Devanmini Halwatura
PhD Research Scholar

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

THE UNIVERSITY OF QUEENSLAND
AUSTRALIA
SMI CMLR
Centre for Mined Land Rehabilitation

2 December 2014

Re: Manuscript revision (hess-2014-138)

Dear Nadia Ursino,
Dear Reviewers,

Please find in the attachment a revised copy of our manuscript "Severity-Duration-Frequency curves of droughts: An early 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: "[…] it is a good attempt in describing crop species and recommended management practices with respect to drought types […]" (Reviewer #2), and "[…] only have minor editorial suggestions […]" (Reviewer #1). We thoroughly addressed all the reviewer's comments and revised the manuscript accordingly (see below). We carefully amended section 4.2 to discuss the application of SDF curves as risk assessment tool (Reviewer #2) and addressed the concerns of Reviewers #3 about application of conditional copulas. Furthermore, we added Table E to back up figure 5 quantitatively (Reviewers #1 and #2). We specifically provided information on the difference between rehabilitation of post-mining lands and other degraded lands in section 4.1 (Reviewer #2). A point-by-point response to the reviewers' comments is attached below.

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.

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. We have addressed all of his/her comments:

1. Comment: Page 4, lines 13 and 17. IFD should be IDF.
2. Page 8, line 2. figure 4 should be Figure 4.
3. Page 9, line 9. confident level should be confidence level.
4. Page 9, line 12. Mt Isa should be Mount Isa.
5. Page 9, line 17. figure 7 should be Figure 7.

Referee report #2

We would like to thank Dr. Prakash Khedun for this critical review and the constructive comments. We have addressed the comments as follows:

Title

Comment 1: The authors should clearly demonstrate how these bivariate SDF curves are superior to traditional practices.

Comment 2: How are SDF curves an "early risk assessment tool?" They give the probability of occurrences. How can this be translated into risks?

Response: To our knowledge SDF curves have not been applied to ecosystem restoration planning in general and specifically for mine rehabilitation, as mentioned in the original introduction: "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".

To further stress the application of SDF curves as early risk assessment tool, we added section 4.2 to the discussion:

"4.2 SDF curves as an early risk assessment tool

Risk assessment based on the design rainfall concept is commonly used as a standard tool by engineers to design infrastructure such as storm water drains, flood mitigation levees, or retarding dams (Chebbi et al., 2013; Hailegeorgis et al., 2013). This research paper aims to demonstrate how these concepts can be used for ecosystem rehabilitation, providing a quantitative estimate of ecosystem rehabilitation failure due to water deficit. Traditionally, ecologist and land managers often use the mean annual rainfall as a co-classifier of biogeographic regionalisation. However, annual rainfall alone cannot account for the vulnerability of a site to non-disruptive water supply, the frequency of water limitations, and seasonality (Audet et al., 2013). For example, although mean annual rainfall is lowest in Bourke, the SDF analysis reveals that severe and prolonged droughts occur most frequently in Mount Isa. This is because in Mount Isa on average 23 out of 100 days are with no rainfall as most of the rainfall occurs in summer as storm events greater than 100 mm (Table 1) (Bureau of Meteorology, 2013). Ecosystem rehabilitation may fail if management actions are based only on the annual rainfall without considering the nature of drought events (i.e., the rate of recurrence of prolonged and severe droughts) (Table 3).

Quantitatively, risk is the product of the probability of an event occurring and the consequences of an event on assets (Athearn, 1971). In the context of post-mining land rehabilitation, the recurrence intervals quantify the probability of occurrence of drought events. If the consequences of drought events for ecosystems are known (Wilhite et al., 2007; Williamson et al., 2000) the risk of ecosystem rehabilitation failure can be quantified. Consequences will typically have to be determined in relation to site specific attributes such as plant species, soil, irrigation etc. (Table 3). Likewise, the consequences can also be related to the costs of rehabilitation. For example, for frequently recurring droughts of high severity and duration irrigation may be a cost-efficient alternative to repeatedly replanting at a rehabilitation site due to establishment failure. These consequences in relation to severity and duration may be identified from the literature, field trials or be derived from expert opinion. A key aspect of our study is that SDF curves provide the probability of occurrence of drought events with a specific duration and severity.

Comment 3: What is special or different about "post-mining landscape" compared to other degraded lands?

Response: We added the following paragraph to the section 4.1 to clarify the difference between post-mining land and other degraded lands.

