Devanmini Halwatura
PhD Research Scholar

Centre for Mined Land Rehabilitation
Sustainable Minerals Institute
The University of Queensland

28 January 2015

Re: Manuscript revision (hess-2014-138)

Dear Nadia Ursino and reviewers,

Please find in the attachment a revised copy of our manuscript "Severity-Duration-Frequency curves of droughts: A foundation for risk assessment and planning tool for ecosystem establishment in post-mining landscapes".

We appreciate the reviewers' positive comments on the previous review of the manuscript: "[…] potential to fill in several research gaps in drought studies involving the use of drought indices […]" (Reviewer #2).

We have thoroughly addressed all the reviewers' comments and revised the manuscript accordingly. The following key changes have been made to the manuscript:

- Addressed the assessment of short- and long-term drought, according to interlaced duration, intensity and frequency (Reviewer #2) in the methodology.
- Added Table F to verify the statistical significance of our analysis (Reviewer #2).
- Explained the reason for using evaporation rather than evapotranspiration to calculate the drought indices (Reviewer #1).
- Included a new paragraph in the discussion section (section 4.1) to describing the seasonal variability of droughts, and evidence similarities/differences between the three drought indices (Reviewer #2).

We thank the reviewers for their critical comments and believe that the latest amendments have greatly improved the work, hopefully toward potential publication in *Hydrology and Earth System Sciences*.

Thank you for your consideration and do not hesitate to contact me should you have any further questions or concerns.

In the following sections we provide more detail on these changes, addressing the reviewers' comments one by one.

Best regards,

Devanmini Halwatura

On behalf of: Sven Arnold and Alex Lechner

Referee report #1

We would like to thank the Anonymous Referee #1 for this review and his/her constructive comments. We have addressed their comments as follows

General comment:

The objective of this study is to quantify the Severity-Duration-Frequency (SDF) curves of short- and long term drought in Eastern Australia using three drought indices, namely SPI, RDI and SPEI. The authors conclude the using these easily accessible data mine rehabilitation managers can adopt the concept of using SDF curves as early risk assessment tool. In view of the interactive discussion and my own review, I recommend that the paper still needs to clarify some major and minor points before it is acceptable for publication.

Comment 1: Page 1, lines 17; page 3, line 33: Although the authors state the objective as to quantify the SDF of short- and long-term drought events and that they define the short-term droughts as droughts of less than three months, they attempted to characterize drought only for medium- (3 months) and long-term assessment throughout the paper (see e.g. p. 5, line 9; Figs. 4 to 6).

Response 1: Thank you for pointing this out. We were not clear in our definition of short and long term droughts. We have modified existing text on page 4, line 2-3 as follows "..short-term droughts are three month or less; medium-term droughts are between four to nine months and long-term droughts are 12 month or more".

Comment 2: Page 5, Materials and methods: There is no detail of the data in use in terms of record length and quality (missing data, gaps). Are the data long enough to conduct a frequency analysis and fit probability functions?

Response 2: We have included the following phrases to address the lack of detail in describing the quality of the data and the length citing the existing Table 1. "We selected 11 sites for which historical observations of monthly rainfall and evaporation (ranging from 30-60 years) (Table 1) were most comprehensive (more than 97% coverage) (i.e., longest and most complete) across Eastern Australia (Bureau of Meteorology, 2013)".

The data corresponds to the recommended length of 30 years required to conduct a frequency analysis and fit probability functions.

Comment 3: Page 5, line 29: Why did the authors use evaporation rather than evapotranspiration to calculate the drought indices if they are talking about agro-climatic regions, extensive cropping and grazing areas as mentioned in the introduction (page 2, lines 12-13)?

Response 3: We agree that the use of potential evapotranspiration is more precise than evaporation. However, potential evapotranspiration is a calculated value which requires more data (temperature, wind speed, air pressure, and solar radiation) that are not necessarily available for all of our sites and other remote locations. Additionally, as pointed out in the introduction (page 2, lines 12-13) our aim was to describe the agro-climatic condition of Eastern Australia rather than emphasising the importance of using potential evapotranspiration. Finally one of the aims of the paper was to utilise (page 17, line 16-19) "… simple and easily accessible meteorological data [as this] is a critical step forward to making it easier for mine rehabilitation managers to adopt the concept of using SDF curves as early risk assessment tool."

Comment 4: Page 7, lines 4 and 5: The authors define drought severity as the summation of negative index values. To my understanding, this is rather the magnitude of drought. Drought severity is defined as the magnitude of drought at a given time. On the other hand, in page 12, line 7, the authors define severity as negative values of drought index. Please clarify based on for instance the following references for definitions of drought characteristics:

Chen, S.-T., Kuo, C.-C., Yu, P.-S., 2009. Historical trends and variability of meteoro-logical droughts in Taiwan. Hydrol. Sci. J. 54 (3), 430–441.

Edossa, D.C., Babel, M.S., Gupta, A.D., 2010. Drought analysis in the Awash Riverbasin, Ethiopia. Water Resour. Manage. 24, 1441–1460.

Mishra, A.K., Singh, V.P., 2010. A review of drought concepts. J. Hydrol. 391, 202–216.

Response 4: Thank you for catching this. We have changed this to "...cumulative negative values of a particular drought…" in line with the reviewers suggestion.

Further, we refer to Dracup et al. (1980) who define the magnitude of a drought as the average water deficiency, while the severity of a drought is the cumulative water deficiency.

Comment 5.1: Pages 9, lines 28 & 29; page 10, lines 1-4; Fig. 5; Appendix E: First, $p > 0.05$ should be corrected to $p< 0.05$.

Response 5.1 We have corrected this accordingly.

Comment 5.2, the correlation coefficients alone are not decisive indicators of match of drought characteristics. A good correlation could be found but this does not mean that the timing of drought matches between the different droughts indices. Serial correlation (autocorrelation coefficient) is more appropriate since a lot of emphasis has been put on recurrence interval.

Response 5.2: We recognise that there are potentially other methods for comparing between indices. However, the two correlation analysis methods (Spearman's Rank and Kendall's Tau) in our paper are widely used methods in the literature for similar drought index comparison studies and thus we chose to use them (Banimahd and Khalili, 2013; Khalili et al., 2011; Beguería et al., 2010; Vicente-Serrano et al., 2014). We do agree that it would be very interesting to look at serial correlation methods. But given that there are very few examples of the literature on how these can be used we feel introducing a new method may make the paper too lengthy and distract from the focus of the paper on Severity-Duration-Frequency curves of droughts as an early risk assessment and planning tool for ecosystem establishment in post-mining landscapes.

