Montogue

# Quiz SL102

# EROSION, DESERTIFICATION, AND DROUGHT

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## PROBLEMS

### Conversation Starter

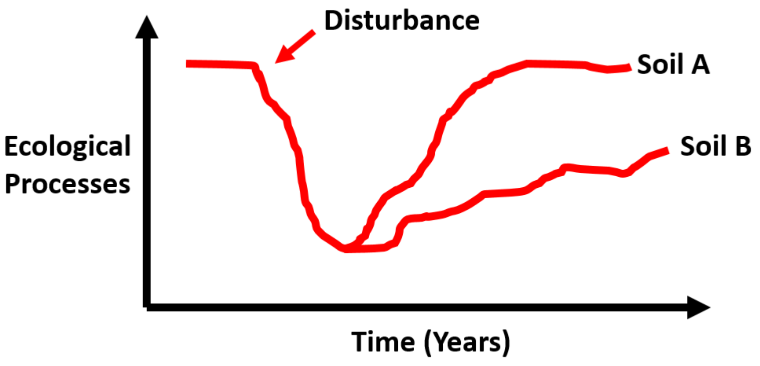
In 1994, the United Nations conceived the United Nations Convention to Combat Desertification (UNCCD). In the same year, a date was chosen as the World Day to Combat Desertification and Drought. This date is:

**A)** February 20
**B)** March 21
**C)** June 17
**D)** October 15

### Problem 2

Regarding various aspects of soil erosion, desertification and drought, true or false?

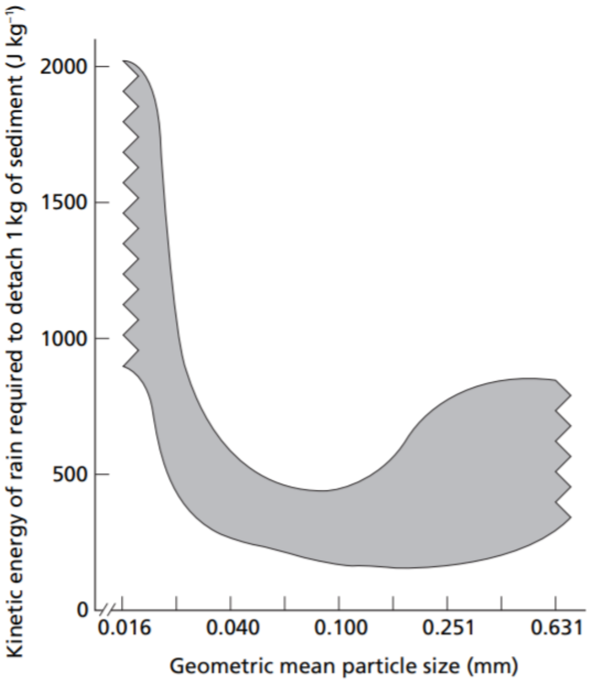
**1.( )** The following graph illustrates the recovery of two soils, A and B, after being subjected to a disturbance (e.g., massive splash erosion and gullying during heavy rainfall). We may surmise that soil A is more resilient than soil B.




**2.( )** Rills are shallow channels cut into soil by the erosive action of flowing water. Rills are formed by the complex interactions between raindrops, overland flow, and the characteristics of the soil surface. In general, concentrated flow erosional processes are intensified when the distance between rills decreases and the depth and width of rills increase.

**3.( )** Another indicator of the degree of water and/or wind erosion is the degree of movement of litter (dead plant material that is in contact with the soil surface). The redistribution of litter within a small area is indicative of more severe erosion, whereas the movement of litter offsite is an indicator of milder erosion.

**4.( )** Investigators of rainsplash erosion have shown that the kinetic energy required to detach a certain amount of sediment – say, 1 kg – from a soil depends on factors such as soil structure, soil-water content, topsoil shear strength, and soil texture. The effect of the latter is shown in the following graph, which displays the relation between geometric mean particle size and the energy required to detach 1 kg of sediment. Clearly, minimal energy is needed for soils with a geometric mean particle size close to 0.125 mm.




**5.(  )** The most commonly used index of rainfall aggressiveness is the Fournier ratio $p^2/P$, where $p$ is the highest mean monthly precipitation and $P$ is the mean annual precipitation. Though originally designed for assessment of sediment yields in rivers, this parameter has been successfully used to examine regional variations in erosion risk. What's more, it is closely correlated with the rainfall erosion index $R$.

**6.(  )** Studies of the hydraulic characteristics of flow over soils show that the change from overland flow to rill flow passes through four stages: unconcentrated overland flow; overland flow with concentrated flow paths; microchannels without headcuts; and microchannels with headcuts. The greatest differences exist between the first and second stages. At the point of hill formation, there is a transition from subcritical to supercritical flow; indeed, deeper investigations on transition between stages have shown that rill formation is a discrete phenomenon and begins precisely when the Froude number reaches unity.

**7.(  )** Formation of gullies has been viewed as a threshold phenomenon related to the size of the contributing area and its slope. A criterion for the formation of ephemeral gullies, i.e. valley floor gullies forming along the thalweg, is

$$S \times A^b > t$$

where $S$ is the local slope gradient (m/m), $A$ is the upslope contributing area (ha), $t$ is a threshold value, and $b$ is the relative area exponent. This latter quantity is a dimensionless parameter and, when greater than 0.2, is indicative of erosion by surface runoff.