"Unlike degraded land (in the sense of gradual loss of ecosystem productivity), in post-mining landscapes most ecosystem components are impacted by mining activities, particularly landform, hydrology, and ecosystem structure (Arnold et al., 2014). Therefore, successful rehabilitation of post-mining land requires the sensible selection of plant species, as well as planting/seeding regime, soil characteristics, irrigation method, and landform characteristics (Table 3)."

Section 2.3: Copula Selection

Comment 4: The authors at the outset limit their choice of copula to two (Frank and Gumbel) based on a few previous studies. Given the wide range of climate reported by the authors, I would recommend that they expand their range of copulas to be included in the study and give a clear account of how the best copula was selected. (Khedun et al., 2013), for example, found that for the same basin, the choice of copula can be very different from one climate region to another. There is no detail on the copula selection in the results section. Which graphical and analytical methods were employed in the copula selection? The only place where the authors state that "Frank" is the copula selected for the bivariate analysis is in Figure 2.

Response: We recognise that there are a range of methods available, but did not go into too much detail to keep the paper focused and concise. However, we added the following sentences to the methodology (section 2.3) and results:

Methodology

"As the choice of copula can be very different from one climate region to another (Khedun et al., 2013) the present study focused on the Frank and Gumbel copula (Appendix B), as they have been shown to perform best when analysing the bivariate drought dependence structure of drought variables such as severity and duration (Ganguli and Reddy, 2012; Reddy and Ganguli, 2012; Shiau, 2006; Lee et al., 2013; Wong et al., 2010; Zhang et al., 2011)."

Result

"For both indices and all selected sites, RDI and SPEI, the gamma and logistic distributions fitted best to the observed drought severity and duration, respectively ($R^2 > 0.98$ for both variables, $p < 0.05$). Likewise, the same distributions fitted best to the drought severity and duration of the generated drought events based on the Frank rather than the Gumbel copula ($R^2 > 0.90$, $p < 0.05$)."

SPI3 and RDI3, and SPI12 and SPEI12?

Comment 5: Figure 5: How statistically significant are these correlations, especially in the arid regions. It is not clear where SPI is recommended and where the other indices are recommended. A table showing the cross-correlation and final recommended indices can help clarify the choice of indices.

Figure 6 shows the bivariate recurrence intervals based on RDI_3 and figure 7 shows the recurrence intervals based on $SPEI_{12}$ for the 11 locations considered in this study. Same thing for Figures D1 and D2. Why the need to compare with SPI?

Response: We added Table E to the appendix E to back up figure 5 quantitatively and revised the paragraph of concern in section 4.1 to further emphasise the value of comparing indices based on rainfall versus indices based on rainfall and evaporation.

Table E. Coefficient values of Pearson's r and Kendall tau for SPI_3 vs. RDI_3, and SPI_{12} vs. $SPEI_{12}$. Correlations were lowest for arid Bourke and Quilpie (bold values).

Location	**SPI_3 vs. RDI_3**		**SPI_{12} vs. $SPEI_{12}$**	
	Pearson's r	Kendall tau	Pearson's r	Kendall tau
Weipa	0.98	0.92	0.83	0.68
Cairns	0.98	0.90	0.96	0.83
Brisbane	0.81	0.62	0.68	0.68
Sydney	0.82	0.61	0.90	0.71
Melbourne	0.98	0.90	0.82	0.70
Kingaroy	0.77	0.54	0.87	0.68
Brigalow	0.90	0.71	0.83	0.64
Wagga Wagga	0.69	0.68	0.84	0.71

Bourke	**0.43**	**0.54**	**0.51**	**0.53**
Quilpie	**0.57**	**0.40**	**0.49**	**0.40**
Mount Isa	0.78	0.60	0.72	0.67

“We compared SPI with SPEI or RDI to determine the potential of using SPI (only based rainfall data) over SPEI or RDI (both based on rainfall and evaporation data). This might be of interest for many parts of the world, where evaporation data are unavailable or incomplete and therefore simple rainfall indices are most commonly used.”

Comment 5.1: An interesting set result would be determining and comparing the recurrence intervals from each index considered seeing which one is more appropriate for each region.

