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Mapping Water Availability and Volatility with Climate Events: Using Finance Indexing Methodology

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Abstract

Australia is renowned as a very arid continent that has wide rainfall variability across its regions, the seasons and years. Water scarcity increases the need to better understand water storage variability. The potential impacts of climate change on regional water availability can be well understood by adopting a tracking technique to continuously record water storage, and its variability at regional levels. This paper develops indices of water availability based on regional water storages in Queensland. Given the impact of climate events on water availability; paper measures and indexes storage volatilities in the presence of climatic events, adapting mapping techniques. Findings of this research afford insights for regional policy-making decisions. In addition, the paper highlights the link between indices and its potential application in business, by shedding light on the financial implications of water availability information.

JEL classification numbers: P34, G17, C43, C51, Q51, Q54
Keywords: finance indexing, water availability, volatility index; climate change, regional economic policy, local business

1 Introduction

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As a natural resource with no substitute, water is gradually considered as something that

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has similar characteristics to oil; availability and supply of both are limited, and demand is likely to increase exponentially, particularly in the regional expanding population and associated industrial demand. Scarcity of water, together with global warming and climate variability may have a restraining effect on regional and national economic development. Renown as the world' most arid inhabited continent[3] Australia is notable for its wide rainfall variability across the regions, seasons and years (Kingsford, 2000). Water storage variability had been always an issue for the Australian rural economy, as agriculture sector comprise more than two-thirds of water consumption in Australia. An example of such dependence is a substantial fall in agricultural outputs due to drought in 2003 by $3 billion from 2001-02 levels, leading to a reduction in GDP of around 1%, and causing difficulties for farms, families, and communities (Lu & Hedley, 2004). Policy makers in Australia have acknowledged and recognised the pressure on Australia's water resources and have begun looking for solutions.

Water scarcity is borne not only by farmers, but also by all the units and agents that comprise regional and national economies, such as banks, insurers, processors and suppliers, water authorities, and ultimately the entire economy. In addition to scarcity, increasing privatisation of water system-related assets, aging infrastructure, and industry consolidation especially under current nationwide water reform impact water availability, particularly in regional Australia. Furthermore, research predicts that water availability may be threatened by climate change in Australia (CSIRO, 2009). Since the variability in water storage is increasing because of climate conditions, water demand rises and competition for water intensifies across regional Australia. As Australia gradually moves into a market-based water economy, the political and social demand for more water for environmental purpose also continues to rise (Randall, 1981; Freebairn, 2003). Further to increasing demand for more water availability and better (geographic) allocation; social impacts of population growth and settlement patterns add to the stressor of regional areas. These socio-economic and climate change pressures can act as impediment, and therefore it is important that these issues are addressed in the design and implementation of the economic policies and planning. Currently, water volatility is not fully considered in regional business plans and practices, especially the day-to-day business cost and risk management practices.

This calls for a systematic water availability monitoring and surveillance study to be conducted over time, which takes into consideration the relationship between water availability and climate events. In order to do so, this paper tends to develop prototype water availability and volatility indices, particularly at catchment level to portray water storage situation of regional Queensland. The paper further maps the indices with climate events of El Niño and La Niña to demonstrate water storage changes as result of such events. This connection may help policy makers further to address the potential impacts of water vulnerability and variability in the policies, and future regional economic business and planning. The novel contribution of this paper is that it uses an indexing methodology commonly used in finance and economics in order to model water indices. The authors believe that this methodology has the capacity to better capture the dynamic trend of water availability and changes. Such attributes enable the indices to be well adopted together with other information (e.g. business cost data, socio-economic variables,

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[3] 70% of Australia is arid

etc.) and to be embedded in the business modelling for effective and objective investment decision-making processes.

The organisation of the paper is as follows. Section 2, very briefly, reviews the existing indices on water availability, outlines their limitations, and highlights the significance of this research. Section 3 succinctly discusses historical climate events of El Niño and La Niña in Australia in order to link these events later with prototyped indices. Section 4 introduces the sample and data used in calculation of water indices. Section 5 introduces the indexing methodology, while sections 6 and 7 describe and interpret water availability and volatility indices developed for Queensland and individual regional catchments. Section 8 exhibits mapping between the indices, the El Niño and La Niña events. Section 9 concludes the paper.

2 Existing Indices, Limitations and the need for a Prototype Index

In the past couple of decades, many indices have been developed by scientists to quantitatively evaluate water resources scarcity and/or stress. One of the early indexes is Falkenmark indicator, developed by Falkenmark (1989). Falkenmark indicator defines water stress as a condition when annual water supplies drop below 1,700 cubic metres per person per year. Similar to Falkenmark indicator, Gleick (1996) developed another water scarcity index based on basic human water needs; this index takes into consideration of minimum water required for drinking, sanitation, bathing and food preparation when calculating water stress. Jiménez-Cisneros (1996) indexed the availability of water by incorporating both water quantity and quality data to redefine national water resource monitoring system in Mexico. Influenced by the work of Falkenmark; Ohlsson (2000) proposed Social Water Stress index, for which index he considered how economic and technological improvement could potentially affect freshwater supply and availability. In more recent attempts, Water Poverty Index (WPI) was proposed by Lawrence et al (2002), and Sullivan et al. (2003), as a holistic tool, to measure water stress. WPI assesses vulnerability of water resources and involves global indices of water poverty.