**8.(  )** Assessment of wind erosion requires knowledge of sediment transport rate. In the 1940s, Bagnold proposed the following equation for determining the maximum sediment discharge per unit width,

$$q = C\sqrt{\frac{d}{D}}\frac{\rho_a}{g}u_*^3$$

where $C$ is an empirical coefficient (values of which are given below), $d$ is the average diameter of the material, $D$ = 0.25 mm is a standard grain diameter, $\rho_a$ is the density of air, $g$ = 9.81 m/s$^2$, and $u_*$ is the shear velocity. With reference to Bagnold's equation, we can surmise that doubling the average diameter and increasing the shear velocity by 50% will raise the sediment transport rate over 4-fold.

| **Sand type** | **Value of *C*** |
|---|---|
| Nearly uniform sand | 1.5 |
| Naturally graded sand (typically found in dunes) | 1.8 |
| Broad-graded sand | 2.8 |

**9.( )** Middleton, one of the pioneers of soil erosion research, proposed a so-called erosion ratio (*ER*) as a function of several soil properties; *ER* is given by $(DR \times ME)/\text{Col}$, where *DR* is the dispersion ratio, *ME* is the erosion ratio, and *Col* is the colloid content. The greater the value of *ER*, the more erodible a soil is.

**10.( )** In the 1990s, the US Agricultural Research Service (USDA-ARS) introduced the Water Erosion Prediction Project, a new mechanistic software for erosion modeling. Operating on a daily time step, WEPP incorporates temporal changes in soil erodibility, management practices, above- and below-ground biomass, plant height, and canopy and ground cover in the prediction of soil erosion. The software operates at two scales, hillslope and watershed, and can efficiently predict a variety of erosional processes, including gully erosion and mass wasting, in areas as large as 10 $km^2$.

**11.( )** The European Soil Erosion Model (EUROSEM) is an event-based model designed to compute the sediment transport, erosion and deposition throughout a storm. It can be applied to either individual fields or small catchments. One appreciable feature of this model compared to other approaches is that EUROSEM simulates interrill erosion explicitly, including the transport of water and sediment from interrill areas to rills, thereby allowing for deposition of material *en route*. This is considered more realistic than assigning all or a set proportion of the detached material to the rills. One important limitation of EUROSEM is that, unlike other models, it does not describe the eroded sediment in terms of particle size.

**12.( )** Sand dunes and sand seas (ergs) are the dominant landforms in deserts such as the Sahara, Australia, and North American aridlands.

**13.( )** The Budyko-Lettau dryness ratio may be interpreted as an indicator of a region's aridity. The greater the value of this parameter, the more humid a region is; indeed, a tropical rainforest has a BLDR close to 10, whereas a desert in general has a BLDR no greater than 2.

**14.( )** Instead of appealing to the BLDR, the aridity of a region can be straightforwardly estimated by the ratio of mean annual precipitation (*P*, mm) to the Penman mean annual potential evapotranspiration (*PET*, mm). With reference to the following table, we surmise that a region with 250 mm of annual precipitation and 2000 mm of potential evapotranspiration is classified as an arid zone.

| Interval | Classification |
|---|---|
| $P/PET < 0.03$ | Hyper-arid zone |
| $0.03 < P/PET < 0.20$ | Arid zone |
| $0.20 < P/PET < 0.50$ | Semi-arid zone |

**15.( )** The Sahel is victim to one of the world's most extreme desertification processes. Underlying the natural surface of this region is a mantle of relict dune sands presently stabilized and anchored by vegetation. Removal of this vegetation cover by anthropogenic causes leads to a significant increase in aeolian activity and in sandstorms, compounded by the characteristically intense winds of the region (e.g., the Harmattan and the Khamsin). In other words, anthropogenic removal of the Sahelian soils' vegetation cover can be associated with greater erosion and, in the long term, desertification.

**16.( )** In the wake of a workshop on desertification held in Dahlem, Germany in 2001, researchers published the so-called Dahlem Desertification Paradigm, a concept paper that sought to frame future debates and research on desertification. In one of the nine points discussed in the paper, the authors surmise that the cost of intervention in damaged soils rises linearly with increasing degradation, and that the biophysical and socioeconomic factors involved in such an intervention could easily be converted to concrete costs with research and data available at the time.

**17.( )** An international workshop on rangeland desertification was held in Iceland in September 1997. The choice of country was not random, in that Icelandic ecosystems have been severely degraded since settlers began populating the country over a thousand years ago; as a result, Icelandic territory is now dotted by barren deserts in spite of its relatively humid climate.

**18.(  )** In their contribution to the Icelandic rangeland desertification workshop, Archer and Stokes proposed a classification model for ecosystem states with respect to degenerative stress. The model consists of four states, namely 'steady-state fluctuations,' 'degradation I', 'degradation II', and 'degradation III'.  As noted by the authors, the most basic concept of degradation, where the synergistic effects of natural and anthropogenic stresses overwhelm the ecosystem's buffering capacity, is associated with the 'degradation III' stage.

**19.(  )** Recent research conducted in China has shown that the ongoing desertification process in the country's northwest has been invariably attributed to human activity as represented by three proxies: area devoted to agriculture, livestock population, and human population.

**20.(  )** Decline in rain-use efficiencies has been associated with advancing desertification. One drastic example is the Sahel, for which researchers have calculated a consistently declining RUE as desertification evolved in the 1982 – 1990 period.