Response: We see how interesting this kind of result would be. Unfortunately, the definition and quantification of drought are normative (as discussed in our paper), that is, no universal reference index is available to compare selected indices with. That said, it is even more important to compare the outcome of the selected indices to, at least, be able to determine whether they can or should be replaced by each other. We added the following footnote to stress this issue: “Note that the definition and quantification of drought are normative. In this regard, our results indicate under what climatic conditions SPEI and RDI can be replaced by SPI rather than which index is the best one for each location.”

Comment 6: Section 4.1, how is this discussion relevant to the paper? Even though it is a known fact that precipitation in Australia is dependent on ENSO, the authors do not demonstrate this fact in this paper. Tables 1 and 2 do not show which event was due to El Niño and/or La Niña. The authors do not demonstrate the influence of ENSO events on the drought events identified via these indices.

The discussion therefore is superficial. Same applies for the discussion in the second paragraph of Section 4.1 re the application of SDF in flood monitoring. These comments are only speculative and should not be in the discussion section

Response:

We agree and condensed original section 4.1 to one paragraph in the general discussion:

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 such as 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). However, due to smaller index fluctuations these major events are more pronounced in the context of long-term droughts (SPEI_{12}) (Fig. 4, and Appendix C).

Minor Comments

Comment 7: Page 12 line 1: "two sophisticated climate parameters." Recurrence intervals are not really "sophisticated" parameters. They have common hydrological parameters that can be derived from univariate or multivariate distributions.

Response: We changed the sentence as "In our study we presented two hydrological parameters describing the average recurrence intervals of…"

Comment 8: Figure 3: Severity is defined as the cumulative sum of SPI values, but in Figure 3, it is indicated as the maximum SPI value. Please amend.

Response: We revised figure 3 as follows:

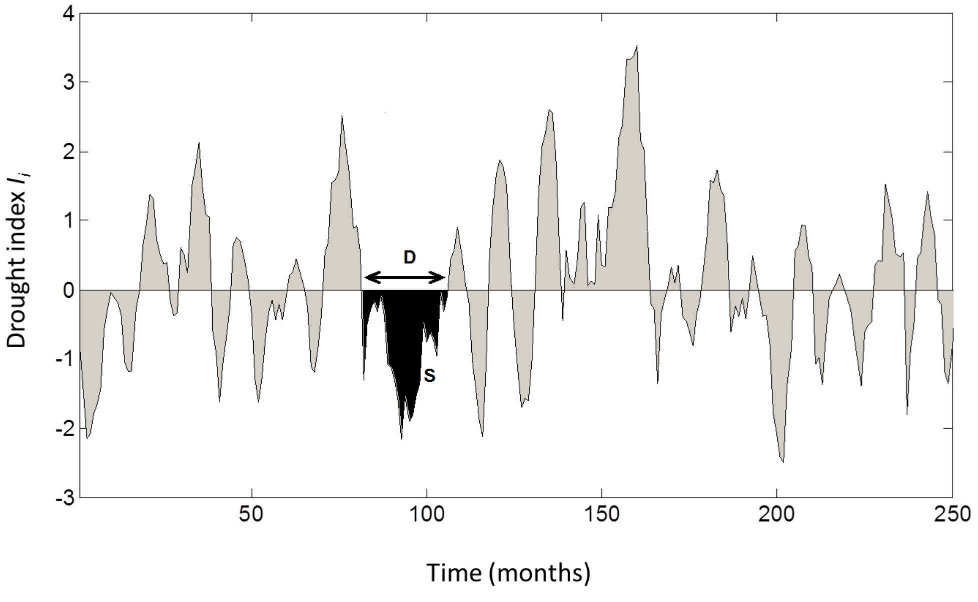

Figure 3. Concept of severity S and duration D of a drought event quantified with drought index I_i, where i refers to any time-scale of interest.

References

Arnold, S., Kailichova, Y., Knauer, J., Ruthsatz, A. D., and Baumgartl, T.: Effects of soil water potential on germination of co-dominant Brigalow species: Implications for rehabilitation of water-limited ecosystems in the Brigalow Belt bioregion, Ecological Engineering, 70, 35-42, http://dx.doi.org/10.1016/j.ecoleng.2014.04.015, 2014.

Athearn, J. L.: What is Risk?, The Journal of Risk and Insurance, 38, 639-645, 10.2307/251578, 1971.

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.

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

Chebbi, A., Bargaoui, Z. K., and Cunha, M. D.: Development of a method of robust rain gauge network optimization based on intensity-duration-frequency results, Hydrology and Earth System Sciences, 17, 4259-4268, 10.5194/hess-17-4259-2013, 2013.