Broadly, these measures provide valuable methods of quantifying differences in water availability in countries and broad regions. Considering the focus of these approaches on quantification of availability, however, it means these measures are partial in assessing the volatility of water at catchment levels. Even if they were applied at catchment scale, they either would have little or no relevance given specific environmental characteristics exclusive to each catchment, or would not provide fine scale representation of water variability and availability. Furthermore, even though most of these valuation techniques generate valid estimates of water scarcity or water stress, this does not mean that estimates can be validly compared. Additionally, none of these techniques offers the capacity to look at temporal data and historical behaviour on water volatility in order to predict future patterns in the presence of global climate variability and change.

Water indices developed and proposed in this paper, not only capture the availability and volatility of water, but also has the capacity to provide the detailed information at catchment level. The prototype index in this paper provides primary platform for relating climate events of El Niño and La Niña with the fluctuations of water resources. As explained in details in section 5, the proposed index enhances measures of availability and variability on catchment basis, and potentially provides refined information to predict future patterns.

3 El Niño and La Niña in Australia

The cycle of El Niño, neutral and La Niña patterns in the Pacific Ocean including Australia, usually occurs on time scales of typically 3-7 years which is described as EI Niño-Southern Oscillation (ENSO) (Bureau of Meteorology, 2008). El Niño events are associated with increased probability of the drier condition over the large parts of Australia while La Niña often leads to wetter conditions. El Niño is responsible for at some stage the rainfall variability in eastern Australia which the rainfall tends to be lower during El Niño years and higher during La Niña years throughout the region (Allan 1988, Balston and Turton, 2009). Both types of climate events have impact on the rainfall, heat waves and evaporation which consequently affect the availability of water and the subsequent changes on the water storage. Changes to the frequency and intensity of climate events have impact on the volume of ground storage in the region, such as the frequent El Niño events decrease wet season rainfall and hence water available for ground water recharge in the region during El Niño years, for instance, since 1976 the frequency and intensity of El Niño events has increased, resulting in a rainfall decrease along the east coast, mostly in the summer and autumn months (Balston and Turton, 2009).

According to Queensland Government's classification of ENSO years, EI Niño and La Niña years are categorised into two periods which strong consequent climate events appeared in Queensland are presented below: *La Niña periods – 1998/99 to 2000/01; 2007 to 2008; 2010 to 2012; EI Niño periods – 2002 to 2003; 2006 to 2007 and 2009-2010.* As water storage data used in calculating prototype indices are from 2002 to 2012, La Niña and El Niño periods prior to 2002 are excluded from the sample. 2007 to 2008 was regarded as the period that a weak to moderate La Niña event occurred over the parts of northern and eastern Australia, and it was regarded as a short, marginal climatic event with its greatest impact across the north of Australia. The close-to-average rainfall was recorded in the north during August to October which below-the-average rainfall occurred in the southeast from November to December of 2008. However, the extreme heat waves were recorded in January and February 2009 which increase the evaporation of the ground water (Bureau of Metrology, 2012 a). 2010-2012 La Niña event consisted of two strong peaks over the summers which one of the strongest on record occurred in 2010-11 since 1917 with Monthly Southern Oscillation Index value reaches the highest since 1876. The 2011-12 event was recorded as a weaker one in contrast to previous peak, but still have moderate strength. 2010-12 was regarded as the wettest period in Australia's La Niña calendar. As the consequence, flooding was widespread in Queensland with the well-known September 2010- March 2011 southeast Queensland flooding. The tropical regions also experienced unseasonable rain events and tropical cyclone – *Yasi* causing the flooding risk in northern Queensland as well (Bureau of Metrology, 2012a).

2002 to 2003 El Ni Niño event was recorded as a weak to moderate one that caused the major drought during the period with rainfall deficiencies over the March 2002 to January 2003. 2006 to 2007 El Niño event was recorded as week: during May 2006 to December 2006 most of Australia experienced the lowest 10% of rainfall with southern Victoria and northern Tasmania receiving lowest on record rainfalls. The dry condition was changed and the rainfall for most areas in Queensland except for southeast has returned to above average level from early. Similarly Bureau of Metrology (2012 b) classifies the overall intensity of 2009-10 El Niño event as weak to moderate. Queensland had large areas with rainfall level of lowest 10% on the historical record during May to October 2009. By November 2009, the rainfall pattern in Queensland has changed to reach the top 10% with most areas. February to March of 2010, heavy rain brought by the surgy of tropical air and the flooding in southern area ended this recent El Niño episode.