**21.(  )** GLASOD (Global Assessment of Human-Induced Soil Degradation) is a 1:10 million global map of human degradation first developed between 1988 and 1991. Since its conception, GLASOD has consolidated itself as an influential tool for appraisal of land quality and environmental policy. However, the map does have important shortcomings, including the fact that it is limited to soil degradation and does not include aspects of climate, vegetation, and water resources. What's more, it is based on expert judgments of soil degradation status (type, extent, degree, rate and cause) at a national and subnational level and as such carries an inevitably subjective component.

**22.(  )** GLADA (Global Assessment of Land Degradation and Improvement) is a follow-up project of GLASOD. At the global scale, GLADA makes use of remote sensing and climate data to produce maps of changes in Normalized Difference Vegetation Index (NDVI) and rain-use efficiency over the past decades. GLADA uses NDVI as a proxy for Net Primary Productivity, and thus employs NPP as a prime indicator for the state of ecosystems. This approach has been commended by most researchers, as there is a strong correlation between NPP and land degradation.

**23.(  )** The 1998 drought of Bahr El Ghazal province in South Sudan is an example of socioeconomic drought accompanied by famine.

**24.(  )** Since the devastating southern Africa drought of 1991/1992, awareness has grown of the potential to better manage climate variability in the region through seasonal climate forecasting and monitoring of El Niño and the Southern Oscillation (ENSO). Accordingly, preparedness has improved and, in 1997, when meteorologists observed a particularly severe El Niño, Africans were better prepared for the severe drought of the next year, which turned out to be more intense than the dry spell of 1991/1992. As a result, socioeconomic damages were reduced to a minimum.

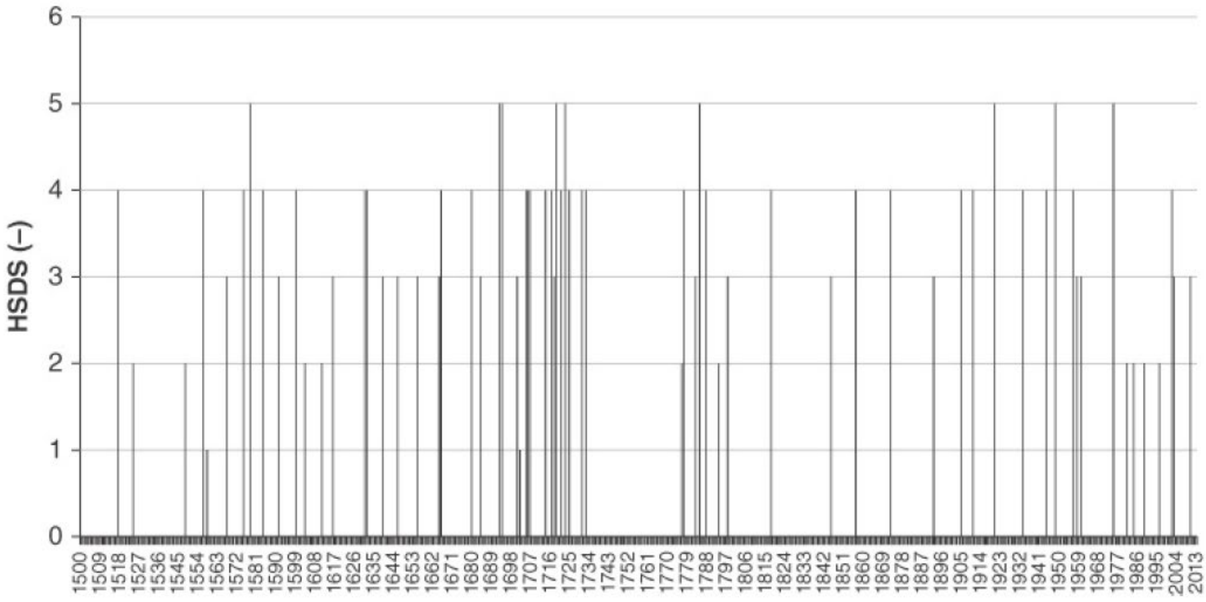
**25.(  )** It has been shown that catchment and climate characteristics have a significant impact on future drought. One important finding in recent studies is that, although drought severity and duration in places such as southern Africa is expected to decrease in the future, drought frequency is bound to increase.

**26.(  )** First released in 1999, the US Drought Monitor maps American territory in five classes of drought severity: D1 – Moderate drought; D2 – Severe drought; D3 – Extreme drought; D4 – Exceptional drought; and D0 – Abnormally dry. The USDM is a comprehensive drought assessment that reflects the existing drought scenario across the country; it was not designed to be a forecast.

**27.(  )** The National Oceanographic and Atmospheric Administration's Climate Prediction Center has devised a drought assessment tool of its own, the US Seasonal Drought Outlook. This resource shows predicted trends for areas currently in drought, as well as areas where new droughts may develop. The USSDO is still in an early stage, and as of the early 2010s its models relied only on a single drought index (the Palmer Drought Severity Index – PDSI); moreover, because of scant, unevenly spread data and difficulties in modeling, NOAA scientists chose not to incorporate soil moisture information in the SDO, making its forecasts less realistic.

**28.(  )** In Europe, drought conditions are monitored by the European Drought Observatory, which provides water scarcity information, graphs and time series at the continental level. Several indicators are computed and regularly updated, including the Standardized Precipitation Index and the Standardized Snowpack Index. Access to the platform is free, but paid users receive access to additional features, including download of data for offline use.

**29.(  )** One author compiled historical meteorological data from France between 1500 and 2014, mapping droughts and classifying them with a Historical Severity Drought Scale (HSDS); values ranged from 1 for absence of rainfall to 5 for exceptional drought. The following chart was then prepared. Clearly, France has experienced a more severe sequence of droughts in 1700 – 1750 than in other recorded periods.