Ganguli, P., and Reddy, M. J.: Risk Assessment of Droughts in Gujarat Using Bivariate Copulas, Water Resource Management, 26, 3301–3327, 2012.

Hailegeorgis, T. T., Thorolfsson, S. T., and Alfredsen, K.: Regional frequency analysis of extreme precipitation with consideration of uncertainties to update IDF curves for the city of Trondheim, Journal of Hydrology, 498, 305-318, http://dx.doi.org/10.1016/j.jhydrol.2013.06.019, 2013.

Khedun, C. P., Chowdhary, H., Mishra, A. K., Giardino, J. R., and Singh, V. P.: Water Deficit Duration and Severity Analysis Based on Runoff Derived from Noah Land Surface Model, Journal of Hydrologic Engineering, 18, 817-833, 2013.

Lee, T., Modarres, R., and Ouarda, T. B. M. J.: Data-based analysis of bivariate copula tail dependence for drought duration and severity, Hydrological Processes, 27, 1454-1463, Doi 10.1002/Hyp.9233, 2013.

Reddy, M. J., and Ganguli, P.: Application of copulas for derivation of drought severity-duration-frequency curves, Hydrological Processes, 26, 1672-1685, 10.1002/hyp.8287, 2012.

Shiau, J. T.: Fitting Drought Duration and Severity with Two-Dimensional Copulas, Water Resources Management, 20, 795–815, 2006.

Wilhite, D. A., Svoboda, M. D., and Hayes, M. J.: Understanding the complex impacts of drought: a key to enhancing drought mitigation and preparedness, Water resources management, 21, 763-774, 2007.

Williamson, G. B., Laurance, W. F., Oliveira, A. A., Delamônica, P., Gascon, C., Lovejoy, T. E., and Pohl, L.: Amazonian tree mortality during the 1997 El Nino drought, Conservation Biology, 14, 1538-1542, 2000.

Wong, G., Lambert M. F., Leonard M., and Metcalfe A. V.: Drought Analysis Using Trivariate Copulas Conditional on Climatic States, Journal Of Hydrologic Engineering, 15, 129-141, 2010.

Zhang, Q., Chen, Y. D., Chen, X., and Li, J.: Copula-based analysis of hydrological extremes and implications of hydrological behaviors in the Pearl River basin, China, Journal of Hydrologic Engineering, 16, 598-607, 2011.

Referee report #3

We would like to thank the Anonymous Referees for this review and their constructive comments. We have addressed their comments as follows:

Comment 1: The paper illustrates the application of Severity-Duration-Frequency (SDF) curves of droughts as a risk-based planning tool in the rehabilitation of post-mining landscapes. The topic is interesting, even if it is not particularly original, since applications of SDF curves of drought are already present in literature (Dalezios et al., 2000; Shiau and Modarres, 2009; Todisco et al., 2009, Reddy and Ganguli, 2012). For example in Shiau and Modarres (2009), SDF curves derived from copula models are obtained (based on SPI); in Todisco et al. (2013) SDF curves are derived empirically and based on an agricultural drought index. Some innovative aspects can be found in the use of indices other than SPI (RDI and SPEI), but (as acknowledged by the authors themselves), the specific aims considered in the paper would require the adoption of agricultural drought indices (able to evaluate the role played by soil characteristics).

Response:

We believe our study is novel as it demonstrates how a tool commonly applied in the disciplines of engineering and agriculture can be applied to ecological issues – to our knowledge the first example of this application. In particular, we demonstrate how SDF curves can be used as risk management tool to overcome challenges of early vegetation establishment. This is novel because frequency patterns of drought events are ignored in all current rehabilitation guidelines and industry plans, where long-term average rainfall is the only parameter upon which management decisions are based on (Audet et al., 2013). We acknowledge the work of (Shiau, 2006; Shiau and Modarres, 2009) which as critical to investigate the above mentioned issues. Furthermore our study is unique because for the first time SDF curves have been derived for eastern Australia, thereby covering a range of climatic regions. We stress all these aspects in the following sentences added to the introduction:

"SDF curves have been used to derive drought variables in different climatic regions (Shiau, 2006; Shiau et al., 2012) but have rarely been used in ecology, and never been used in relation to rehabilitation and restoration."

