Drought: What is it, are we in one or accelerating the systemic aridification of regions?

Walter Jehne

Regenerate Earth

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Introduction

Australia is 'a land of drought and flooding rains'. It is the driest inhabited continent with the most variable, unreliable rainfall that averaged 452 mm/an but is declining as climates change.

As such Australia can expect there will often be dry periods and shortages of water or 'droughts'. How severe the shortages of water or 'droughts' are may vary greatly between different landscapes, depending on their resilience and our expectations of their capacity to sustain water supplies.

Hence whether we are in a 'drought' is often the gap between our physical reality and expectations and assumptions. Whether our residual bio-systems can buffer and survive these water shortages as they mostly did naturally or are vulnerable to them due to our degradation of their hydrology.

While all people are affected by drought, the severity of its impacts may vary widely depending on the vulnerability of different farmers and communities to the inevitable reality of rainfall variations.

While help needs to be extended equitably to minimize the collective ecological and social impacts of droughts, we need to take responsibility for this reality and its symptoms that we have often compounded and not externalize or blame nature or others for our water shortages or 'droughts'.

Dry periods are, and will become an increasing reality in Australia and globally that we need to take responsibility for and become more response able to minimize along with their drought symptoms.

As analysed below we also need to question the assumption that we are not responsible for many of the drought effects or our accelerated systemic aridification of Australia and arid regions globally. Keeping our head in the sand on the expedient assumption that 'droughts' are; normal, bad luck, an act of God that will pass, ignores this reality of physics, climatology, the past and our pending future.

This reality for Australia is that it is located in the mid latitudes surrounded by three oceans that govern how vast quantities of heat and humidity pass over Australia via the El Nino-La Nina cycles and the Indian Ocean dipole. As Australia's topography is largely old, weathered and flat this limits orographic rainfall induction, making whether rain can fall more reliant on landscape properties.

These realities have governed Australia's seasonal dry and hot physical climate for millions of years. They help drive Australia's unpredictable cycles of extreme heat, drought, storms and flooding rain. However what they cant explain are the systemic shifts in Australia's climate to often greater aridity over the past millennia and century as evidenced in the pollen record, beyond this cyclic variability.

While there is much to learn, it is critical that we look objectively at the evidence and understand what may be causing this systemic aridification of much of Australia and its increasing 'droughts'.

To examine the often close link between systemic changes in Australia's vegetation and our climate. While most agree that the rainfall and climatic of an area will influence its vegetation, we need to examine if our changes to the vegetation of an area can and has influenced its rainfall and climate? Is there a dual causal relationship and to what extent is the climate dependent on the vegetation?

More practically and specifically we need to examine and better understand;

1. **Can we by changing the vegetation via our land use, change local or the global climate?**
2. **What is the evidence for such vegetation induced systemic climate changes?**
3. **What processes may be driving this and can these verify that a causal relationship exists?**
4. **What is the evidence that we may be altering these processes via our land management?**
5. **If so what may be the consequence of our current land management on our climate?**
6. **Could we, by regenerating bio-systems, influence or help restore former or new climates?**
7. **Is this feasible or practical at a local, regional or global level and how may we do this?**
8. **What issues, impediments and policy barriers may arise in examining this potential?**

Given the reality that we have already induced abnormal global climate changes via our changes to the Earth's natural heat balance through the greenhouse effect could the answers to the above questions provide us with a wider understanding and practical options to offset this effect so as to reverse systemic changes, rehydrate aridifying regions and safely cool and restore former climates?

Given that our global warming is due to the atmosphere to retaining some 3 watts/square of extra incident solar radiation by preventing it from being re-radiated back out to space and given this is less than 1% of the heat the Earth continually re-radiates back out to space, could the restoration of the former re-radiation levels via our changes to natural hydrological and vegetation processes help address not just our increased 'droughts' but also help limit dangerous climate changes?

Clearly we are already seriously influencing the Earth's climate in multiple, not fully recognized ways. Australia with its already dry variable climate is highly vulnerable to such changes and their impacts.