Comment 5.3: can the author give any physical explanation why correlations were lowest for arid areas?

Response 5.3 The correlations were lowest for arid areas, because in arid rather than tropical and temperate climates evaporation plays a critical role in the water balance. We added the following sentence to section 4.1: "By contrast, in arid Bourke, Quilpie, or Mount Isa correlations between SPI and the more complex indices were weaker, because evaporation plays a critical role in arid climates rather than in tropics and temperate regions".

Comment 6: Page 12, line 20; Section 4.2, lines 19-21: The authors claim that their concept provides "a quantitative estimate of ecosystem rehabilitation failure due to water deficit". This concern was also raised in the referee report # 2, but the answer still remains superficial and speculative if no quantitative measure of consequent risk is given. For instance, the possible outcomes of disaster on a cropping system must consider the crop yield to assess the risk. It is to be emphasized here that not all drought events cause failure. If the authors cannot identify the consequence of ecosystem rehabilitation failure, these objective and statements should be removed from the whole paper. Then, the title of the paper should be changed to Severity-Duration-Frequency curves of drought: a tool for ecosystem managers to address site-based climatic conditions

Response 6: We somewhat agree with the reviewer's suggestion, and have changed the title, because as the reviewer suggests we do not assess the consequences of drought explicitly: "Severity-Duration-Frequency curves of droughts: A foundation for risk assessment and planning tool for ecosystem establishment in post-mining landscapes". We think the method described in this paper provides the "foundation" for a risk assessment tool. The "recurrence intervals quantify the probability of occurrence of drought events" while consequence will always be site specific in the case of mine rehabilitation" (page 14, line 21-23). So the method we describe can be considered the foundations of a risk assessment. We do not provide a measure for consequence as these are site specific. But we have provided examples in table 3 on how this can be calculated. Our method is in line with previous literature on the use of IDF for assessing the risk of flooding on hydrological infrastructure (as described in page 4, line 11-14). What we have done is try and take tools and the language used in the discipline of hydrological engineering to the discipline of restoration ecology.

Comment 7: List of references: The authors should be consistent in formatting the titles of references as regards the use of capital and small letters based on the journal guidelines. In this manuscript, a mixture of these formats is used.
Response 7: We revised the reference accordingly

Comment 8: Table 1: The reader cannot understand the too many undefined symbols and abbreviations (columns 4 to 6) though this table has been referred to at least 4 times in the introduction. I recommend removing these abbreviations and leave the text.
Response 8: We removed all the symbols in column 5 and 6 to simply the table, however, we have had to retain the symbols in column 7 (agro-climatic regions) as they are part of the classification nomenclature.

Table 1. Climate indices and classification of selected locations across eastern Australia with focus on rainfall.

Location	**Length of meteorological data (years)**	**Climate index**		**Climate classification system**			
		R/PET[a]	**R_w/R_s**[b]	**Köppen-Geiger**[c]	**Australian Agricultural Environment**[d]	**Agro-climatic**[e]	**potential productive landuse**[e,d]
Weipa	1960-1994 (34)	0.99	0.01	Tropical, savannah	Tropics (wet/dry season)	I1 – wet/dry season	crops, rangeland
Cairns	1965-2013 (48)	0.91	0.10	Tropical, savannah	Tropical coast (wet)	I3 – wet/dry season	crops, rangeland, sugarcane
Brisbane	1986-2013 (27)	0.55	0.38	Temperate, without dry season	Subtropical coast (wet)	F4 – wet	horticulture, pasture, sugarcane
Sydney	1970-1994 (24)	0.53	0.51	Temperate, without dry season	Temperate coast east (wet, winter-dominant rainfall)	F3 – wet	crops, horticulture, pasture
Melbourne	1955-2013 (58)	0.51	0.95	Temperate, without dry season	Temperate coast east (wet, winter-dominant rainfall)	D5 – wet	crops, forestry, horticulture, pasture
Kingaroy	1967-2001 (34)	0.47	0.34	Temperate, without dry season	Wheatbelt downs (summer-dominant/moderate rainfall)	E4 – water-limited	cotton, crops, pasture,
Brigalow Research Station	1968-2011 (43)	0.32	0.27	Temperate, without dry season	Subtropical plains (summer-dominant/moderate rainfall)	E4 – water-limited	
Wagga Wagga	1966-2013 (47)	0.30	1.21	Temperate, without dry season	Wheatbelt east (winter-dominant rainfall)	E3 – water-limited in summer	crops, horticulture, pasture
Bourke	1967-1996 (29)	0.20	0.61	Arid, steppe	Arid (dry)	E6 – water-limited	rangeland, wildland
Quilpie	1970-2013 (43)	0.14	0.36	Arid, steppe	Arid (dry)	H – water-limited	
Mount Isa	1975-2013 (38)	0.13	0.05	Arid, steppe	Arid (dry)	G – water-limited	

a – (UNEP, 1992)
b – Based on average of three months of rainfall during winter (June – August) and summer (December – February)
c –(Peel et al., 2007)
d –(Woodhams et al., 2012)
e – (Hutchinson et al., 2005)

Comment 9: Table 2: Where is this table mentioned in the text?

Response 9: We have cited table 2 in the original text as follows:
Result: page 9 line 16, 18, 21, 23, 27 and page 10 line 15
Discussion: page 10 line 29 and page 11 line 3

References

Banimahd, S., and Khalili, D.: Factors influencing markov chains predictability characteristics, utilizing SPI, RDI, EDI and SPEI drought indices in different climatic zones, Water Resources Management, 27, 3911-3928, 10.1007/s11269-013-0387-z, 2013.

Beguería, S. , Vicente-Serrano, S. M., and Angulo-Martínez, M.: A multiscalar global drought dataset: The SPEIbase: A new gridded product for the analysis of drought variability and impacts, 2010.

Bureau of Meteorology, Climate data: http://www.bom.gov.au/climate/data/, access: April, 2013.

Dracup, J. A. , Lee, K. S., and Paulson, E. G.: On the definition of droughts, Water Resources Research, 16, 297-302, 10.1029/WR016i002p00297, 1980.

Hutchinson, M. F. , McIntyre, S. , Hobbs, R. J. , Stein, J. L. , Garnett, S., and Kinloch, J.: Integrating a global agro-climatic classification with bioregional boundaries in Australia, Global Ecology and Biogeography, 14, 197-212, 2005.