"While other studies assessed the SDF characteristics at locations with the same climate in Iran (Shiau and Modarres, 2009) Shiau et al. (2012), no such investigations are known for any climatic region in Australia, neither for the same climate nor across different climates."

" […] because frequency patterns of drought events are ignored in current rehabilitation guidelines and industry plans, where long-term average rainfall is the only parameter upon which management decisions are based on (Audet et al., 2013)."

We agree that the implementation of soil properties is critical to assessing the suitability of land-climate scenarios to rehabilitate ecosystems. However, we believe that using meteorological data is a critical step forward. We also believe if such methods are to be adopted by mine rehabilitation managers it is important for the derivation of the indices to be as simple as possible. In contrast to agricultural drought indices, meteorological indices can be derived from rainfall and/or evaporation data only. Whether the value of the two types of indices is different might depend on soil-climate scenarios, but this important research question still needs be addressed. We discuss this in detail in section 4.4. To clarify this we added the following two sentences to section 4.4:
“However, using simple and easily accessible meteorological data 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 2: The first observation is about the method used by the authors to derive the SDF curves (shown in figures 6 and 7, for the OR condition and in Appendix D for the AND condition). These curves represent joint drought duration and severity return periods (Shiau, 2006) and from a statistical viewpoint they actually link duration, severity and frequency. Moreover, we think that the information obtained from these curves could be used with proficiency for the aims of the paper (i.e. to find drought management strategies well-matched with the specific behaviour of the drought characteristics D and S).The problem is that IDF curves (for rainfall) as well as SDF curves (for drought) have to be derived from joint conditional probabilities (Singh and Zhang, 2007; Shiau and Modarres, 2009) and not from simple joint probabilities (as done by the authors in the paper). There are differences from both the statistical and practical viewpoint. For drought management purposes, the type of curves given in fig. 6 and 7 could be exhaustive, but these curves are different from those that are usually called SDF. The authors should clarify this point taking into account the references given above.

Response: We carefully reviewed our method (i.e. the Matlab code) and found that we used the conditional distribution function as described in (Shiau and Modarres, 2009) to calculate the CDF’s and incorrectly presented the equation as simple joint probabilities. Thank you for catching this mistake. We changed the equations accordingly:

The conditional cumulative distribution function $F_{S|D}(s|d)$ relates to the joint cumulative distribution function (JCDF) of drought severity and duration $F_{S,D}(s,d)$ and the cumulative distribution function (CDF) of drought duration $F_D(d)$ is given by the following relationship (Shiau and Modarres, 2009):

$$F_{S|D}(s|d) = \frac{\partial F_{S,D}(s,d)}{\partial F_{D(d)}}, \qquad (2)$$

where $F_D(d)$ is the CDF of drought duration, and $F_{S,D}(s,d)$ is the JCDF of drought severity and drought duration. The JCDF of drought severity and duration in terms of copulas is a function of univariate CDFs of duration and severity:

$$F_{S,D}\,(s,d) = C(F_S(s), F_D\,(d)), \qquad (3)$$

where $F_s(s)$ and $F_D(d)$ are CDFs for drought severity and duration, respectively, and C is a copula function. The conditional distribution function $F_{S|D}$ (s|d) (Eq. 2) can also be expressed as a function of the copula (Shiau and Modarres, 2009):

$$\mathrm{F_{S|D}}\;(\mathrm{s}|\mathrm{d}) = \frac{\partial F_{S,D}(s,d)}{\partial F_D\,(d)} = \frac{\partial C\,(F_S(s),\;F_D\,(d))}{\partial F_D\,(d)} = C_{F_S|F_D}\left(F_S\,(s)|F_D\,(d)\right), \qquad (4)$$

Comment 3 (part 1): At line 16 of page 6 the authors indicate that in Appendix A there is a description of the equations required for the calculation of the considered drought indices (namely SPI, RDI, SPEI). Appendix A contains many inaccuracies and errors

a. The equation provided for SPI (A1) is not related to its calculation, but to the calculation of the severity of a drought event, based on SPI. This information, in a slightly different form, is already given in the text (pag. 6 line 27). Anyway, nothing is said about SPI calculation in Appendix A

Response (part 1): We removed equation A1 because as the reviewer points out, it describes the severity rather than SPI. Description of SPI is provided in section 2.1:

2.1 Step 1: Calculate drought indices

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 (Edwards, 1997).