As such it may be relevant to answers the above critical questions and review;

A. The evidence for systemic changes in Australia's climate and its link to landscape changes.

B. The processes governing the vegetation-aridification linkages and climate changes.

C. Leading studies of how to manage these processes to limit 'drought' and cool climates.

Collectively this evidence and these analyses may help us to define; what is 'drought', if we are in one, or if we are just accelerating the self induced systemic aridification of much of Australia.

This insight may be critical to Australia's wellbeing and future and for many other regions globally.

A. Are there links between recent systemic changes in Australia's climate and landscape changes?

Much of Australia is again in drought, 8 years since the last 1 in 1000 year millennium drought. Indeed, a sequence of such 'abnormal' severe droughts have occurred in most decades somewhere in Australia since the late 18th century when Europeans first settled in Australia.

Despite their regularity, droughts are seen as 'exceptions' from what is assumed to be Australia's 'normal' rainfall as indicated by the average rainfall statistics, often excluding such drought 'outliers'. These assumptions of what was 'normal' was often reinforced by the high productivity and resilience of Australia's native bio-systems that 'would be inconsistent' if drought conditions were 'normal'.

The fact that 95% of Australia's land surface remains vegetated and seasonally green even in deserts receiving less than 100 mm of rain and despite regular 'droughts' clearly misled many opportunists into assuming that such land was more mesic and productive than the low variable rainfall indicates.

Such assumptions have led to many historical agricultural failures but also impaired recognition that the high productivity of Australia's vegetation despite such 'droughts' was due to the evolution of unique processes that helped them buffer, avoid and survive the periodic extreme drought stresses. Impaired recognition that these processes may have helped their resultant bio-systems to moderate Australia's hydrology, rainfall and thus micro-climates and help sustain them despite droughts.

If so understanding how these processes may influence the local hydrology and climate is important. It certainly explains why we can not assume that we can replace these natural arid bio-systems with agricultural crops if we destroy the processes that governed the hydrology of the native bio-systems. Conversely if we sustain or restore these processes, can we regenerate productive and resilient bio-systems in arid and degraded regions despite and to help restore their impaired hydrology?

Up to now the failure of agriculture even in well watered regions and seasons could always readily be blamed on 'drought', bad luck or acts beyond our control, not our degradation of or failure to understand these processes governing the soil's natural hydrology and how plants can aid this.

This externalization of our responsibility to come to terms with and manage the natural hydrological ecology of our soils and climate has been reinforced by our short term expedient political focus that; sympathize with the bad luck, call for prayers, promise to look at non-existing options to build dams, subsidize actions to reduce drought symptoms, offer more debt finance and provide crisis support all to sustain rural communities and votes while they hope that other issues dominate, or it will rain.

Australia's recent 'National Drought Summit' in late 2018 failed totally to face up to any of the real issues facing its agriculture from its scientifically inevitable 'more extreme and aridifying climate' nor it did discuss realistic options to address this pending reality and crisis, beyond just hoping for rain. As such Australia's farmers and communities can either watch as their bio-systems further aridify and collapse or consider how we can naturally rehydrate and restore their resilience to drought by regenerating the soil and hydrological processes that underpinned their former natural productivity.

To understand the latter it may help to examine leading examples of how the hydration of former bio-systems and regions has deteriorated so as to understand why and how this is occurring. This should help us to understand the processes involved and our options for practically regenerate them so as to rehydrate our bio-systems, regions and help cool and stabilize our climate.

Our past 200 years of agriculture provides many cases where country 'dries out' once we 'improve' it via our clearing, burning and cultivation of it for use by agriculture. This evidence confirms how this is systemically aridifying regions and resulting in climate changes. Leading cases include;

1.The systemic aridification of south west Western Australia since the mid 1970s.

The Australian Bureau of Meteorology and CSIRO have confirmed how over 10 million hectares of crop land in the south west of Western Australia has systemically aridified since the mid 1970s as rainfalls have declined by some 30% with higher decreases in stream flows and the recharge of soil moisture and water storages. As vegetation covers thin and dry evaporation rates have increased as have wildfire levels and risks.

This ongoing systemic aridification of SW WA as with many Mediterranean regions globally has been caused by fundamental shifts in global pressure belts due to human induced warming of the Earth. In essence the increased heating in the tropics has expanded the tropical Hadley pressure cells to extend some 300km pole wards. This has pushed the cool moist Ferral cells from the southern ocean that generated most of the regions former winter rainfall further south resulting in the ongoing systemic aridification of these regions.