4 Sample

The regional water availability indices developed in this study is applied to some of the Queensland regional water resources; spreading from Mareeba in Far North, west to Mount Isa, and South to St George and Goondiwindi. This water storage and distribution network comprises of 19 major dams and 36 weirs and barrages included in the sample as show in Table 1.

Table 1: Water Storages and Schemes in NQ

Scheme	**Storage**	**Total Storage Capacity in Millilitre (ML)**	**Stream**	**Nearest Town**
Barker Barambah	Bjelke-Petersen Dam	134900	Barker Creek	Mugon
	Joe Sippel Weir	710		Mugon
	Silverleaf Weir	620		Mugon
Bowen Broken Rivers	Bowen River Weir (Collinsville Weir)	943	Broken River	Collinsville
	Eungella Dam	112400		Eunhella
	Gattonvale Offstream Storage	5234		Collinsville
Boyne River And Tarong	Boondooma Dam	204200	Boyne River	Proston
Bundaberg	BenAnderson Barrage	30300		Bunderberg
	Bucca Weir	11600		North Kolan
	Fred Haigh Dam	562000	Kolan River	Gin Gin
	Kolan Barrage	4020		Bunderberg
	Ned Churchward Weir	29500		Wallaville
	Paradise Dam	300000	Burnett River	Bigggenden
Burdekin Haughton	Burdekin Falls Dam	1860000	Burdekin River	Ravenswood
	Clare Weir	15900		Claredale
	Giru Weir	1020		Giru
	Val Bird Weir	615		Giru
Callide Valley	Callide Dam	136300	Callide Dam	Biloela
	Kroombit Dam	14600	Kroombit Creek	Biloela
Chinchilla Weir	Chinchilla Weir	9780		Chinchilla
Cunnamulla Weir	Allan Tannock Weir	4770		Cunnamulla
Dawson Valley	Glebe Weir	17700		Taroon
	Gyranda Weir	16500		Cracow
	Moura Offstream Storage	2820		Moura
	Moura Weir	7700		Moura
	Neville Hewitt Weir	11300		Baralaba
	Orange Creek Weir	6140		Cracow
	Theodore Weir	4760		Theodore
Eton	Kinchant Dam	62800	Sandy Creek	North Eton
Julius Dam	Juluis Dam	107500	Leichhardt River	Mount Isa
Macintyre Brook	Ben Dor Weir	700		Inglewood
	Coolmunda Dam	69000	Macintyre Brook	Inglewood
	Whetstone Weir	506		Inglewood

Mareeba Dimbulah	Tinaroo Falls Dam	438900	Barron River	Atherton
Nogoa Mackenzie	Bedford Weir	22900		Blackwater
	Bingegang Weir	8060		Dingo
	Fairbairn Dam	1301000	Nogoa River	Emerald
	Tartrus Weir	12000		Marlborough
Pioneer river	Dumbleton Weir	8840		Mackay
	Marian Weir	3980		Marian
	Mirani Weir	4660		Mirani
	Teemburra Dam	147500	Teemburra Creek	Mirani
Proserpine River	Peter Faust dam	491400	Proserpine River	proserpine
St George	Buckinbah Weir	5120		St George
	E.J Beardmore Dam	81700	Balonne River	St George
	Jack Taylor Weir	10270		St George
	Moolabah Weir	250		St George
Three Moon Creek	Cania Dam	88500	Three Moon Creek	Monto
Upper Burnett	Claude Wharton Weir	12800	Nogo River	Gayndah
	John Goleby Weir	1690		Ceratodus
	Jones Weir	3720		Mundubbera
	Kirar Weir	9540		Eidsvold
	Wuruma Dam	165400		Eidsvold
Upper Condamine	Leslie Dam	106200	Sandy Creek	Warwick
	Yarramalong Weir	390		Pampas

Source: Authors extracted information from SunWater

5 Methodology

Indexing technique is a popular method in economics and finance disciplines to track the changes of the objectives that economists intend to research, in particular in the areas focusing on natural resource studies in order to enable them to further explore the environmental impacts and volatilities (Curran and Moran, 2007; Klassen and McLaughlin, 1996). The indexing methodology applied in natural resource research varies with different disciplines due to the specialised disciplinary techniques. This paper adopts the indexing techniques that are widely used to structure financial market indices.

In the financial sector, major market indices provider, such as Standard & Poor (S&P) and International Securities Exchange (ISE) develop their own index using mathematics methodologies, which are widely applied in calculating market indices or market associated indices. The foundation of those financial indices is the prices of relevant financial products, which most of them are the equity prices that well track the movement and volatility of particular market. Departing from financial indices, water availability and volatility indices require appropriate design of indexing methodology that are endowed with financial attributes. The combination allows us to well align the regional water condition with the financial and business risk management products and strategies to serve both water users and general investors.