Comment 3 (part 2): b. For RDI two equations are provided (A2 and A3). The explanation of the terms that appear in these equations is confusing (lines 8-9) and contains some errors. There is also a reference to a term not reported in the equations (Yk).

Response: We revised the description of the equation accordingly.

A1 RDI

The standardised RDI_{st} is given as:

$$RDI_{st}(k) = \frac{y_k - \bar{y}_k}{\hat{\sigma}_k}, \qquad (A1)$$

with

$$y_k = \ln \frac{\sum_{j=1}^{j=k} P_j}{\sum_{j=1}^{j=k} PET_j} \qquad (A2)$$

where $\hat{\sigma}$ is the standard deviation, y_k is month k of year y, $\bar{y}_k$ is the arithmetic mean of y_k, $\hat{\sigma}_k$ is the standard deviation of y_k, and P_j and PET_j are precipitation and potential evapotranspiration for the jth month of the hydrological year, respectively (Tsakiris and Vangelis, 2005).

Comment 3 (part 3): c. For SPEI, only the final part of the index calculation is provided (eq. A4, A5) and there is a reference to a not defined D value. In the paper D stands for Duration of drought, but in SPEI calculation it should represent the difference between precipitation and reference evapotranspiration. Moreover, equations A4 and A5 are not specific for SPEI, since they are also used for SPI (it is just necessary to change the reference variable). In practice Appendix A is completely useless in the present form.

Response: We revised the description of the equation accordingly.

A2 SPEI

The SPEI is calculated as:

$$SPEI = W - \frac{C_0 + C_1 W + C_2 W^2}{1 + d_1 W + d_2 W^2 + d_3 W^3}, \qquad (A3)$$

with

$$W = \sqrt{-2\,ln(P)} \quad for\ P \le 0.5, \qquad (A4)$$

Where P is the probability of exceeding a determined value of the difference between the precipitation and potential evapotranspiration (P = 1- F(x)). If $P > 0.5$, then P is replaced by 1 - P and the sign of the resultant SPEI is reversed. The constants are $C_0 = 2.515517$, $C_1 = 0.802853$, $C_2 = 0.010328$, $d_1=1.432788$, $d_2=0.189269$, and $d_3=0.001308$ (Vicente-Serrano et al., 2010).

Comment 4: In the application of copula models, the selection of both univariate distributions and copula models is critical for the reliability of the application. In the paper, the results of these selection processes can be only deduced from figure 2, but the authors do not provide any discussion. For example: what is the goodness of fit criterion used for univariate distributions? Why Frank copula is judged better than Gumbel copula?

Response: We recognise that there are a range of methods available, but did not go into too much detail to keep the paper focused and concise. However, we added the following sentences to the methodology (section 2.3) and results:

Methodology

“As the choice of copula can be very different from one climate region to another (Khedun et al., 2013) the present study focused on the Frank and Gumbel copula (Appendix B), as they have been shown to perform best when analysing the bivariate drought dependence structure of drought variables such as severity and duration (Ganguli and Reddy, 2012; Reddy and Ganguli, 2012; Shiau, 2006; Lee et al., 2013; Wong et al., 2010; Zhang et al., 2011).”

Result

“For both indices and all selected sites, RDI and SPEI, the gamma and logistic distributions fitted best to the observed drought severity and duration, respectively ($R^2 > 0.98$ for both variables, $p < 0.05$). Likewise, the same distributions fitted best to the drought severity and duration of the generated drought events based on the Frank rather than the Gumbel copula ($R^2 > 0.90$, $p < 0.05$).”

Comment 5: In the section “future research” the authors indicate the opportunity to introduce in this type of application, some information related to soil properties (for example by using agricultural drought indices instead of meteorological drought indices). This could, actually, improve the reliability of the application.

Anyway, if the objective is the minimization of the risk of failure of initial ecosystem establishment, the use of a standardized index (meteorological or agricultural) could have some weak points. Indeed, the risk of failure related to the establishment of a certain vegetation type, is more dependent on the absolute (and not relative) availability of water. For example a SPI value of -1 in winter at Sydney (table 1) should have no practical consequences on vegetation, because the normal (i.e. SPI=0) rainfall amount, can likely determine a surplus condition in terms of plant water availability. This aspect should be discussed by the authors.