Khalili, D. , Farnoud, T. , Jamshidi, H. , Kamgar-Haghighi, A., and Zand-Parsa, S.: Comparability Analyses of the SPI and RDI Meteorological Drought Indices in Different Climatic Zones, Water Resources Management, 25, 1737-1757, 10.1007/s11269-010-9772-z, 2011.

Peel, M. C. , Finlayson, B. L., and McMahon, T. A.: Updated world map of the Köppen-Geiger climate classification, Hydrol. Earth Syst. Sci., 11, 1633-1644, 10.5194/hess-11-1633-2007, 2007.

Vicente-Serrano, S. M. , Van der Schrier, G. , Beguería, S. , Azorin-Molina, C., and Lopez-Moreno, J.-I.: Contribution of precipitation and reference evapotranspiration to drought indices under different climates, Journal of Hydrology, http://dx.doi.org/10.1016/j.jhydrol.2014.11.025, 2014.

Woodhams, F. , Southwell, D. , Bruce, S. , Barnes, B. , Appleton, H. , Rickards, J. , Walcott, J. , Hug, B. , Whittle, L., and Ahammad, H.: Carbon Farming Initiative: A proposed common practice framework for assessing additionality, Canberra, August, 2012.

Referee report #2

We would like to thank the Anonymous Referee #2 for this review and his/her constructive comments. We have addressed his/her comments as follows

General comments:

The authors present a study which compares three rainfall based drought indices for assessment of drought risks in Eastern Australia. Such assessment is vital to understanding the success and failures of ecosystem rehabilitation in post mined landscapes which forms the focus of the study.

Comment 1: The study has potential to fill in several research gaps in drought studies involving the use of drought indices if adequate attention is given on discussing the results of drought simulation by the indices. There is no discussion on the seasonality of droughts simulated by the indices. This forms a big caveat in the current study given that the success and failures of ecosystem rehabilitation in post mined landscapes is tied to the seasonality of droughts. There is limited discussion on how the drought indices compare against each other in terms of the time series. It is useful to know if aspects of droughts (e.g. duration) at a given time have been over or underestimated by one index over the other and/or to investigate how the indices simulate drought evolution.

Response 1: We agree that there should be more discussion about how land managers should address seasonality using the recurrence interval curves, because some of our selected locations (Weipa, Cairns, Mount Isa, Brigalow belt) have distinct seasonal variation in winter and summer rainfall (Table 1). Therefore, we modified the 2nd paragraph of the original discussion and combined it with the 4th paragraph of section 4.1 (original manuscript). Additionally we included a new paragraph about the effect of seasonality to the section 4.1.

"The locations with distinct patterns of seasonality such as Weipa, Cairns, Mount Isa, or the Brigalow Belt are the exception to this pattern due to the distinct distribution of winter and summer rainfalls (Table 1). The short-term drought index (RDI_3) detects most severe and prolonged droughts in tropical Weipa and Cairns (Table 2), where rainfall is low in winter and high in summer. Annually recurring seasonal patterns also explain the low variability of short-term drought severity and duration. In contrast the long-term drought index ($SPEI_{12}$) detects most severe and prolonged droughts in arid Quilpie and Mount Isa, as well as temperate Melbourne (Table 2). Major weather events such as El Niño and La Niña from recent decades coincided with low and high drought indices, respectively (Fig. 4 and Appendix C). Therefore the land managers who are interested in locations which has seasonality of rainfall should refer the seasonal rainfall patterns with the SDF curves."

Comment 2: There is a flaw in the approach of comparing drought characteristics between a 3month index and a 12month index because different termination rules results in different drought characteristics with shorter, more frequent and less intense droughts usually associated with a shorter termination rule (e.g. 3month). The authors should be looking to compare drought characteristics between indices using the same time scale.

Response 2: In our study we did not compare different time scales. We compared different drought indices at the same time scale (Figure 5 and Appendix E). We realise that the sentence 9:15-16 is misleading and therefore we have changed it.
Also we included the following phrase to p3, 25-33 to be clearer about what we are analysing "In many parts of the world evaporation data are unavailable or incomplete and simple rainfall indices such as SPI are most commonly used. In this study we compare SPI with RDI at the 3 month time scale and SPI and SPEI at the 12 month time scale to determine the difference between using SPI with a more complex indices that incorporate evaporation in different climatic regions."
This is in addition to existing text within the methods section:
5, 14-15 "We characterised droughts using the RDI and SPEI for 3 and 12-month time scales respectively, and compared these indices with the SPI at the same time scales."

Comment 3: The severity duration frequency (SDF) curves were used, but there is limited discussion of how the SDF curve can be used as a tool for early risk assessment. In particular, how consistent/different are the recurrence intervals simulated by the SDF from those by the intensity duration frequency (IDF)? The authors can enhance this by discussing the advantages and caveats of the SDF curve both in the context of the present study and elsewhere (given that there is a growing drought literature on the SDF curve).

Response 3: IDF analysis is a multivariate tool which relates rainfall intensity, rainfall duration and frequency of occurrence (Shiau and Modarres, 2009). Dalezios et al. (2000) used a similar method of IDF analysis to develop drought severity-duration-frequency (SDF) curves. Though both, SDF and IDF curves, are used to estimate extreme rainfall events, IDF curves are used for detect excessive rainfall events (floods), while SDF curves are used to detect water deficits (droughts). Since our study focuses on droughts which are critical drivers for rehabilitation, especially in arid zones, it is out of scope of our paper to assess the consistencies/differences between SDF and IDF curves. We do however, briefly describe IDF curves and their use on line 11-16 page 4:

Comment 4: I feel that the inclusion of management recommendations in section 4.3 is not necessary as it "dilutes" the study. I strongly recommend focusing just on discussing the drought indices and the SDF.
Response 4: We included section 4.1 in response to two reviewers' suggestions in the second round of review of our manuscript. At the editor's discretion we would like to keep section 4.3 to maintain the flow of the manuscript. Furthermore, we believe it provides important information on how SDF can be used in conjunction with practical environmental data for an assessment of risk see section 4.2.

Major comments:

Comment 5: 3:18-20: The statement beginning with "As none of these indices apply universally to any climate region...". There is ample literature to show that certain indices work better in a given climatic region. The authors should refer to/cite the various drought index inter-comparison studies.