**30.(  )** In the early 1990s, the Australian government introduced the National Drought Policy, and under it a number of assistance programs were implemented. Two such programs, the EC Interest Rate Subsidy and the EC Relief Payment, offered grants and interest rate subsidies to farmers in so-called Exceptional Circumstances (EC) areas. Although EC assistance has been shown to be ineffective, as of the early 2010s the Australian government continues to issue EC declarations and, in view of the popularity of this policy among the rural electorate, has consistently resisted calls for modernization of its drought programs.

**31.(  )** Despite its widespread use in the United States, the Palmer Drought Severity Index (PDSI) has a number of shortcomings. For example, the PDSI calculation allows no runoff to occur until the water capacity of the surface and subsurface soil layers is full (saturated), which may lead to an underestimation of runoff.

**32.(  )** The PDSI was conceived for assessment of meteorological drought, and research carried out since the publication of Palmer's original paper has shown that his model indeed results in reliable forecasts of this type of water scarcity. However, the PDSI should not be used to analyze hydrological droughts.

**33.(  )** A wet period or drought is said to have ended when the PDSI equals zero.

**34.(  )** In his original paper, Palmer based the evapotranspiration component of water balance on the Thornthwaite equation.

**35.(  )** Australia's territory is particularly prone to intense dry spells. Drawing on American experience, the Australian Drought Watch System uses the PDSI as its main drought index.

**36.(  )** Palmer also introduced the Moisture Anomaly Index, or Z-index. This parameter serves as a measure of how observed moisture conditions compare to normal (or climatically appropriate) moisture conditions. Like the PDSI, the Z-index at a certain month is substantially affected by moisture conditions in previous months.

**37.(  )** Three years after his 1965 paper, Palmer proposed yet another drought assessment parameter, the Crop Moisture Index (CMI). As the name implies, this parameter was specifically designed to assess water availability for a planted area. Palmer originally formulated the CMI in weekly time steps, therefore this parameter is primarily intended for short-term agricultural analyses and decision making.

**38.( )** One immediate advantage of the Standardized Precipitation Index (SPI) over the PDSI is the spatial invariance of the former, which readily enables comparison across space and time. The calculation of the SPI is also simpler: whereas the PDSI is a nonlinear function of precipitation and temperature, the SPI is based on precipitation only.

**39.( )** Another incontestable advantage of the SPI is the fact that it can be computed with short – say, less than 20 years – and incomplete precipitation datasets.

**40.( )** The Effective Drought Index (EDI) was proposed in the 1990s as an attempt to model drought more accurately than other indices available at the time. In papers published in the early 2000s, drought scientists showed that the EDI indeed conveys accurate results, but use of this method has been hindered by one important limitation: the original EDI algorithm is based on monthly precipitation data, and tedious calculations are necessary to adapt it to weekly or daily hydrological information.

## → Problem 3.1

The following data describe a 90-minute rainstorm over a catchment covered by a homogeneous loess soil. Using these data, determine the Wischmeyer erosivity index, which is defined as the product of total kinetic energy and maximum 30-minute intensity.

*Hint:* Storm kinetic energy can be related to rainfall intensity by the equation

$$KE = 0.0119 + 0.0873 \log_{10} I$$

where *KE* is given in MJ/ha/mm and *I* is given in mm/h.

| Time from start of storm (min) | Rainfall (mm) | Intensity (mm/h) |
|---|---|---|
| 0 - 14 | 1.61 | 7.11 |
| 15 - 29 | 15.3 | 60.2 |
| 30 - 44 | 27.4 | 105 |
| 45 - 59 | 32.3 | 138 |
| 60 - 74 | 8.44 | 35.5 |
| 75 - 89 | 0.96 | 2.88 |

**A)** $E \times I_{30}$ = 1250 MJ mm ha$^{-1}$ h$^{-1}$
**B)** $E \times I_{30}$ = 1860 MJ mm ha$^{-1}$ h$^{-1}$
**C)** $E \times I_{30}$ = 2200 MJ mm ha$^{-1}$ h$^{-1}$
**D)** $E \times I_{30}$ = 2830 MJ mm ha$^{-1}$ h$^{-1}$

## → Problem 3.2

Determine the Hudson erosivity index, defined as the sum of the total kinetic energies for intervals in which the rain exceeds 25 mm/h.

**A)** $HI$ = 9.32 MJ ha$^{-1}$
**B)** $HI$ = 11.7 MJ ha$^{-1}$
**C)** $HI$ = 15.4 MJ ha$^{-1}$
**D)** $HI$ = 19.6 MJ ha$^{-1}$

# SOLUTIONS

### P.1 ➡ *Solution*

The World Day to Combat Desertification and Drought was set at June 17. February 20 is the World Day of Social Justice. March 21 is the International Day of Forests. October 15 is the International Day of Rural Women.

♦ The correct answer is **C**.

### P.2 ➡ *Solution*

**1. True.** Resilience is an ecosystem's capacity of recovering after a disturbance. By inspection, we see that soil A recovers faster than soil B; accordingly, soil A is more resilient than soil B.

**2. True.** Indeed, soil erosion is said to have accelerated when rills become more numerous, the distance between them decreases, and their depth and width increase. The potential for rills increases as the degree of disturbance and slope increases.