Modified capitalisation weighted methodology is one of the most common financial indexing techniques used by major indices developers. S&P (2012) and ISE (2006)'s indexing methods have similar base formulae although the interpretations are slightly different :

S&P version:

$$\text{Index value} = \frac{Index\ Market\ Value}{Index\ Divisor},\ I_{(i)} = \frac{\sum_i P_i * S_i * IWF_i * FxRate}{D_{(i)}} \quad (1.1)$$

ISE version.

$$\text{Index value } I_{(t)} = \frac{\sum_{i=1}^{n} P_{i(t)} * S_{i(t)}}{D_{(t)}} \quad (1.2)$$

$$\text{Initial Index divisor } D_{(o)} = \frac{\sum_{i=1}^{n} P_{i(o)} * S_{i(o)}}{I_{(o)}} \quad (1.3)$$

where, P_i similar to $P_{i(t)}$ below is the price of stock (i) (at time t); $I_{(i)}$ similar to $I_{(t)}$ are the index value at time i or t; S_i or $S_{i(t)}$ is the number of assigned shares of stock (i) at time (t). IWF is the stock's float factor and FxRate is exchange rate which is applicable when the foreign exchange is part of the condition. n is the number of stocks in the index while $D_{(i)}$ or $D_{(t)}$ is the index divisor at time (t). $D_{(O)}$, $P_{i(o)}$, $S_{i(o)}$ and $I_{(o)}$ are the initial index divisor, stock price, number of assigned stocks and base index value at the beginning of sample period. If there is no index composition change, $D_{(t)}$ equals to $D_{(o)}$.

In order to formulate water availability index one needs carefully compare above two methods and determine what index divisor to be used. The index value formulae of S&P and ISE are similar, in a way that ISE formula is a simpler version of S&P's method. The types of financial information that are indexed by S&P significantly varies (since foreign exchange-related information might be associated with stocks included in S&P indices), in contrast to ISE indices, S&P methodology includes more calculating components that potentially contribute to the index value. However such complexity does not apply to our water availability indices. Similar to ISE method, our prototype water index should have a straight forward format to address the basic information of the water storage. S&P methodology considers the stock's float factor and includes IWF in the formula to address the different weightings between each type of stocks to avoid disadvantaging "less-weighted" stocks in the index. This is certainly the case in this paper, as different types of water stations selected (i.e. dam, weir and barrages) have various capacities causing weighting differences.

Therefore below formula developed for our prototype water availability index includes three basic but fundamental calculation components:

1) daily water storage
2) weight factor to address the differences of the water storage capacities of individual station as their size varies
3) the index devisor.

In this paper authors use the initial weighted total water storage as the index divisor. Given the numbers of water stations remain unchanged from 2002 to 2012, there is no index composition change which $D_{(t)}$ equals to $D_{(o)}$ and are represented as D in below formula.

$$\text{Water availability index } WAI_{(t)} = \frac{\sum_{i=1}^{n} WS_{(i,t)} * WF_{(i)}}{D} \quad (1.4)$$

where,

$WAI_{(t)}$ = Water availability index at day *t*

$WS_{(i,t)}$ = Water storage of dam (weir) i at day t

$WF_{(i)}$ = Weight factor –the weight of each water storage (dam/weir)'s capability in terms of total water storage capability based on entire sample

D is the index devisor, which the initial index value $I_{(o)}$ is set as 100.

Initial Index divisor D = $\frac{\sum_{i=1}^{n} WS_{(i,0)} * WF_{(i)}}{I_{(o)}}$ (1.5)

6 Main Results

6.1 Application to QLD Regional Water Resources

The water availability index based on entire sample represents actual storage as a percentage of 'full capacity' (show below in figure 1). The index thus moves up and down in response to actual water stored. The initial index value is set as 100. The minimum index value is zero. As storage increases in response to water inflows, the relevant index will also rise and vice versa.