Response 5: We have clarified this sentence and cited some inter-comparison studies in the introduction as follows (page 3, line 20-25):

"Though there are numerous comparative studies of drought indices in certain climatic regions such as Mediterranean climate (Paulo et al., 2012; Livada and Assimakopoulos, 2007), Carpathian region (Spinoni et al., 2013), arid conditions (Peel et al., 2007; Zarch et al., 2011) none of these indices apply universally to any climate region and it is best for land managers to use a range of drought indices at various temporal scales (Heim, 2002; Spinoni et al., 2013)"

Comment 6: 3:22-24: Why did the authors choose the SPI, SPEI and RDI instead of other indices? This needs to be explained. In addition, I feel that it is redundant for the authors to compare the SPI with the SPEI given that the SPEI is just another version of SPI but incorporating the effects of evaporation (hence, more accurate) which is useful for assessment of droughts under climate change conditions. It is fine if the authors seek to compare the SPI and the SPEI to investigate if there are differences in drought characteristics simulated by both indices, but not to determine the "accuracy of using the SPI". Checks on accuracy of droughts simulated by an index should be compared against hydrological data (e.g. river flow).

Response 6: We agree with your comment that in our study we are only making comparisons between indices and not determining accuracy. We replaced the word "accuracy" by "difference". We chose to look at SPI, RDI and SPEI in our study because in many mine rehabilitation sites only rainfall data will be available. We were keen to see if SPI with its lower data requirements preformed as well as SPEI or RDI. Additionally, for our study area we only had rainfall and evaporation data. Finally we plan to investigate more complex indices as stated in our discussion 4.4 about future work. The next stage of this research is to find the accuracy of drought indices using soil water potential simulations.

Comment 7: 4:17: The statement containing "... and refer to this concept as severity duration frequency design drought" gives the impression that the authors are introducing a new drought characteristic. In the following statement the authors state that the SDF curve have been used elsewhere, citing the work of Shiau (2006) and Shiau et al (2012). The authors need to explain how their SDF curve is different from the SDF concept used in other studies. If this is not the case, the source of SDF concept needs to be appropriately referenced. Regardless, the concept of SDF needs to be elaborated.

Response 7: We agree with the reviewers comment and realise that this sentence needs clarification. The new concept that we are introducing in our study is the use of the existing SDF concept as a risk management tool to overcome challenges of early vegetation establishment – in the same way the Intensity Duration Frequency (IDF) curves used in risk assessment of hydrological infrastructure. For example, line 23-26, page 4: "While IDF

design rainfalls are a well-established tool in civil engineering and hydrology, we believe SDF design drought could be used in a similar way to assess the risk of ecosystem rehabilitation failure due to droughts.“ As suggested, we have included references that refer to SDF concept to the manuscript:
(Shiau, 2006; Shiau et al., 2012; Lee and Kim, 2012; Todisco et al., 2013; Mirabbasi et al., 2012)

Comment 8: 4:18: It is not clear what is meant by "drought variables".
Response 8: We included the following drought variables to clarify this:
"[…] variables (severity, duration, frequency of occurrence) […]"

Comment 9: 4:24: The statement beginning with "This approach contrasts current climate classification methods...". The SDF should be a complementary classification and not a competing one to those in Table 1. One provides a basic climatic state and is not meant to give an assessment of vulnerability, whereas the other provides the state of drought recurrence.
Response 9: We agree that the SDF are not competing with the climatic classifications sated in Table 1. We include those climatic classifications to use as in conjunction to assess the vulnerability of water deficit. We include the following phrase to the sentence for further clarification:
"This approach […] which can be used as a conjunction to assess the vulnerability of water deficit."

Comment 10: 4:31: Can the authors provide what methods have been utilized in the context of the phrase "... so far methods for quantifying the frequency of drought events have been rarely applied ..."?
Response 10: In order to keep the introduction focused we have cited a study by Audet et al. (2013) which specifically addresses this issue and makes that conclusion. Please refer to Audet et al. (2013) for further clarifications.

Comment 11 & 15
Comment 11: 5:9: Why did the authors choose to use a 3month timescale for RDI but 12month for SPEI when the authors have acknowledged that "it is best to use a range of drought indices at various temporal scales" (3:1920). Comparing the performance of RDI, SPEI and SPI at both 3and 12months could provide valuable information on the temporal consistency of these indices in simulating droughts at these timescales. Furthermore, studies have shown that drought characteristics are influenced by the n month termination rules (see also comment 9:15-16).
Comment 15: 6:11-15: The authors need to illustrate the merits and shortfalls of the 3/6month RDI and 12month SPEI. In what ways are the RDI/SPEI better (e.g. better simulation of duration?) at the given timescale? In addition, to what extent are the findings from Banimahd and Khalili (2013) and Egidijus et al (2013) representative of climate conditions in Eastern Australia?

Response 11&15: We have clarified in the text in what ways RDI/SPEI are better than SPI and the similarities and differences in different climatic regions as follows. However there are not many studies that identified the merits and shortfalls of SPI, RDI/SPEI.

[…] the RDI plays a strong role in detecting maximum drought severities at the medium time-scale (3 to 6 months) (Banimahd and Khalili, 2013), while the SPEI plays a strong role in detecting annual drought events by identifying the hydrological summer drought events (Egidijus et al., 2013). There are evidences that SPI overestimates small rainfall scarcity even if excessive rainfall occurs just before the period of interest (Kim et al., 2009). Also for humid climate there is a good correspondence between the computed SPI_3 and RDI_3 (Khalili et al., 2011). For Mediterranean climate SPI and SPEI at 9- and 12-month time scales are well correlated (Paulo et al., 2012), and in Carpathian region SPI, SPEI, and RDI are highly comparable over annual periods (Spinoni et al., 2013). In arid regions the correlation of SPI and RDI is more considerable at the 3, 6 and 9 monthly time scale (Peel et al., 2007; Zarch et al., 2011).

According to the Köppen-Geiger classifications the study areas of (Banimahd and Khalili, 2013) represent arid regains (Isa, Quilpie, Bourke) of Eastern Australia while locations of (Egidijus et al., 2013) represent temperate regions such as Melbourne (Peel et al., 2007).

Comment 12: 6:1:2: Out of the 11 sites, eight are what you would consider coastal locations. There may be a contrast between droughts generated at coastal sites and those in interior locations in terms their severity and timing due to the influence of maritime winds, weather types amongst others. In the later parts of the manuscript, results (Figure 5, Appendix E) suggest that this could be the case with the Quilpie and Bourke locations forming "outliers". The authors should conduct tests on rainfall data between sites within the same climate class to ascertain/reject locational influence.