Response: Indeed, meteorological drought indices indicate deviations of rainfall and/or evaporation relative to the long-term average. For native climax vegetation, these deviations are less sensitive because they are well adapted to the long-term weather conditions. However, in post-mining landscapes – unlike degraded lands that have had their ecosystem productivity gradually degraded – not only is the vegetation composition and structure disturbed, but also other ecosystem components such as landform and hydrology. Therefore, post-mining ecosystem rehabilitation is very sensitive to decisions made on the re-established of topographical and soil characteristics, as well as planting/seeding regimes and irrigation methods. In this regard, the frequency of meteorological droughts relative to long-term conditions is the critical driver of these management decisions.

We stress these issues by adding two paragraphs to section 4.1 and 4.3”

“Unlike degraded land (in the sense of gradual loss of ecosystem productivity), in post-mining landscapes most ecosystem components are impacted by mining activities, particularly landform, hydrology, and ecosystem structure (Arnold et al., 2014). Therefore, successful rehabilitation of post-mining land requires the sensible selection of plant species, as well as planting/seeding regime, soil characteristics, irrigation method, and landform characteristics (Table 3)."

"Meteorological droughts indicate deviations of rainfall and/or evaporation relative to the long-term average. Native climax vegetation, which is well adapted to the local climate, is hardly sensitive to these anomalies. However, within the process of post-mining land rehabilitation, establishment of well-adapted climax vegetation is impossible. In fact, post-mining ecosystem rehabilitation is very sensitive to decisions made on the re-established topography and soil characteristics, as well as planting/seeding regimes and irrigation methods (Table 3). In this regard, the frequency of meteorological droughts relative to long-term conditions is the critical driver of these management decisions. For example, seedling establishment might fail under conditions of frequently occurring short-term droughts even if the absolute rainfall in between droughts is high. Under these conditions, landform and soil need to be restored such that periods of water limitation can be minimised."

Minor points

Comment 6: Line 24 pag. 6: the reference to rainfall deficit is not completely correct since RDI and SPEI are based not only on rainfall.

Response: We agree with you and changed the references.

Comment 7: Line 30 pag. 6: a brief description of the methods and criteria used to assess the goodness of fit of D and S marginal distribution should be provided.

Response: Please see our repose to this in comment 10.

Comment 8: Lines 28-30 pag.7 and lines1-4 pag.8: The authors probably want to describe the procedures adopted for the copula model selection (Frank or Gumbel) not for parameters selection (the parameter fitting is obtained by the IFM method as already explained by the authors).

Response: See comment 4.

Comment 9: Lines 3-4 pag.8: Section 2 is for the description of the methods. The information that the best distribution for S and D are respectively the gamma and the logistic, should be reported (and possibly discussed) in the result section.

Response: we added the following sentences to the methodology (Section 2.2) and results.

Method

The coefficient of determination at $p < 0.05$ and the 95% confidence intervals were calculated for each distribution in order to select the best distribution.

Result

For both indices and all selected sites, RDI and SPEI, the gamma and logistic distributions fitted best to the observed drought severity and duration, respectively ($R^2 > 0.98$ for both variables, $p < 0.05$). Likewise, the same distributions fitted best to the drought severity and duration of the generated drought events based on the Frank rather than the Gumbel copula ($R^2 > 0.9$, $p < 0.05$).

Comment 10: Line 18 pag. 8: Appendix C instead of D

Response: Thank you for catching this. We changed it.

Comment 11: Lines 23-24 pag.8 and fig.4. In our opinion a comparison of two different indices (RDI and SPEI) at two different time scales (3 and 12 months) makes not sense. And the observation at lines 25-26 is a logical consequence of the fact that the shorter the time scale, the higher is the oscillation frequency of the index time series, so shorter duration and severities are expected (but more drought events).

Response: We added Table E to the appendix E to back up figure 5 quantitatively and revised the paragraph of concern in section 4.1 to further emphasise the value of comparing indices based on rainfall versus indices based on rainfall and evaporation.

Table E. Coefficient values of Pearson's r and Kendall tau for SPI_3 vs. RDI_3, and SPI_{12} vs. $SPEI_{12}$. Correlations were lowest for arid Bourke and Quilpie (bold values).

