Surface temperatures and ventilation may account for the apparent discrepancy between the classical model and the present findings. Serving as an efficient heat sink (Hoffman and Gates 1970), higher surface temperatures characterized the bedrock surfaces and especially the south-facing bedrock throughout the night and the early morning hours (Fig. 11). The differences in surface temperatures may explain the relatively low near-ground dew values obtained at all midslope stations characterized by a rock-to-soil ratio of $\geq 1$ and especially the midslope south-facing station. It may also explain the relatively higher dew amounts using the Duvdevani gauges at the midslope south-facing station (placed at 4.5 cm above ground as compared with the plate measurements at 0.7 cm above ground), and the higher amounts of dew obtained at 40 cm above ground at this station. Indeed, the temperature of near-ground deposition plates was consistently 0.5–0.9 degC higher than the plates at 40 cm above ground at the south-facing midslope station. The apparent temperature impact was thus in accordance with Monteith (1957), Angus (1958), and Duvdevani (1964) findings, concerning the paramount role of minor temperature differences in controlling dew condensation.

While temperature difference may account for some of the results, wind impact is seen to be responsible for the relatively higher dew amounts obtained at the hilltops and upper stations on the one hand, and the lower quantities obtained at the wadi beds, on the other hand. These differences may be explained by the strong afternoon winds characterizing the Negev Highlands during autumn (Fig. 12; Zangvil and Druian 1980). These strong winds stem from the high temperature differences between the coastal regions and the desert. A strong horizontal vector promotes free convection, channelling the daily sea breeze (Oke 1978; Zangvil 1996). Thus, apart from the important role of wind as a carrier of sea moisture inland (Monteith 1957; Zangvil 1996), it is suggested that the winds may act as an efficient surface cooling agent. As the winds are more pronounced at the exposed upper and hilltop stations (Fig. 13), the dew-point temperature may be reached earlier, resulting in earlier dew condensation and consequently higher dew quantities. Dew measurements taken during the early evening indeed showed high dew condensation at the elevated stations in comparison with the wadi stations (Kidron, personal communication). At the same time, the low ‘sky view factor (SVF)’, i.e. the proportion of sky ‘seen’ by the deposition surface (see Oke
(1978)), may retard near-ground dew condensation in the wadis. Due to a lower SVF in
the wadis, and their relatively wind-sheltered location, near-ground dew condensation
in the wadis may be delayed, consequently resulting in lower dew amounts.

While dew measurements farther away from the rock surface of the south-facing
midslope resulted in higher dew amounts, more efficient radiational cooling at 40 cm
above ground at the wadi beds also resulted in much higher dew amounts. Thus, whereas
the low amounts of near-ground dew at the leeward south-facing midslope and at the
wadi beds were not in agreement with the Geiger (1966) and Oke (1978) model, dew
measurements at these locations 40 cm above ground corresponded with the classical
model. Dew amounts at 40 cm above ground at the leeward south-facing midslope
station were in fact higher than those at 40 cm above ground at the windward north-
Facing midslope station, consistent with Geiger's (1966) and Oke's (1978) classical
model. Likewise, dew measurements at 40 cm above ground at the wadi beds were
higher than at 0.7 cm above ground, with the wadi E/W station exhibiting the highest
measured dew amounts. Allowing for efficient radiational cooling on the one hand, and
a nocturnal cold-air concentration (due to its lowest topographical elevation) on the
other hand, dew measurements at 40 cm above ground at the wadi E/W station thus
correspond to the classical model. The data thus pointed to the fact that whereas wind
and air movements described by Geiger (1966) and Oke (1978) are apparently universal
within a drainage basin and may be detected at the Sede Boqer drainage basin at 40 cm
above ground, high surface temperatures and the impact of ventilation may highly affect
near-ground dew measurements, which may thus not be consistent with the classical
model.

(c) Implications

The above results may offer a variety of ecological implications for micro-
organisms, plants and animals which may enjoy a differential dew regime within a
single drainage basin. As dew during the summer and autumn may be the only water
source available for these organisms, dew distribution may largely affect their distribu-
tion (Kappen et al. 1980; Shachak et al. 1987), and may dictate, to a large degree, their
growth and success.

The glass plates placed on top of the surface closely simulated loose cobbles. Dew
amounts and duration, as measured during the present research, may thus serve as a
good indicator for dew availability for the dense population of lichens inhabiting loose
cobbles within the research site. Dew distribution patterns may also offer insight into the
as-yet-to-be-explored role of dew in weathering processes, and into related soil-forming
processes. The above results also highlight the fact that dew values based on single-site
measurements should be cautiously examined, as dew quantities may be highly variable
within a drainage basin.

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