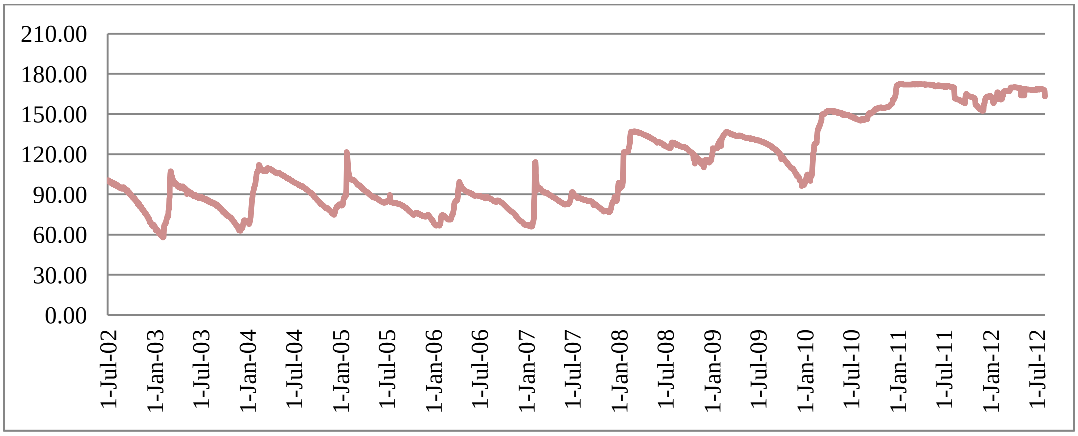

Figure 1: Regional QLD Water Availability Index

Source: Authors' calculation

Figure 1 shows fluctuated water availability in the entire sample for the past 10 years from July 2002 to July 2012. Periodic fluctuation and seasonality are observed on yearly basis. Downward trends are seen during the second half of each year from July and upward trends appearing around January of the following year. This seasonality pattern matches the timing of the wet and dry seasons, influenced by rainfall, in QLD. The lowest level of water availability was observed on 3rd February 2003 with the index number of 57.88 while the highest water availability is recorded for 16th January 2011 at 172.35. The water availability index reaches highest in January 2011, which indicates the potential impact from 2010-2011 La Niña event that is regarded as one of the strongest on record since 1917 (the strongest since 2002). The figures representing individual regional catchment's water availability indices (together with volatility indices) are included in Appendix A.

Table 2 features descriptive statistics including the measure of central location (i.e. mean), measures of variability or spread (i.e. standard deviation, variance, minimum and maximum values), and measures of distributional shapes (i.e. Kurtosis and Skewness). The descriptive statistics, in Table 2, are calculated at both catchment scale and regional scale (i.e. full sample scale).

Table 2: Summary Statistics of Water Availability Indices (Regional QLD Catchments)

Catchments	**Mean**	**Std. Dev.**	**Variance**	**Kurtosis**	**Skewness**	**Min**[4]	**Max**[5]
Barker Barambah	55.8	52.3	2739.6	-0.4	1.0	0.0	157.5
Bowen Broken Rivers	84.1	46.3	2140.3	-1.7	-0.2	16.6	133.4
Boyne River and Tarong	83.6	47.6	2266.7	-0.8	0.7	0.0	165.5
Bundaberg	135.0	38.6	1486.8	-1.3	0.6	88.9	196.8
Burdekin Haughton	99.1	14.3	205.4	2.6	-1.0	0.5	169.8
Callide Valley	57.0	60.8	3691.8	1.0	1.5	10.8	216.8
Chinchilla Weir	137.1	56.6	3208.5	-1.3	-0.1	0.0	282.9
Cunnamulla weir	106.1	19.0	360.5	1.5	-1.0	0.0	159.1
Dawson Valley	120.6	15.7	246.9	1.0	-1.3	36.6	150.2
Eton	120.6	59.5	3544.7	-1.2	-0.7	0.0	179.4
Julius Dam	116.6	12.5	156.9	1.4	-0.6	73.3	217.5
Macintyre Brook	74.3	35.3	1249.1	-1.0	0.1	11.7	136.7
Mareeba Dimbulah	110.0	27.0	730.4	0.4	-1.0	32.9	145.0
Nogoa Mackenzie	106.1	60.1	3616.0	-1.7	0.2	0.0	184.5
Pioneer river	78.7	41.3	1705.3	-1.7	-0.1	0.0	122.6
Proserpine River	89.8	49.0	2399.4	-1.4	0.3	0.0	167.0
St George	115.1	49.9	2485.2	-1.0	-0.4	0.0	52.5
Three Moon Creek	101.6	115.9	13433.0	0.7	1.5	0.0	480.4
Upper Burnett	101.8	165.7	27462.9	1.3	1.8	0.0	480.4
Upper Condamine	210.0	246.6	60788.8	1.1	1.7	0.0	796.5
Catchments Average	105.1	60.7	6695.9	-0.1	0.1	27.7	229.7
Regional Water Availability Index	111.9	33.5	1119.3	-1.1	0.5	57.9	172.4

Source: Authors' calculation

As seen in the table, while the spread and variability of water storage across catchments captured through measures of spread such as standard deviation; the volatility is captured through statistical measures of kurtosis and skewness. Skewness measures how symmetric the data is, and it measures the difference between the average and median of the water storage data. For a symmetric distribution, like the normal, the skewness is zero.

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[4] minimum volatility index values at catchment level

[5] maximum volatility index values at catchment level

If the skewness is negative, then the distribution is skewed to the right and if it is positive, then the data is skewed to the left. Kurtosis, on the other hand, is a measure of extreme observations (in our case water storage). So while the sign of skewness is enough to tell us something about the water data, kurtosis is, often, expressed relative to that of a normal distribution. By definition, the kurtosis of a normal distribution is 3, and fat-tailed distributions have values of Kurtosis that are greater than 3. Moreover, distributions with negative or positive excess kurtosis are called platykurtic distributions or leptokurtic distributions respectively. Table 2 shows that there is mainly platykurtic distribution among data. The lower, wider peaks around the mean and thinner tails observed in majority of indices are shown by negative excess kurtosis. Such distribution characteristics help featuring future patterns of water availability and variability which enable researchers to understand and incorporate the potential cost variation in business cost and risk management analysis. In detail, standard deviation of full sample index is 33.455 while a high stand deviation of 246.554 is observed with Upper Condamine catchment which is greater the catchments average of 60.704 and the full sample index. Other statistic features (mean, variance, minimum, maximum and skewness) of all catchments and full sample indices are reported in below table as well.