Location	**SPI_3 vs. RDI_3**		**SPI_{12} vs. $SPEI_{12}$**	
	Pearson's r	Kendall tau	Pearson's r	Kendall tau
Weipa	0.98	0.92	0.83	0.68
Cairns	0.98	0.90	0.96	0.83
Brisbane	0.81	0.62	0.68	0.68
Sydney	0.82	0.61	0.90	0.71
Melbourne	0.98	0.90	0.82	0.70
Kingaroy	0.77	0.54	0.87	0.68
Brigalow	0.90	0.71	0.83	0.64
Wagga Wagga	0.69	0.68	0.84	0.71
Bourke	**0.43**	**0.54**	**0.51**	**0.53**
Quilpie	**0.57**	**0.40**	**0.49**	**0.40**
Mount Isa	0.78	0.60	0.72	0.67

"We compared SPI with SPEI or RDI to determine the potential of using SPI (only based rainfall data) over SPEI or RDI (both based on rainfall and evaporation data). This might be of interest for many parts of the world, where evaporation data are unavailable or incomplete and therefore simple rainfall indices are most commonly used."

References

Arnold, S., Kailichova, Y., Knauer, J., Ruthsatz, A. D., and Baumgartl, T.: Effects of soil water potential on germination of co-dominant Brigalow species: Implications for rehabilitation of water-limited ecosystems in the Brigalow Belt bioregion, Ecological Engineering, 70, 35-42, http://dx.doi.org/10.1016/j.ecoleng.2014.04.015, 2014.

Athearn, J. L.: What is Risk?, The Journal of Risk and Insurance, 38, 639-645, 10.2307/251578, 1971.

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.

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

Chebbi, A., Bargaoui, Z. K., and Cunha, M. D.: Development of a method of robust rain gauge network optimization based on intensity-duration-frequency results, Hydrology and Earth System Sciences, 17, 4259-4268, 10.5194/hess-17-4259-2013, 2013.

Ganguli, P., and Reddy, M. J.: Risk Assessment of Droughts in Gujarat Using Bivariate Copulas, Water Resource Management, 26, 3301–3327, 2012.

Hailegeorgis, T. T., Thorolfsson, S. T., and Alfredsen, K.: Regional frequency analysis of extreme precipitation with consideration of uncertainties to update IDF curves for the city of Trondheim, Journal of Hydrology, 498, 305-318, http://dx.doi.org/10.1016/j.jhydrol.2013.06.019, 2013.

Khedun, C. P., Chowdhary, H., Mishra, A. K., Giardino, J. R., and Singh, V. P.: Water Deficit Duration and Severity Analysis Based on Runoff Derived from Noah Land Surface Model, Journal of Hydrologic Engineering, 18, 817-833, 2013.

Lee, T., Modarres, R., and Ouarda, T. B. M. J.: Data-based analysis of bivariate copula tail dependence for drought duration and severity, Hydrological Processes, 27, 1454-1463, Doi 10.1002/Hyp.9233, 2013.

Reddy, M. J., and Ganguli, P.: Application of copulas for derivation of drought severity-duration-frequency curves, Hydrological Processes, 26, 1672-1685, 10.1002/hyp.8287, 2012.

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.

Tsakiris, G., and Vangelis, H.: Establishing a drought index incorporating evapotranspiration European water 9/10, 3-11, 2005.

Vicente-Serrano, S. M., Beguería, S., and López-Moreno, J. I.: A Multiscalar Drought Index Sensitive to Global Warming: The Standardized Precipitation Evapotranspiration Index, Journal of Climate, 23, 1696-1718, 10.1175/2009JCLI2909.1, 2010.

Wilhite, D. A., Svoboda, M. D., and Hayes, M. J.: Understanding the complex impacts of drought: a key to enhancing drought mitigation and preparedness, Water resources management, 21, 763-774, 2007.

Williamson, G. B., Laurance, W. F., Oliveira, A. A., Delamônica, P., Gascon, C., Lovejoy, T. E., and Pohl, L.: Amazonian tree mortality during the 1997 El Nino drought, Conservation Biology, 14, 1538-1542, 2000.

Wong, G., Lambert M. F., Leonard M., and Metcalfe A. V.: Drought Analysis Using Trivariate Copulas Conditional on Climatic States, Journal Of Hydrologic Engineering, 15, 129-141, 2010.

Zhang, Q., Chen, Y. D., Chen, X., and Li, J.: Copula-based analysis of hydrological extremes and implications of hydrological behaviors in the Pearl River basin, China, Journal of Hydrologic Engineering, 16, 598-607, 2011.