Response 12:

While some of these sites may have a maritime influence such as Melbourne, Sydney, Cairns and Weipa. The rest of the sites are unlikely to be driven predominantly by maritime influences. Even the sites near the coastline are influenced by very different climatic factors as they are far away from each other. The distance between Melbourne to Weipa is ~2800 km. To put it in perspective this is a similar distance as Cairo to Moscow (see http://www.ga.gov.au/scientific-topics/geographic-information/dimensions/australias-size-compared). Of the non-coastal cities that are nearest the coast Wagga Wagga is ~260 km from the coast and Kingaroy is ~125 km from the coast. Both these cities are on the other side of the great divide, a mountain range that is found along the east of Australia. Thus their climates are not maritime. Eastern Australia makes a very good case study for this kind of research as there are a wide range of climates in which data has been gathered using a consistent method by one agency.

However we added the highlighted sentence in to the introduction page 5 line 8-10.

Comment 13: 6:4-5: I would not label the SPI as "the simplest drought index" as there are other indices which are simpler to calculate than the SPI.

Response 13: We agree that the SPI is not the simplest drought index. In our manuscript we state that “Amongst the three indices the SPI is the most widely used and simplest drought index…”.

Comment 14: 6:6-7: The SPI is limited because it does not factor in other meteorological data, not because of the lack of them.
Response 14: We changed the phrase as follows:
“[…] SPI may not adequately characterise drought events because it does not incorporate other meteorological data.”

Comment 16: 6:18: Did the authors use the gamma distribution function for use in the drought indices, or did the authors explore other functions? If the latter is true, how are the results different?
Response 16: We used the standard approach e.g. (McKee et al., 1993) to calculate the SPI. (Page 7, line 1-5) “The SPI is derived by fitting a probability distribution to the rainfall record and then transforming that to a normal distribution such that mean and standard deviation of the SPI are zero and one. Positive or negative values of the SPI represent rainfall conditions greater or smaller than average rainfall, respectively (McKee et al., 1993)”.

Comment 17: 9:6-10: It would be useful to table the results (R2 and p value) of all distributions and copula used.
Response 17: We added a new table (table F) to the appendix and added references in text to this table. Page 9, line 19, 21; Appendix F page 26

Comment 18: 9:12-14: Given that only 11 sites are considered, it should not be difficult to incorporate the results of all sites instead of using selected examples.
Response 18: We have already included the rest of the sites in the appendixes (Appendix C, Figure C1 and C2). We have added a reference to the appendix the text.
“Figure 4 depicts calculated time series of RDI_3 and $SPEI_{12}$ for Weipa, Sydney and Quilpie, respectively (see Appendix C for rest of the sites)”.

Comment 19: 9:15-16: There is no basis to compare results of RDI3 and SPEI12 given that the characteristics of droughts change with different n month termination rules. The authors should be comparing the results of RDI and SPEI using the same timescale i.e. RDI3 and SPEI3 and/or RDI12 and SPEI12.
Response 19: We addressed to this in response 2

Minor comments:

Comment 20: 2:22: The statement beginning with "In the past century..." Can the authors comment on the temporal distribution of the periods of water deficits? For example, are these water deficits concentrated over a certain period e.g. late 20th century?
Response 20: According to Murphy and Timbal (2008) the southeast of Australia suffered from an extended dry spell in 2007 and mean rainfall over the decade, from spring 1996 to

the end of 2006 in the southeast, has been below average. However Australia is a very large country with a land mass similar to Europe (http://www.ga.gov.au/scientific-topics/geographic-information/dimensions/australias-size-compared) and thus as stated in the manuscripts “these drought events are distributed diversely with regard to their duration, severity, and frequency of occurrence over the continent.” and we really can’t make many generalisations. Droughts will be site specific.

Comment 21: 2:26: Rephrase the statement "Ecosystem attributes are sensitive to the occurrence of drought events, for example the distribution of native tropical species are sensitive to the occurrence of drought events ..." to "Ecosystem attributes such as the distribution of native tropical species, the structure and functioning of forests... are sensitive to the occurrence of drought events".
Response 21: We changed the sentence as suggested

Comment 22: 2:31: "... droughts also play a critical role for the early establishment of plants". I believe the role of droughts is as important as floods in this context (also shown in Table 1). Can the authors briefly explain if post mined landscapes are more sensitive to water deficits than excess?
Response 22: In Australia floods as well as droughts are critical factors to consider in mined land rehabilitation. The nature of the vegetative ecosystems depend on the annual rainfall. However, lack of water plays a critical role for the early establishment of plants as approximately one–third of Australia is arid with rainfall less than 250 mm per year, and another one–third is semi-arid (250–500 mm per year). There are few areas where rainfall exceeds evaporation on an annual basis (Bell, 2001). We added the highlighted sentences to the introduction pp 2, line 23-27

Comment 23:3:67: Please provide an indication of the duration of short, medium and long term droughts.
Response 23: We have already included text in this regard, however, we have provided further clarification on the range of the duration which we consider to be short, medium and long term droughts p4- line 2-3 “There are three time scales with which drought indices are usually calculated for: short-term droughts of three months or less; medium-term droughts between four to nine months and long-term droughts of 12 months or more (Zargar et al., 2011)”
Also we included the clarification in 3: 10-11 as suggested.
For climax vegetation, however, medium to long-term drought (greater than nine months) periods rather than short-term droughts (three months or less) may…

Comment 24: 3:10: The statement beginning with "Methods for characterizing droughts vary in complexity ...” My take is that there are two methods with which droughts can be characterized through drought indices or hydrological models. Drought indices largely do not factor in the water budget, hence are much simpler in computation and data needs than hydrological models although indices such as the Palmer Drought Severity Index are much more difficult to compute and demands more data. I would recommend rephrasing the

statement with "Droughts are usually characterized through the use of indices which vary in complexity and data needs".
Response 24: We changed the sentence as suggested.

Comment 25: 3:15: "... provide the foundation for quantifying the duration and severity ...". The term "foundation" is unsuitable given the context. I would recommend rephrasing to "...provide the means to quantifying the duration and severity ...".
Response 25: We changed the sentence as suggested.