6.2 The Water Availability- Volatility Indices

In finance literature, a fundamental factor in the measurement of index performance is the volatility. A wide range of different approaches and models has been used to derive volatility indicators. A number of contrasting theoretical arguments and approaches is used by finance researchers to calculate different types of volatility (i.e. Canina and Figlewski, 1993; Stivers, 2003 and Bollen and Inder, 2002; however most of the volatility types are derived based on the prices of financial assets which are inappropriate to be employed here such as realised volatility, future volatility, stochastic volatility and implied volatility. In this paper, water availability indices are modelled using a derived equity indexing method, given the nature of sample data (water storage) the volatility of water availability, then, is calculated using standard deviation in the monthly format (July 2002 to July 2012), instead of complex financial models. After the calculation step, monthly volatility of availability is indexed to show the statistical descriptions (see Figure 2).

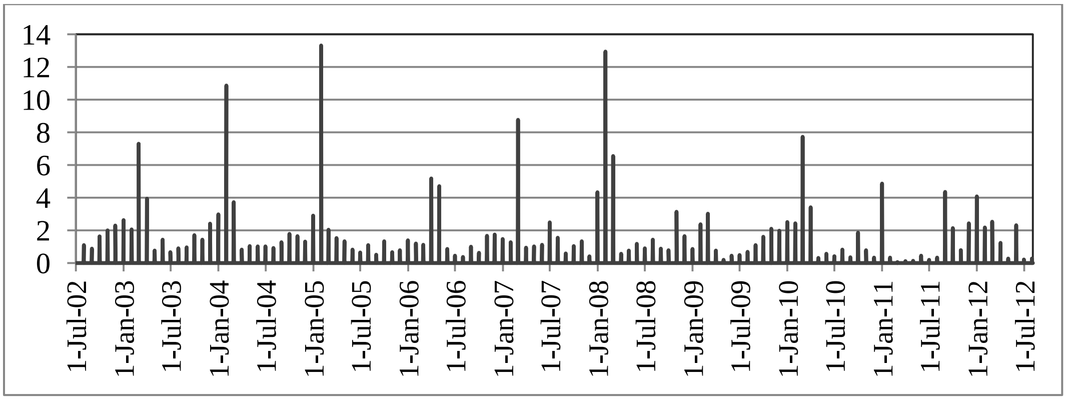

Figure 2: QLD Water Availability Volatility Index

Source: Authors' calculation

While Table 3 records the extreme volatilities observed based on the information derived from Figure 2; Table 4 portrays key statistic features of the developed volatility indices. Full sample volatility index, in contrast to individual catchment's indices as shown in the Table 4, has modest volatility with standard deviation of 2.3, minimum of 0.1 and maximum of 13.3. Its kurtosis and skewness at 10.8 and 3.05 respectively indicate a leptokurtic distribution that has a more acute peak around the mean and fatter tails.

Table 3: Extreme volatilities recorded

Dates	Index value
28th February 2003	7.29
31st January 2004	10.87
31st January 2005	13.31
28th February 2007	8.77
31st January 2008	12.95
28th February 2010	7.72

However, amongst catchments' volatility indices, extreme volatilities are observed as shown in Table 4. High standard deviation and variation are recorded with catchments of Nogoa Mackenzie. Three Moon Creek, Upper Burnett, and Upper Condamine that their variances are greater than 100, while high excess positive kurtoses are observed with catchments of Boyne River and Tarong, Callide Valley, Upper Burnett and Upper Condamine. In addition, Three Moon Creek (at 123.6), Upper Burnett (at 178.6) and Upper Condamine (259.9) show extremely high index numbers which are far beyond the average level of 61.4 as well as the maximum index number of full sample volatility index at 13.3. Again, such distribution features convey valuable information for the design of the financial derivatives' pricing model, in particular it assists to evaluate and thus select existing pricing models as the starting point.