**3. False.** Actually, the greater the area of redistribution of litter, the more severe erosion is. Litter movement is one of the USDI indicators of rangeland health. The USDI document notes that the size of litter moved by wind or water is also an indicator of the degree of litter redistribution. In general, the greater the distance that litter is moved from its point of origin and the larger the size and/or amount of litter moved, the more the site is being influenced by erosive processes.

**4. True.** By inspection, we can in fact surmise that the KE for detachment of 1 kg of sediment is indeed lowest at a mean particle size close to 0.125 mm. Coarser soils are resistant to detachment because of the weight of the larger particles, whereas finer soils are resistant because the raindrop energy has to overcome the adhesive or chemical bonding forces that link the minerals comprising the clay particles.

*Reference:* MORGAN, R. (2005). *Soil Erosion and Conservation*. 3rd edition. Oxford: Blackwell.

**5. False.** While it is true that the Fournier ratio has been successfully used to investigate regional variation in erosion risk, its correlation with rainfall erosion indices is rather poor. The emphasis given in $p^2/P$ to the month with the highest rainfall underplays the contribution of the rainfall in the rest of the year to erosion. If the mean annual rainfall increases but the highest monthly total remains the same, the Fournier ratio actually falls in value even though the potential for erosion should increase, since a proportion of the additional rain is likely to be erosive.

*Reference*: MORGAN, R. (2005). *Soil Erosion and Conservation*. 3rd edition. Oxford: Blackwell.

**6. False.** Actually, the overall change in flow conditions seems to take place smoothly as the Froude number increases from about 0.8 to 1.2, rather than occurring when a threshold value is reached. For this reason, attempts to explain the onset of rilling through the exceedance of a critical Froude number have not been successful and additional factors have had to be included when defining its value; examples include the particle size of the material and the sediment concentration in the flow.

**7. True.** Indeed, a surface area exponent greater than 0.2 is commonly associated with erosion by surface runoff, while a value lower than 0.2 is indicative of subsurface processes and mass movement.

**8. True.** All we have to do is substitute $d' = 2d$ and $u'_* = 1.5u_*$ in Bagnold's equation, giving

$$q' = C\sqrt{\frac{d'}{D}}\frac{\rho}{g}u'^3_* = C\sqrt{\frac{2d}{D}}\frac{\rho}{g}\left(1.5u_*\right)^3 = 4.77C\sqrt{\frac{d'}{D}}\frac{\rho}{g}u'^3_*$$

$$\therefore q' = 4.77q$$

The modifications proposed will raise the sediment transport rate by approximately 380%.

**9. True.** Non-erodible soils generally have $ER < 10$, while erodible soils have $ER$ ranging from 12 to 115. In the Middleton model, a soil is resistant to erosion if it possesses a larger content of clay particles, a higher colloid content, a greater specific weight, a lower plasticity limit, and a lower dispersion.

**10. False.** The statement errs twice, firstly by mentioning that the WEPP models erosion in areas as large as 10 km$^2$ (actually, the modeled area should be no larger than 2.6 km$^2$) and secondly by stating that gully erosion and mass wasting are among the processes supported by the software (they aren't).

**11. True.** This is an excerpt from Morgan's discussion on EUROSEM.

*Reference*: MORGAN, R. (2005). *Soil Erosion and Conservation*. 3rd edition. Oxford: Blackwell.

**12. False.** Although dunes and sand seas are the first morphological feature that come to mind, these are not the main landform in many of the world's deserts. A recent landform map of North Africa (mostly the Sahara

Desert) produced through moderate resolution imaging spectroradiometer indicated that the two most dominant land types were stone pavements (hamada, serir, reg, desert pavement) at about 25% cover, followed by sand seas (ergs) at about 20%. The North American arid zone includes extensive areas of alluvial fans, mountains, desert flats, playas and arroyos, while sand dunes and sheets constitute less than 5% of the arid territory.

**13. False.** The greater the Budyko-Lettau dryness ratio, the more arid an environment is; the numbers mentioned in the statement are made-up. One way to compute the BLDR is by dint of the equation

$$BLDR = \frac{R}{L\bar{P}}$$

where $R$ is the solar irradiation rate, $L$ is the water latent heat of vaporization, and $\bar{P}$ is the annual average precipitation. Budyko considered environments with $BLDR > 3.4$ to be desertic in nature, but in a more recent review of this parameter environments with $BLDR \leq 2$ are in the outer limit of the arid zone and $BLDR = 10$ represents the desert margin.

**14. True.** With a ratio $P/PET = 250/2000 = 0.125$, the area in question is indeed within the interval associated with arid zones. In broad terms, an arid zone has an annual rainfall of 80 – 150 mm and 200 – 350 mm in winter and summer rainfall areas, respectively; inter-annual rainfall variability is 50 – 100%; there is scattered vegetation; nomadic livestock rearing is possible and agriculture based upon local rainfall is only possible through rainwater harvesting techniques.

**15. True.** This is a modified excerpt from the article on deserts and desertification in the *Encyclopedia of Atmospheric Sciences*.

**16. False.** The relationship between land degradation and intervention costs is not as simple as the statement presumes. In the very title of assertion 4 of the Dahlem Desertification Paradigm, it is said that *the cost of intervention rises non-linearly with increasing degradation*. The authors do observe that, albeit complicated, the evaluation of intervention costs as functions of various biophysical and socioeconomic factors should be nonetheless quantifiable.

*Reference:* Reynolds, J., Stafford-Smith, D. and Lambin, E. (2003). Do Humans Cause Deserts? An Old Problem through the Lens of a New Framework: The Dahlem Desertification Paradigm.' *VIIth International Rangelands Congress*, Durban, South Africa, 26th July – 1st August 2003.