This aridification has been intensified by our widespread clearing of the former native low forest 70 years ago for agriculture. The cleared and cropped land now absorbs and thus also re-radiates much more energy from the sun and often forms domes of hot high pressure air over the cleared areas. These heat domes inhibit the inflow of cool moist low pressure air from the ocean. Regions that have been reforested limit the formation of such high pressure heat domes and as a result now receive consistently higher humid air inflows and rainfalls relative to adjacent cleared regions.

Consequently not only has our land management affected the regions heat and water dynamics and thus the climate and rainfall at a macro level but these practices and processes also affect rainfall and the aridification of regions at a local level. Our land management can influence these greatly. Our regeneration of regions may thus help to sustain or rehydrate bio-systems at risk of 'drought'.

2. The expansion of Australia's arid zone eastward due to 20th century land management practices.

Analyses of the fluctuations and trends in the vast meteorological data from across Australia for the past 150 years by the Bureau of Meteorology confirms that there was a systemic aridification of much of eastern Australia over the first 70 years of agriculture with aridity zones shifting eastward often by hundreds of kilometres (Kraus, Gentilli). These shifts were most marked after major drought in the early and mid 20th century and overgrazing by sheep and rabbit and have continued despite intervening wet periods. Less disturbed regions often had increased rainfalls over the same periods.

While numerous physical and seasonal factors can influence the rainfall of regions these data indicate that whether rain falls on a region is not random but closely associated with the conditions of that landscape which is directly influenced by our management of that vegetation. As such we may be not just responsible for these landscape conditions but also response able to improve them.

3.The sequential decline in rainfalls and the aridification of former tropical humid regions.

Data on changes in the 20 year mean rainfall along Australia's eastern tropical coast for the past 100 years (BOM) indicate there has been a continued decline in the mean rainfall for typically, the City of Rockhampton on the Tropic of Capricorn, from some 1050mm/an in 1900 to 750mm/an in 2000.

This systemic decline has been associated with the increased grazing of these former grassy forests. The trend data confirms that mean rainfalls have not only declined during droughts as expected but consistently failed to recover to their former levels in subsequent wet periods. This would indicate that the effect of the droughts and overgrazing during it had so degraded these soils and vegetation that this has impaired the formation of rain from humid air flows in wet periods despite the same air generating high rainfalls in nearby undisturbed forested regions.

These data further question to what extent the actual precipitation of rain, as distinct from flows of humid air due to global physical heat dynamics, is influenced by the soil or vegetation conditions which we can directly influence via our agricultural management or landscape regeneration?

4.The effect of land clearing on its heating, re-radiation and creation of heat domes and rain.

Soils that are cleared and left bare will inevitably absorb vastly more incident solar radiation than adjacent land with protective plant covers with higher albedo reflectance and transfers of latent heat into the air via transpiration. As the bare soil will heat up much more, often exceeding 70 oC, it will also re-radiate vastly more infra red heat back out into the air as a typical 'black body radiator'.

As the re-radiation of heat from the Earth is the key driver and determinant in how much Hat can be absorbed by greenhouse gases it is the major variable in our control to lower the greenhouse effect.

The level of this re-radiation of heat from the Earth also governs how much heat can be absorbed by water vapour in the air to create the humid high pressure heat domes that form over bare hot areas. These high pressure heat domes can block the inflow of cool moist low pressure air, from the ocean into these hot regions which can impair rainfalls and thus further aridify these bare hot regions.

While vegetated, Australia's east coast and its tablelands to the west regularly received high rainfalls as well as precipitation from fog and dew from these cool moist onshore air flows. The well watered coastal ranges and tablelands were the base of much of Australia's dryland dairy, horticulture and forest industries. Australia innovated the cavity wall in houses specifically to minimize the unhealthy humidity in these wet misty cloud-lands.

As we progressively cleared these forests, overgrazed the pastures and bared soil their heating and high pressure heat domes we have greatly reduced these humid air inflows, rainfalls and mists. Much of these coastal ranges and tablelands have 'dried out' as a result and are now beef or sheep pastures and dry sclerophyll woodlands that intensify wildfire risks and their further aridification.