Table 4: Summary Statistics of Water Availability Volatility Indices (QLD & Regional Catchments)

Catchments	**Mean**	**Standard Deviation**	**Variance**	**Kurtosis**	**Skewness**	**Min**[6]	**Max**[7]
Barker Barambah	1.3	2.9	8.4	31.2	5.1	0.0	23.0
Bowen Broken Rivers	0.9	1.7	3.0	39.0	5.5	0.0	15.0
Boyne River and Tarong	1.5	3.9	15.2	48.9	6.7	0.0	33.6
Bundaberg	3.3	7.6	57.8	14.7	3.7	0.0	47.3
Burdekin Haughton	2.4	4.3	18.4	16.5	3.9	0.0	28.1
Callide Valley	2.6	8.5	72.7	52.0	6.8	0.0	76.4
Chinchilla Weir	5.8	9.3	86.3	13.8	3.4	0.0	58.0
Cunnamulla weir	4.7	8.0	63.4	11.2	3.1	0.0	46.3
Dawson Valley	4.2	4.9	24.2	3.9	2.0	0.0	23.5
Eton	3.5	3.7	14.0	3.5	1.9	0.2	17.5
Julius Dam	2.3	3.4	11.7	14.6	3.5	0.0	23.6
Macintyre Brook	3.1	5.1	26.0	17.8	3.8	0.0	35.4

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[6] minimum volatility index values at catchment level

[7] maximum volatility index values at catchment level

Mareeba Dimbulah	2.3	3.1	9.5	13.6	3.3	0.0	20.9
Nogoa Mackenzie	5.3	12.2	149.4	10.1	3.3	0.1	61.1
Pioneer river	2.2	6.8	46.3	24.6	4.9	0.0	43.1
Proserpine River	2.7	7.9	62.3	26.8	5.0	0.0	52.5
St George	6.6	9.2	84.9	14.9	3.6	0.3	60.4
Three Moon Creek	3.7	14.4	206.4	47.2	6.5	0.0	123.6
Upper Burnett	4.0	21.4	455.9	55.6	7.4	0.0	178.6
Upper Condamine	8.3	28.6	818.3	53.8	6.8	0.0	259.9
Catchments Average	3.5	8.3	111.7	25.7	4.5	0.0	61.4
QLD Water Availability Volatility Index	1.9	2.3	5.2	10.8	3.1	0.1	13.3

Source: Authors' calculation

6.3 Mapping Indices with Climate Events

Based on the El Niño and La Niña events calendar years, and intensity categories explain in section 4; authors linked the water availability and volatility indices at entire sample level to the information sourced from the Bureau of Metrology to map the impact of such regional climate events on water availability and associated volatility. By mapping La Niña events with the prototyped index as represented in Figure 3. An obvious upward trend is observed during strong La Niña years, and a modest rising trend with comparably lower water storage level during a moderate La Nina period, and a relatively flat trend is observed during weak La Niña years. Comparable to availability index, mapping between volatility index, La Niña years, and intensity indicates a similar relationship as portrayed in Figure 4.

Mapping between El Niño events and full sample water availability index in Figure 3 shows a combination of the impacts: El Niño events with weak to moderate intensity (i.e. the strongest intensity classification recorded from 2002 to 2012) appear to be the cause of decreased availability index values from 2008 to 2012. However, the highest water storage is observed when the La Niña is at the strong level. In addition, during the weak El Niño years, the water availability level is at its almost lowest which is reasonable given the drier condition brought by the El Niño events. Similarly, the volatility index shows such a relationship as well. Nonetheless, the seasonal pattern of the rainfall (i.e. water recharges in summer which causes both water availability and volatility indices to reach their highest at first 4-6 months of the year) seems to influence the volatility of water storage more than the impacts from El Niño and La Niña events.