**17. True.** Iceland is a case study on how the association of desertification with arid lands is limited in scope. As noted by one contributor in the workshop proceedings (see reference below), nearly half of Iceland is barren wasteland, where nature provides neither food nor shelter from the howling North Atlantic winds. Severe desertification appears to have begun soon after initial settlement about 1125 years ago. The main cause for the massive ecosystem degradation appears to have been animal grazing and wood harvesting. The soils, mostly Andosols, were very susceptible to erosion by wind and water, and to cryogenic processes. The surface was subjected to frequent volcanic ash deposition, which intensified aeolian processes where the vegetation had been disturbed by utilization. The climate was already becoming cooler when settlers arrived, and this cooling trend continued long after the arrival of man. Sand encroachment on vegetated land also played a major role, especially in the highlands. The cumulative effect of cooler climate and increased aeolian deposition added to the susceptibility of Icelandic soils to erosion.

*Reference*: ARNALDS, O. and ARCHER, S. (Eds.). (2000). *Rangeland Desertification*. Heidelberg: Springer.

**18. False.** The description provided in the statement actually refers to the 'degradation II' stage, which the authors (see reference below) also name "accentuated degeneration." 'Degeneration III,' which the authors also call "degenerative 'recovery'", occurs when undesirable states arise in the presence of favorable conditions and become increasingly favored over time as a positive feedback develops. In the worst cases, positive feedbacks would be established in which the delayed response would continue long after the inducing stresses had been alleviated. This would indicate the crossing of a physiognomic or domain threshold with potentially irreversible changes to the ecosystem.

*Reference:* Archer, S. and Stokes, C. (2000). "Stress, disturbance and change in rangeland ecosystems." In: ARNALDS, O. and ARCHER, S. (Eds.). *Rangeland Desertification*. Heidelberg: Springer.

**19. False.** In a 2008 review, Wang et al. (see reference below) have documented the evolution of desertification in China and concluded that anthropogenic action is probably not the main cause of the country's ongoing desertification process. For instance, the three proxies for human impacts have increased appreciably since the 1950s, but arid China has experienced a bout of rehabilitation since the 1990s. In addition, although some land rehabilitation techniques have been used since the 2000s to combat desertification (e.g., afforestation, engineering to control sand movement, and returning farmland to forestry uses) and may have assisted ecological recovery in some regions of arid and semiarid China, this change cannot explain why rehabilitation has occurred in many parts of arid and semiarid China since the late 1980s, before these measures were implemented.

*Reference:* Wang, X., Chen, F., Hasi, E., and Li, J. (2008). Desertification in China: An assessment. *Earth-Science Reviews*, 88: 188 – 206.

**20. False.** On the contrary, Prince et al. (see reference below) found that there was no dramatic downward trend in RUE for the nine-year period in question, as might be expected in a progressively degrading Sahel. In fact, there were small but significant upward trends in the RUE. This was most probably caused by the increase in rainfall in the years since 1984, that is, the years that dominate the time series. Another possible explanation is a slight shift towards grassland from woodland, since some authors have suggested that grassland typically has slightly higher RUE than woody vegetation.

*Reference:* Prince, S., Brown de Colstoun, E. and Kravitz, L. (1998). Evidence from rain-use efficiencies does not indicate extensive Sahelian desertification. *Global Change Biology*, 4: 359 – 374.

**21. True.** This is an excerpt from Vogt et al. (see reference below). The authors add that the subjective metrics employed in GLASOD have never been tested for their consistency and the relationship between the level of degradation and the social and economic impact of the degradation remains unclear. Other limitations mentioned by Vogt et al. include the map's visual exaggeration of the extent of soil degradation, the use of extent classes rather than percentages, and the complex legend.

*Reference:* Vogt, J., Safriel, U., von Maltitz, G., Sokona, Y., Zougmore, R., Bastin, G. and Hill, J. (2011). Monitoring and assessment of land degradation and desertification: towards new conceptual and integrated approaches. *Land Degradation and Development*, 22: 150 – 165.

**22. False.** As explained by Vogt et al. (see reference below), use of NPP as an ecosystem health indicator is quite ambiguous. Changes in NPP do not necessarily equal land degradation phenomena such as soil erosion, salinity or nutrient depletion. Land use change from forest to cropland of lesser biological activity (decrease in NPP), for example, may be well sustainable and profitable, and an increase in biological production (increase in NPP) may reflect bush encroachment in rangeland or cropland, considered as degradation.

*Reference:* Vogt, J., Safriel, U., von Maltitz, G., Sokona, Y., Zougmore, R., Bastin, G. and Hill, J. (2011). Monitoring and assessment of land degradation and desertification: towards new conceptual and integrated approaches. *Land Degradation and Development*, 22: 150 – 165.

**23. True.** South Sudan's 1998 dry spell can be classified as a socioeconomic drought because it was exacerbated by government mismanagement and armed conflict. It is also classified as a famine, in that it stripped the food security of thousands of people and claimed an estimated 70,000 lives.

**24. False.** Although regional crop production was slightly below average, the severe drought of 1998 never materialized. Nevertheless, the increased preparedness established before this would-be drought can be seen as a triumph. Important actions taken included issuance of guidance to the public, ongoing monitoring and vigilance efforts including the development of national preparedness programs in some countries, pre-positioning of food stocks, donor coordination, and greater reliance on the private sector for meeting regional food needs. On the other hand, such worrisome drought warnings may also have prompted farmers to buy less seeds, reduce planted area, and devote lass labor to agriculture, presumably leading to substantial economic damage.