The physics of black body heat re-radiation and onshore humid air flows have not changed. Just as we degraded and aridified these bio-systems we can regenerate and rehydrate them. What needs to change is our recognition that it is we who largely governs these processes and through that the extent to which 'droughts' occur and can be minimized by regenerating these processes.

5.The impeded recharge of Australia's 'in soil reservoirs' as natural drought avoidance buffers.

Australia is not only the driest inhabited continent but also the flattest. By global standards its inland rivers have minimal flows, with only 6% of this naturally reaching the ocean. However in response to this aridity over the past 46 million years Australia's biota has evolved highly efficient processes in which its soils could infiltrate, retain and efficiently use and recycle every limited raindrop that fell.

Naturally 98% of the rain that fell was infiltrated into Australia's soft spongy soils, that the explorers often described as 'moulds'. Some 10% of this rain flowed through sub-soils to recharge streams, billabongs and rivers which often terminated in inland deltas and swamps except in extreme floods.

As most of the rain that fell was stored in deep well structured 'in soil reservoirs it was protected from evaporation and able to be used efficiently for the transpiration and growth of the deep rooted perennial vegetation. Any excess water from these in soil reservoirs recharged deeper sedimentary strata and artesian aquifers that underlie much of Australia and recharge some streams from below.

As such these extensive deep in soil reservoirs across most of Australia's 770 million hectares was a major natural fresh water storage resources that was naturally recharged in wet periods and drawn on by plants when dry to buffer both floods and droughts and their erosive impacts. Vast areas of such in soil reservoirs in the Chanel Country in far western Queensland were recharged periodically by wet season tropical rains in the north and then able to sustain highly productive rangelands for up to a decade despite this region being arid and often in prolonged 'drought'.

Our extensive grazing of these perennial native pastures and particularly overgrazing in droughts when these soils were bare has resulted in the substantial degradation of their former spongy soil structures and the collapse of their in soil reservoir capacity. As a result even though western Queensland had major rainfall and flood events in 2010 and 2012 that previously would have recharged these in soil reservoirs to enable them to sustain pastures for years into the next dry, these soils and pastures can no longer do this. Instead they have become droughted and bare again within years of the wet that formerly would have recharged them for over the next decade.

As such it is our management of these pastures and our degradation of their soil structures thatnow result in these drought effects, not the reality that there are wet and dry seasons. We can blame the dry but this will not fix 'our soil degradation induced droughts'.

Conversely if we recognize that such droughts are partly in our control via our wise grazing of these pastures to ensure that these in soil reservoirs are regenerated rather than degraded we should be able to substantially avoid such drought impacts, even as it becomes systemically much dryer.

6. Our intensification of droughts via our production of haze aerosols and persistent humid hazes.

Droughts occur physically when regions don't get the rain they do normally or that we may expect. Whether regions get rain depends on if there is adequate moisture in the air and if so, can it form and be precipitated as raindrops. Natural physical and microbial processes govern both of these.

As how we manage our landscapes also influences these processes it also influences, if there is rain and the severity of droughts; even where there may be abundant moisture in the air.

Air normally contains from 1-5% water by weight. As there is 1000 grams of air above each square centimetre of the Earth's surface there is up to 50 cm of water in that air. Vast quantities of water flow continually over most of the Earth, including most deserts. When evaporated by the sun this water is invisible as water vapour. When it cools much of this vapour will condense onto microscopic aerosol nuclei to form haze micro-droplets. These haze micro-droplets are far too small and light to fall out of the air under gravity and stay in the air as suspended humid hazes or water vapour.

The level of humid hazes is governed largely by the numbers of haze nuclei emitted into the air. A wide range of natural organic volatiles, dusts and particulates can serve as these haze micro-nuclei. So too can dust, particulates and volatiles emitted from our agricultural and industrial practices.

Given that we have been adding over 4 billion tonnes of additional dust, 3 billion tonnes of carbon particulates and an unknown volume of industrial volatile pollutants to the air annually we have massively increased the level of these haze micro-nuclei and humid hazes. Asia is often blanketed with a pollutant brown haze with aerosol levels now hundreds of times over safe or previous levels. These aerosol nuclei sustain humid hazes of high persistent relative humidity that can not form rain.