Comment 26: C3:17-18: The statement citing Heim (2002) is the same as the statement citing Andregg et al (2013) on lines 11-13.I recommend omitting the latter.
Response 26: We removed the line 3:11-13

Comment 27: 3:29-32: The examples of time scales used by those in different fields are not necessary.
Response 27: We removed the examples

Comment 28: 7:20-23: The examples of application of copulas in different fields are not necessary
Response 28: We removed the examples

Comment 29: 9:28: Change "P >0.05" to "p >0.05"
Response 29: thank you for catching this we corrected the typo

Comment 30: Fig. 4: It makes an easier comparison of time series if the plots are arranged vertically, rather than horizontally, and making full use of the width of the paper. Similarly for Figs. C1and C2.
Response 30: We changed the figures

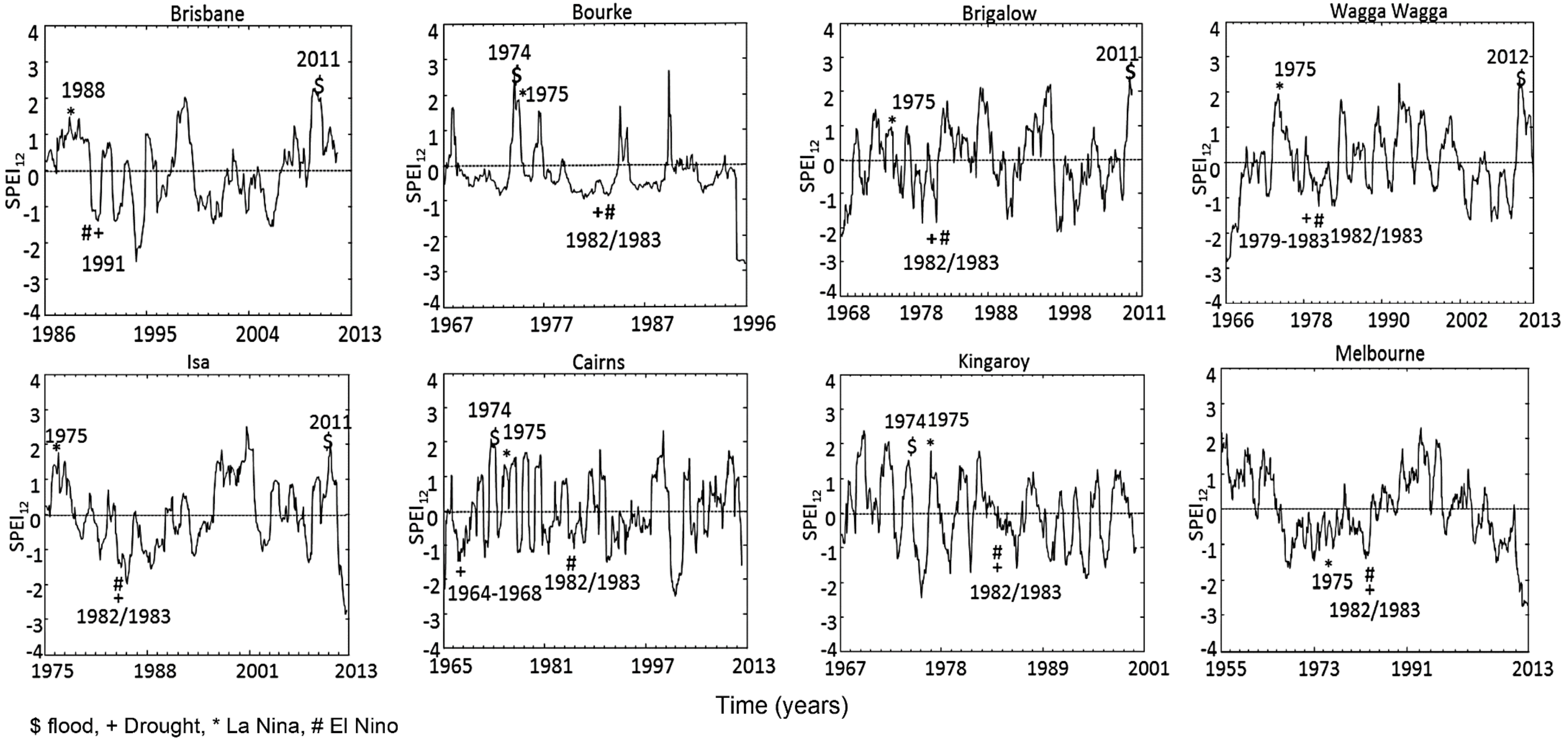

Figure C1. Calculated $SPEI_{12}$ for selected locations across Eastern Australia.