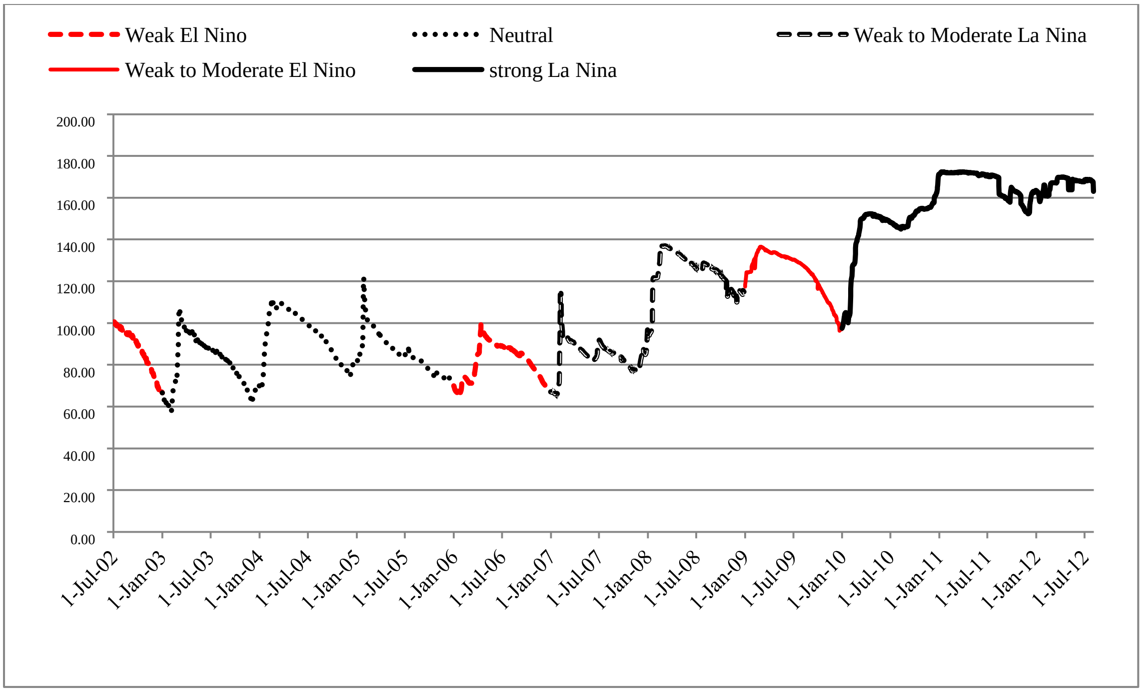

Figure 3: Water Availability Index during El Niño and La Niña Years

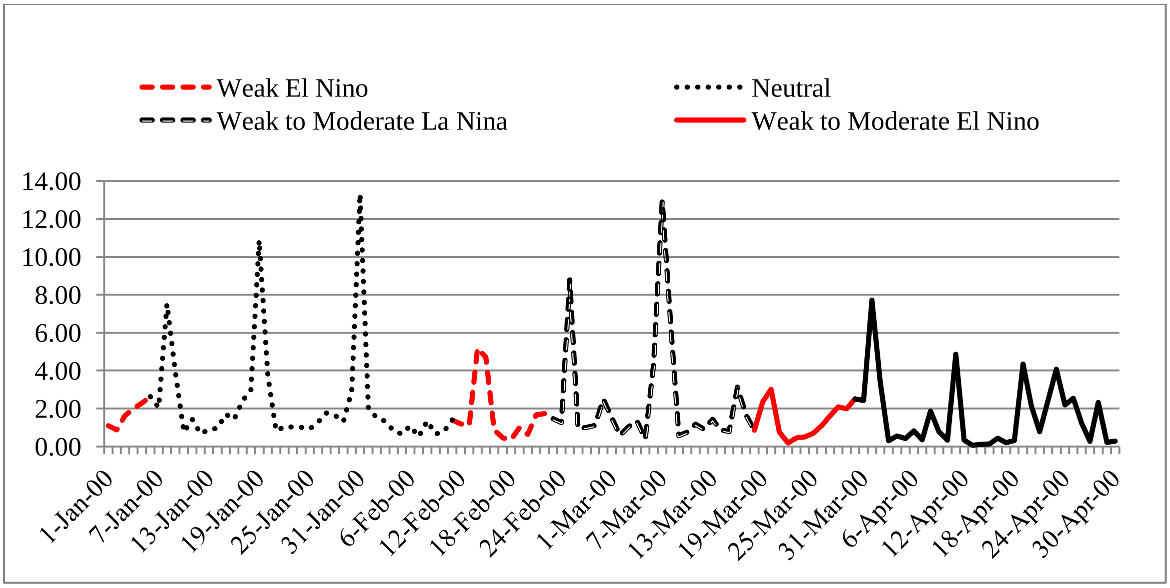

Figure 4: Water Volatility Index during El Niño and La Niña Years

Source: Authors' calculation

7 Concluding remarks

The paper focused on the objective of seeking to improve our understanding of the extent to which indexing methodology commonly used in economics, ecological economics and finance could be applied in water availability and variability studies. The paper offered a novel approach to develop a prototype water availability – volatility index, at catchment level in QLD, based on S&P and ISE indexing methods. The sample data is collected from SunWater database, and includes 19 major dams and 36 weirs and barrages. The water availability and volatility indices display periodic fluctuation and strong seasonality on yearly basis with downward trends seen during second half of each year, and upward trends appear around January of the following year. An noticeable relationship between water availability, variability and El Niño and La Niña events is unveiled, which implies that the highest water storage appeared during a strong La Niña period and reaches its almost lowest level when the intensity of El Niño is weak.

Finding of this research signpost that it may be important to try to look into more accurate indexing methodologies in order to have better estimates of water variability over time. Better estimates of water trends assist associated governance systems to monitor water variability within individual catchments and/or regional water resources, and to account for volatility and vulnerability of water supply when making regional economic, environmental, and business decisions. While authors believe indexing methodology introduced in this paper has the capacity to help featuring past, current and future water trends; further improvement can be made through incorporating other climate-related information such as: inclusion of rainfall into the prototype water indices developed here under a revised indexing methodology in order to better address a comprehensive climate impacts on the water resource at the regional level.

In addition, the volatility indices showcased in this paper are introduced with an intention to draw the attention from the business sector on this dynamic feature of water resource and believe the indices based on a finance indexing technique have the ability to be applied more directly in the cost and risk management procedures for decision-making purpose. This becomes an important topic for a sustainable business/industry as climate-induced costs on natural resource are expected to rise either due to declines supply or increased prices or demand. Finally, authors acknowledge that no single valuation method can be applied in all situations and all regions. One needs to consider a variety of different issues, including data availability, climatic and environmental characteristics, as well as socio-economic structures before adapting an indexing methodology.

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