For rain to form millions of haze micro-droplets need to be coalesced into a raindrop that is large and heavy enough to fall from the air under gravity. As the haze micro-droplets repel each other via electrostatic charges they can only be coalesced by precipitation nuclei with hygroscopic properties able to overcome these repulsive charges. Whether and how much rain can form, even from humid air, depends largely on the relative numbers and hygroscopicity of the precipitation nuclei in the air.

Effectively we have created droughts and deserts by the massive increase in our emission of these haze micro-nuclei that create the aridifying warming humid hazes and our impairment of the natural balancing precipitation nuclei needed to remove these humid hazes from the air as rain.

Large areas of the Earth are now covered by these persistent warming and aridifying humid hazes. The Asian brown haze is accentuating dangerous 'humid heat' health risks and a 30% reduction in rainfall in key food growing regions that now threatens the reliability and scale of Asia's monsoon. Given that human activities largely govern what quantity and type of aerosol micro-nuclei we emit into the air, we also govern the level, persistence and consequences from these humid hazes.

We have also significantly impeded the production of the natural hygroscopic precipitation nuclei that are critical to coalesce these warming aridifying haze micro-droplets and remove them as rain.

By warming the planet and the atmosphere via these humid hazes and their greenhouse effects we have reduced the potential for ice nuclei to form in the air of warmer regions, to coalesce and remove these humid haze micro-droplets hygroscopically as raindrops. Our clearing and burning of much of the Earth's primary forests has also greatly impeded the natural production of the microbial precipitation nuclei that are fundamental in creating rain particularly in warmer inland regions.

In doing so we have grossly disturbed the balance that had evolved naturally between these natural nucleating processes that governed the formation of the humid hazes and its warming and drying effects and their hygroscopic coalescence via precipitation nuclei to create cooling clouds and rain.

As such our land management practices, rather than regional or seasonal climate variables, need to be seen as primary causal factors in much of our increasing drought reality; not the victim of them.

7. Our direct impairment of natural rainfalls due to our land and forest management practices.

Drought is often defined as a lack of rainfall, both in absolute terms and relative to our expectations. As rainfall is assumed to be a natural physical phenomena, any deficit relative to our expectations is seen as abnormal, a 'drought' that is beyond our control and thus an excuse to hide from reality.

However if the lack of rain is directly due to us, these illogical assumptions and excuses cant hold up. We become responsible for our reality and can hopefully can become response able to help fix it.

The south west of Western Australia naturally was a low woodland that extended 400 kilometres to the north and east. It received reliable winter rainfalls that declined from some 900 mm/an close to the coast to 200 mm/an at its northern and eastern fringes. From 70 years ago the woodland in the better watered western zone was cleared for agriculture up to, the rabbit proof fence. As rainfalls were considered to be too low for reliable crops east of the rabbit proof fence these woodland were retained as natural undisturbed bio-systems.

Soon after this clearing farmers noted that they were not receiving their former or expected rainfalls on the cleared land. In contrast the uncleared but naturally drier woodland east of the rabbit proof fence continued to receive its normal rainfall. Over time this difference has increased with the uncleared land north and east of the rabbit proof fence now getting 20% more rain than the cleared area under crops; that formerly got more rain. Observations (BOM,CSIRO) confirm that clouds and then rain starts forming once the humid marine air flows from the west flow over the uncleared woodlands east of the fence but rarely while flowing over the cleared former moister lands.

As such some factor of the woodland hydrology east of the rabbit proof fence must be inducing this higher cloudiness and rainfall that has been impaired in the cleared agricultural crop land. This accords with evidence that some forests produce microbial precipitation nuclei that can coalesce clouds and rain from such humid air flows more so than the green crops that have replaced them.

Far from being just a physical variable, if the induction of rain is influenced by biotic factors that are directly influenced by our land management, then we may have agency over that rain and droughts.

As such much of our rainfall, the lack of it and thus many droughts needs to be reconsidered to be directly linked to how we have manage our landscape. Droughts are no longer an excuse that allows us to externalise our responsibility for them to; bad luck or nature but our reality and responsibility. Nor can the symptoms of our droughts, even where harsh, justify that we should be subsidised for our degrading landscape practices and their consequences as exceptional circumstances.