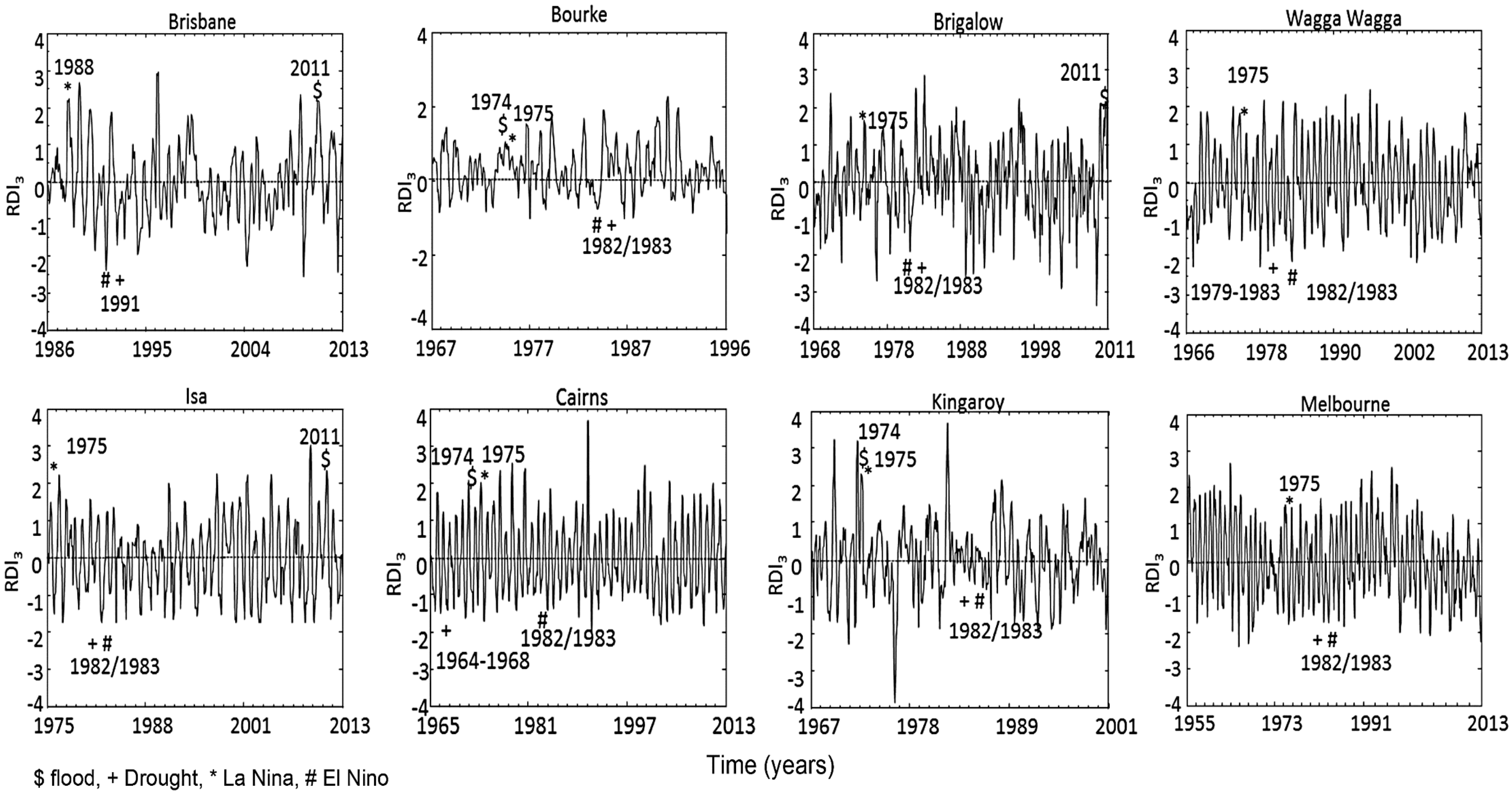

Figure C2. Calculated RDI_3 for selected locations across Eastern Australia.

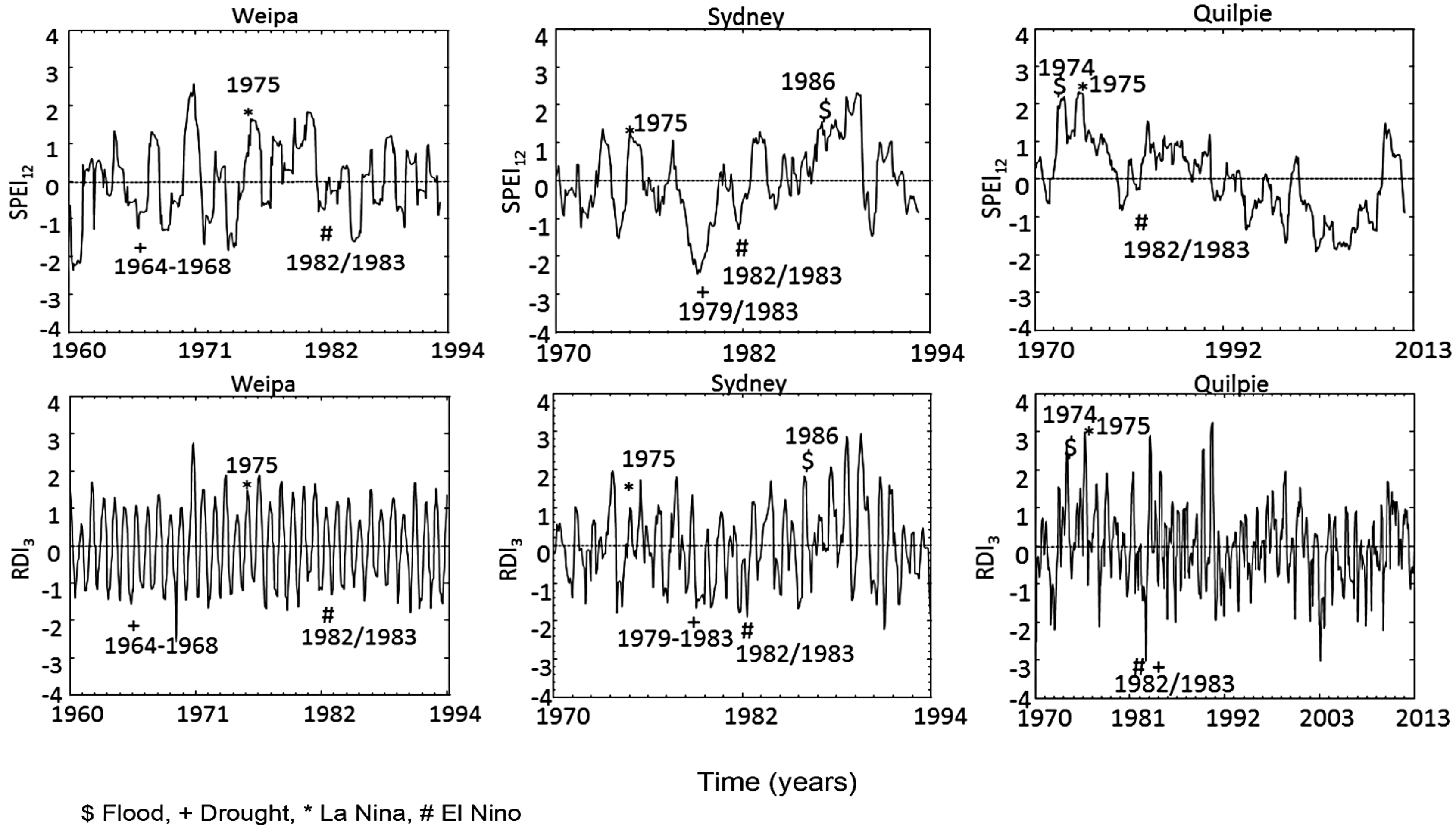

Figure 4. Calculated $SPEI_{12}$ (upper row) and RDI_3 (lower row) for Weipa, Sydney and Quilpie including major weather events. The same indices are depicted for all other selected locations in Appendix B.