*Reference:* Dilley, M. (2000). Reducing vulnerability to climate variability in southern Africa: The growing role of climate information. *Climactic Change*, 45: 63 – 73.

**25. False.** Wanders and Van Lanen (see reference below) conducted an attribution study and found that, although drought frequency is expected to decrease on a global scale, an increase in severity and duration is to be expected. On average, drought duration is projected to increase by 180% and 240% in the near and far future, respectively. The regions that can expect the most severe impact of these changes are to be found in desert and snow-dominated climates.

*Reference:* Wanders, N. and van Lanen, H. (2015). Future discharge drought across climate regions around the world modelled with a synthetic hydrological modeling approach forced by three General Circulation Models. *Natural Hazards and Earth System Science*, 15: 487 – 504.

**26. True.** The USDM is in fact a "current-status" platform, not a forecasting tool. Several characteristics have made the USDM a successful drought monitoring resource, including its use of an ample assortment of data, including streamflow, measures of recent precipitation, drought indices, remotely sensed products, and modeled soil moisture. Many other ancillary indicators are also used, depending on the region and the season. For example, in the western United States, indicators such as snow water content, reservoir information, and water supply indices are important for evaluating the current and future availability of water. These indicators inherently incorporate the effects of hydrological lag and relationships across space and time between climate and the surface or groundwater system.

*Reference:* Hayes, M., Svoboda, M., Le Comte, D., Redmond, K. and Pasteris, P. (2005). "Drought monitoring: New tools for the 21st century." In: WILHITE, D. (Ed.). *Drought and Water Crises*. London: Taylor and Francis.

**27. False.** The SDO actually offers nationwide, frequently updated parameters other than the PDSI, including the Standardized Precipitation Index (SPI) and the Crop Moisture Index (CMI). Further, soil moisture is also part of the SDO, and the CPC portal regularly publishes calculated soil moisture charts.

**28. False.** Access to all features of the EDO, including download of data for offline use, is entirely free.

**29. True.** Indeed, 21 of the 68 drought episodes mapped by Garnier (see reference below) took place in the 18th century, and 14 occurred in the 1700 – 1750 period, totaling one drought every 3.5 years. This period also stands out for the severity of the dry spells, in that 10 of the 21 droughts had *HSDS* = 4 or 5. One exceptional year in this period was 1719, which set a record-breaking 220 days with no recorded pluviometry.

*Reference:* Garnier, E. (2019). "Historic drought from archives: beyond the instrumental record." In: IGLESIAS, A., ASSIMACOPOULOS, D. and VAN LANEN, A. (Eds.). *Drought: Science and Policy*. Hoboken: John Wiley and Sons.

**30. False.** As reported in the website of the Australian Department of Agriculture, Water and the Environment, the Exceptional Circumstances model was gradually abandoned in the 2000s, as it became clear that drought support based on ECs was no longer appropriate in the face of a variable climate. The Australian government stopped issuing EC declarations, and the last ones lapsed in 2012. As observed by Wilhite et al. (see reference below), experience with the EC policy between the 1990s and 2000s exposed at least two important limitations. First, the term *exceptional circumstances* was not defined in either the legislation establishing the provision or any of the accompanying explanatory material, such as ministerial speeches; attempts have been made over the life of the National Drought Policy to develop an objective, "scientific" definition of exceptional drought, but, as is generally agreed in the international literature, drought is very difficult to define. Second, exceptional circumstances declarations have been geographically based, resulting in what has become known as the "lines on maps" problem; farmers in arguably objectively similar circumstances ended up being treated quite differently because of the placement of the boundary delineating exceptional circumstances areas.

*Reference*: Wilhite, D., Botterill, L. and Monnik, K. (2005). "National Drought Policy: Lessons learned from Australia, South Africa, and the United States." In: WILHITE, D. *Drought and Water Crises.* London: Taylor and Francis.

**31. True.** A rather inconvenient interpretation of runoff is indeed a shortcoming of Palmer's index. Runoff varies due to differences in precipitation intensity, slope, soil type, land use, land cover, and land management practices, and the complex interplay of these factors is not accounted for in the PDSI. When making use of Palmer's index, the drought scientist should bear in mind that this model was originally devised for use in central Iowa and western Kansas, and some of the parameters involved in the calculation have little scientific meaning.

**32. False.** The PDSI was in fact devised for study of meteorological drought, but researchers have found that it responds rather slowly to changes in moisture conditions. One researcher (quoted in the reference below) has found that the PDSI has a 'memory' (its spectrum conforms to that of an autoregressive process) and is highly correlated with the 12-month Standardized Precipitation Index (SPI). This means that the PDSI is more appropriate for measuring hydrological droughts.

*Reference*: Quiring, S. (2009). Monitoring drought: an evaluation of meteorological drought indices. *Geography Compass*, 3/1: 64 – 88.

**33. True.** Although seemingly convenient, the PDSI = 0 criterion for drought end is debatable. When PDSI = 0, moisture demand is satisfied, but it may not endure. A return to normal weather following readjustment of large-scale or regional-scale atmospheric circulation patterns will have to persist for much longer in order for the index to truly reflect a return to normal conditions. This means that the criteria for ending a drought (wet period) should be more stringent than simply having PDSI = 0.