8.Can we restore rainfalls at regional and national levels by restoring such landscape processes?

Detailed scientific analyses of pollen histories in sediment cores from lakes including in inland arid regions confirm that up to 6000 years ago Australia had an often wetter climate that sustained gallery rainforests and grassy woodlands into our current arid centre. This flora was sustained by the then much more extensive Australian monsoon as seasonal rain extended into the centre as evidence by the local paleo river channels and now dry lake sediment data. The question is did this flora across inland Australia help sustain those monsoon rains and what happened to change them?

Certainly central Australia has progressively aridified from that time as the monsoon retreated to the north, droughts and fires intensified, streams became ephemeral and the flora changed to the now dominant arid adapted Acacia and spinafex associations. What the data does not tell us is what caused what. Did the vegetation change drive the climate aridification or vice versa?

Australia's first nations people certainly record these changes and in their 'storm water dreaming' which question how their caring for country may have changed the 'rainbow serpent', the monsoon, whose retreat resulted in the aridification of their habitat and landscape. While a range of factors may have induced macro-climatic changes at that time, the above evidence suggests that even local vegetation, fire and land management changes can rapidly and readily change local micro-climates.

As discussed above if extensive areas of vulnerable arid land is overgrazed or burnt and allowed to become bare especially during a periodic drought this can trigger a sequence of soil heating, re-radiation, dust erosion and structural oxidation effects each of which can have an adverse, but at a process level a 'positive multiplier' effect that intensifies and extends that drought and aridification.

The high pressure heat domes generated by the re-radiation of heat from the bare soils could readily block the inflow of humid low pressure air into these regions as evidenced along the east coast. The overgrazing or burning of forests responsible for producing the precipitation nuclei could readily have impaired rainfalls from any humid monsoonal air flows that could penetrate past the heat dome as evidenced at the rabbit proof fence. Other stresses would have contributed synergistically.

The evidence indicates that higher human population pressure, the loss of Australia's browsing megafauna and the more intense wildfires around that time could have induced such soil impacts and thus the sequence of aridifying climate changes leading to our current vegetation and climate.

While we cant be certain if or how this happened, we can be certain that our vegetation and soil management changes now can influence local micro-climates greatly and extrapolate how such effects may have governed the development of bio-systems in the past and can do so in the future. That we can use these land management practices to regenerate and rehydrate degraded arid areas as well as buffer and minimize the adverse impacts from 'droughts' from variations in rainfalls.

Key findings from analysis of these drought-land management relationships.

The above eight relationships between the onset and intensity of rainfall, 'droughts' and human induced landscape changes in Australia reinforce similar associations in other parts of the world. They confirm that far from being an innocent 'victim' of drought brought about by natural climate variations, bad luck or an assumed act of God, our impacts in altering and degrading our landscape can often directly induce or intensify 'drought' effects.

Even if we individually are not directly responsible, we can individually be response able. While all people may be adversely impacted by droughts, there is often a vast difference in how severely close by individuals are impacted by the same drought depending on how response able they are. As climate extremes and droughts intensify, it is certainly in our own self interest to be response able so as to better avoid, buffer and survive the adverse impacts from drought and re-grow once they pass.

By becoming response able we may be able to restore rainfalls even in arid regions through the ecological regeneration of these natural soil, hydrology and vegetation processes. Extended over even modest areas such a rehydration and regeneration of former degraded and arid vegetation may be able to generate adequate transpiration and natural hydrological cooling effects to restore the inflow of humid air into that region to further enhance its rehydration and climate.

The rehydration and regeneration of such healthy soils could help significantly in restoring the in soil reservoir, longevity of green growth, resilience and thus capacity of these regenerated bio-systems to buffer, avoid and survive aridification extremes and the existence and perception of droughts.

To take this responsibility we need to better understand the processes that governed the hydration of the bio-systems we depend on fundamentally and how they have helped buffer and sustain our local cooler and more mesic safe climates. To understand how we may need to and can regenerate these natural bio-systems and processes to help rehydrate and restore our former safe climates.

The following analyses outline some of the scientific processes that we can utilize to reinforce our resilience to and minimize the impact of droughts as well as the practical evidence from leading case studies of the outcomes and benefits realized through such drought avoidance strategies.