Table F. R^2 and p values for fitted cumulative distribution functions and Copula parameters for the studied sites

Station	**Cumulative distribution functions**												**Copula**			
	Exponential		Logistic		Lognormal		Bimodal lognormal		Gamma		Extreme value		Gumbel		Frank	
	R^2	p	R^2	p	R^2	p	R^2	p	R^2	p	R^2	p	R^2	p	R^2	p
Weipa	0.24	0.00	0.99	0.00	0.00	0.31	0.00	0.57	0.99	0.00	0.60	0.00	0.97	0.00	1.00	0.00
Cairns	0.00	0.20	1.00	0.00	0.00	0.52	0.00	0.68	1.00	0.00	0.53	0.00	0.98	0.00	0.99	0.00
Brisbane	0.00	0.30	1.00	0.00	0.00	0.61	0.00	0.61	0.98	0.00	0.57	0.00	0.96	0.00	0.98	0.00
Sydney	0.31	0.00	0.99	0.00	0.00	0.64	0.00	0.52	1.00	0.00	0.55	0.00	0.97	0.00	1.00	0.00
Melbourne	0.25	0.00	0.99	0.00	0.00	0.63	0.00	0.64	0.99	0.00	0.42	0.00	0.96	0.00	1.00	0.00
Kingaroy	0.00	0.08	1.00	0.00	0.00	0.42	0.00	0.43	0.99	0.00	0.68	0.00	0.98	0.00	0.99	0.00
Brigalow	0.00	0.06	0.96	0.00	0.00	0.64	0.00	0.26	0.99	0.00	0.62	0.00	0.96	0.00	1.00	0.00
Wagga Wagga	0.00	0.15	0.96	0.00	0.00	0.61	0.00	0.54	0.91	0.00	0.43	0.00	0.97	0.00	1.00	0.00
Bourke	0.00	0.21	0.94	0.00	0.00	0.31	0.00	0.34	0.98	0.00	0.62	0.00	0.95	0.00	1.00	0.00
Quilpie	0.12	0.00	0.98	0.00	0.00	0.15	0.00	0.29	0.99	0.00	0.53	0.00	0.96	0.00	0.99	0.00
Mount Isa	0.20	0.00	0.99	0.00	0.00	0.56	0.00	0.46	0.97	0.00	0.68	0.00	0.95	0.00	1.00	0.00

Reference:

Audet, P. , Arnold, S. , Lechner, A., and Baumgartl, T.: Site-specific climate analysis elucidates revegetation challenges for post-mining landscapes in eastern Australia, Biogeosciences, 10, 6545-6557, 2013.

Banimahd, S., and Khalili, D.: Factors influencing markov chains predictability characteristics, utilizing SPI, RDI, EDI and SPEI drought indices in different climatic zones, Water Resources Management, 27, 3911-3928, 10.1007/s11269-013-0387-z, 2013.

Bell, L. C.: Establishment of native ecosystems after mining — Australian experience across diverse biogeographic zones, Ecological Engineering, 17, 179-186, http://dx.doi.org/10.1016/S0925-8574(00)00157-9, 2001.

Dalezios, N. R. , Loukas, A. , Vasiliades, L., and Liakopoulos, E.: Severity-duration-frequency analysis of droughts and wet periods in Greece, Hydrological Sciences Journal-Journal Des Sciences Hydrologiques, 45, 751-769, 10.1080/02626660009492375, 2000.

Egidijus, R. , Edvinas, S. , Vladimir, K. , Justas, K. , Gintaras, V., and Aliaksandr, P.: Dynamics of meteorological and hydrological droughts in the Neman river basin, Environmental Research Letters, 8, 045014, 10.1088/1748-9326/8/4/045014, 2013.

Heim, R. R.: A review of twentieth-century drought indices used in the United States, Bulletin of the American Meteorological Society, 83, 1149-1165, 2002.

Khalili, D. , Farnoud, T. , Jamshidi, H. , Kamgar-Haghighi, A. A., and Zand-Parsa, S.: Comparability analyses of the SPI and RDI meteorological drought indices in different climatic zones, Water resources management, 25, 1737-1757, 2011.

Kim, D.-W. , Byun, H.-R., and Choi, K.-S.: Evaluation, modification, and application of the Effective Drought Index to 200-Year drought climatology of Seoul, Korea, Journal of Hydrology, 378, 1-12, http://dx.doi.org/10.1016/j.jhydrol.2009.08.021, 2009.

Lee, J. H., and Kim, C. J.: A multimodel assessment of the climate change effect on the drought severity–duration–frequency relationship, Hydrological Processes, 2012.

Livada, I., and Assimakopoulos, V. D.: Spatial and temporal analysis of drought in greece using the Standardized Precipitation Index (SPI), Theoretical and Applied Climatology, 89, 143-153, 10.1007/s00704-005-0227-z, 2007.

McKee, T. B. , Doesken Nolan J, and Kleist John: The relationship of drought frequency and duration to time scales, Proceedings of the 8th Conference on Applied Climatology, Anaheim, California, 1993, 179-183,

Mirabbasi, R. , Fakheri-Far, A., and Dinpashoh, Y.: Bivariate drought frequency analysis using the copula method, Theoretical and Applied Climatology, 108, 191-206, 2012.

Murphy, B. F., and Timbal, B.: A review of recent climate variability and climate change in southeastern Australia, International Journal of Climatology, 28, 859-879, 10.1002/joc.1627, 2008.

Paulo, A. , Rosa, R., and Pereira, L.: Climate trends and behaviour of drought indices based on precipitation and evapotranspiration in Portugal, 2012.

Peel, M. C. , Finlayson, B. L., and McMahon, T. A.: Updated world map of the Köppen-Geiger climate classification, Hydrol. Earth Syst. Sci., 11, 1633-1644, 10.5194/hess-11-1633-2007, 2007.

Shiau, J.-T. , Modarres, R., and Nadarajah, S.: Assessing multi-site drought connections in Iran using empirical Copula, Environ Model Assess, 17, 469-482, 10.1007/s10666-012-9318-2, 2012.

Shiau, J. T.: Fitting drought duration and severity with two-dimensional Copulas, Water Resources Management, 20, 795–815, 2006.

Shiau, J. T., and Modarres, R.: Copula-based drought severity-duration-frequency analysis in Iran, Meteorological Applications, 16, 481-489, 10.1002/met.145, 2009.

Spinoni, J. , Antofie, T. , Barbosa, P. , Bihari, Z. , Lakatos, M. , Szalai, S. , Szentimrey, T., and Vogt, J.: An overview of drought events in the Carpathian Region in 1961–2010, Advances in Science and Research 10, 21-32, 10.5194/asr-10-21-2013, 2013.

Todisco, F. , Mannocchi, F., and Vergni, L.: Severity-duration-frequency curves in the mitigation of drought impact: an agricultural case study, Natural Hazards, 65, 1863-1881, 10.1007/s11069-012-0446-4, 2013.

Zarch, M. A. A. , Malekinezhad, H. , Mobin, M. H. , Dastorani, M. T., and Kousari, M. R.: Drought monitoring by reconnaissance drought index (RDI) in Iran, Water resources management, 25, 3485-3504, 2011.

Zargar, A. , Sadiq, R. , Naser, B., and Khan, F. I.: A review of drought indices, Environmental Reviews, 19, 333-349, 2011.