**34. True.** Palmer used the Thornthwaite equation of potential evapotranspiration. First proposed in 1948, this equation is expressed as

$$\theta = 16\left(\frac{S}{12}\right)\left(\frac{N}{30}\right)\left(\frac{10T_d}{H}\right)^{\alpha}$$

where $\theta$ is the estimated potential evapotranspiration (mm/month), $S$ is the average day length (hours) of the month being calculated, $N$ is the number of days in the month being considered, $T_d$ is the average daily temperature ($^{o}$C, if negative use 0), and $H$ and $\alpha$ are parameters. Notice that the Thornthwaite method is based on monthly temperatures, which is an important limitation for applications involving reduced (say, 15-days long) time scales. More realistic estimates can be generated by using a physically-based method such as the FAO Penman-Montieth equation.

**35. False.** Australian drought scientists chose precipitation deciles over the PDSI for simplicity, consistency, and understandability.

**36. False.** While both the $Z$-index and the PDSI are derived using the same data, their monthly values are quite different. The $Z$-index is not affected by weather conditions in previous months, so it can vary dramatically from month to month. On the other hand, the PDSI varies more slowly because antecedent conditions account for only two thirds of its value.

**37. True.** Indeed, the CMI was formulated with weekly time steps. The CMI in a given week is given by weekly precipitation and temperature data, in addition to the CMI value for the previous time step.

**38. True.** The SPI can be promptly used in comparisons between places and periods. What's more, the SPI is easier to understand and interpret than the PDSI because its value is only based on precipitation and because it is reported in standard deviations from the mean.

**39. False.** The SPI actually requires a long and complete precipitation record. The SPI is strongly influenced by record length, so that, when performing comparisons of different stations, it should be verified that different SPI values were based on datasets of the same length. The minimum precipitation record for calculating this parameter is 30 years, but a common recommendation is to employ 50+ years of measurements; extreme values of SPI may only be accurate when even longer datasets (e.g., 80 years) are used.

*Reference*: Quiring, S. (2009). Monitoring drought: an evaluation of meteorological drought indices. *Geography Compass*, 3/1:64 – 88.

**40. False.** From the outset, the Effective Drought Index was designed to work with daily data points. In an early paper on the EDI, Byun and Wilhite (see first reference below) complain that most drought indices available at the time were based on monthly or weekly data, so an approach to daily precipitation data was in order. Nonetheless, the EDI has been also successfully adapted to monthly information and as such was implemented in a drought modeling software devised by South-African researchers (see second reference below).

*References:*

→ Byun, H. and Wilhite, D. (1999). Objective quantification of drought severity and duration. *Journal of Climate,* 12(9): 2747 – 2756.

→ Smakhtin, V. and Hughes, D. (2007). Automated estimation and analyses of meteorological drought characteristics from monthly rainfall data. *Environmental Modeling and Software*, 22: 880 – 890.

## P.3 ➡ *Solution*

**Part 1**: By inspection, it is easy to see that the maximum 30-minute intensity is registered between time from start 30 – 59, so that

$$\text{Maximum 30-minute rainfall} = 27.4 + 32.3 = 59.7\,\text{mm}$$

The maximum 30-minute intensity is then 59.7/0.5 = 119.4 mm/h. We also need the kinetic energy of the storm. The KE can be related to intensity by the relationship we were given, namely

$$KE = 0.0119 + 0.0873\log_{10} I$$

For interval 15 – 29 min, for example, $I$ = 7.11 mm/h and $KE$ = 0.0863 MJ/ha/mm. The total kinetic energy, in turn, is given by the product of $KE$ and intensity; the data are processed below.

| Time from start of storm (min) | Rainfall (mm) | Intensity (mm/h) | Kinetic energy (MJ/ha/mm) | Total kinetic energy (MJ/ha) (Col. 2 x Col. 4) |
|---|---|---|---|---|
| 0 - 14 | 1.61 | 7.11 | 0.0863 | 0.139 |
| 15 - 29 | 15.3 | 60.2 | 0.1673 | 2.559 |
| 30 - 44 | 27.4 | 105 | 0.1883 | 5.161 |
| 45 - 59 | 32.3 | 138 | 0.1987 | 6.418 |
| 60 - 74 | 8.44 | 35.5 | 0.1472 | 1.243 |
| 75 - 89 | 0.96 | 2.88 | 0.0520 | 0.050 |
| | | | | Total = 15.57 |

It remains to determine the Wischmeyer erosivity index,

$$E \times I_{30} = 15.57 \times 119.4 = \boxed{1860\ \text{MJ}\,\text{mm}\,\text{ha}^{-1}\text{h}^{-1}}$$

♦ The correct answer is **B**.

**Part 2**: The Hudson index is given by the sum of the total kinetic energies for intervals in which the rain intensity exceeded 25 mm/h. In the present case,

$$HI = 2.559 + 5.161 + 6.418 + 1.243 = \boxed{15.4\,\text{MJ}\,\text{ha}^{-1}}$$

♦ The correct answer is **C**.

## REFERENCES

In addition to the references directly quoted in the Solutions section, the following books were consulted.


- ANDREU, J., ROSSI, G., VAGLIASINDI, F. and VELA, A. (Eds.). (2006). *Drought Management and Planning for Water Resources*. Boca Raton: CRC Press.
- NORTH, G., PYLE, J. and ZHANG, F. (Eds.). (2015). *Encyclopedia of Atmospheric Sciences*. 2nd edition. Amsterdam: Elsevier.
- SEN, Z. (2015). *Applied Drought Modeling, Prediction, and Mitigation*. Amsterdam: Elsevier.
- ZACHAR, D. (1982). *Soil Erosion.* Amsterdam: Elsevier.