Climate Change Impacts on 'Seasonality Index' and its Potential Implications on Rainwater Savings

Monzur A. Imteaz[1] · Iqbal Hossain[1]

Abstract

Seasonality Index (SI) is commonly used to define rainfall variability within a year for a locality, which has got significant impact on the water resources planning and management. Both the longer periods of dry and wet conditions are reflected by SI value. As SI is calculated using historical rainfall data, a historical average value is represented for a locality. However, with the emerging impacts of climate change SI values based on historical data are likely to change. This paper presents expected changes in future SI values for the largest city of Australia (Sydney) based on projected future rainfall scenarios for the city. The paper further illustrates potential water savings through rainwater tanks under projected climate change scenarios using an earlier developed daily water balance model, eTank. For the simulations of potential water savings through rainwater tanks, projected daily rainfall data was collected from Australian government data portal for four stations within Sydney. Future potential rainwater savings efficiencies were correlated with the corresponding SI values. It is found that such correlation closely matches with an earlier developed correlation using past historical data, however the future water savings efficiency will be slightly lower than the past water savings efficiency.

1 Introduction

The seasonality index (SI) is a measure of intra-annual rainfall variability for a particular area. In regard to water resources planning and management, it is an important decision-making factor significantly influencing water resources allocation and diversion planning, especially for irrigation. It is likely that some regions while experiencing high magnitude of total annual rainfall, however the monthly rainfalls are not uniformly distributed throughout the year. Such type of monthly rainfall distribution will render less agricultural benefit compared to the situation where similar amounts of rainfall is uniformly distributed throughout the year. Moreover, localities having non-uniformly distributed high annual rainfalls are

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likely to experience floods during high rainfall periods. As expressed by Sumner (1988), SI is calculated through the equation below:

$$SI = \frac{1}{R} \sum_{j=1}^{12} \left| X_j - \frac{R}{12} \right| \qquad (1)$$

where, SI is the Seasonality Index, R is the mean annual rainfall and Xj is the mean monthly rainfall for month 'j'. Hypothetically, the values of SI can vary from 0 - 1.83. If every month of a year has same magnitude of rainfall, then the value of SI is '0', whereas if all the total annual rainfall occurs within one month, the value of SI is '1.83'; nonetheless both of these values are unlikely (Risbey et al. 2009).

It is well-known amongst environmental scientists that effects of climate change are modifying the earth's atmospheric conditions, thus leading to potential increases in extreme meteorological events (Easterling et al. 2000; Mikhaylov et al. 2020). This includes the alteration of total annual rainfall which in effect will alter the precipitation distribution in seasonality and interannual variability (Feng et al. 2013). The dynamic change of precipitative actions will heavily influence regions that are dependent on seasonal rainfall for different crop growth. Rainfalls in different Australian cities show high degree of variability, and such variabilities are most likely to be worsen due to emerging global warming and subsequent climate changes (Chowdhury and Beecham 2010). Different climate studies predict that dry regions are expected to become drier, while some wet regions are expected to become wetter. Changes in typical rainfall patterns are already observed in different parts of Australia, which is a challenge for the efficient management of water resources in this continent (King et al. 2020). Recently, an increasing trend in rainfall is observed towards the west, whereas a decreasing trend is observed towards the northeast coast (Kamruzzaman et al. 2013). Such increasing trend would be a concern regarding potential flooding, on the other hand a decreasing trend is a concern in regard to fresh water availability and irrigation need.

It was established that several large-scale climate drivers such as El Niño–Southern Oscillation (ENSO), Indian Ocean dipole (IOD), Atmospheric Blocking, Southern Annual Mode (SAM) and Madden–Julian oscillation (MJO) influences Australian climates and rainfalls in different seasons, which in fact governs the SI of a particular region (Risbey et al. 2009). In many cases influence by more than one drivers and their interactions (i.e. combined effect) become critical (Esha and Imteaz 2020; Islam and Imteaz 2020). Hendon et al. (2007) emphasized the need of understanding the dynamics and variation patterns of these climate indices for the efficient management of scare water resources. While there were numerous studies on the above-mentioned large-scale climate drivers and their relationships with different climate variables (Ghamariadyan and Imteaz 2021; Esha and Imteaz 2020, 2019; Hossain et al. 2020, 2018; Rasel et al. 2017), there is scarcity on research related to SI and its implications. Imteaz et al. (2021c) have presented detailed climatic and spatial variabilities of SI values considering rainfall data from six major Australian cities while incorporating selected data from different weather conditions such as dry, average and wet. Pascale et al. (2015) analysed the changes and correlation between rainfall seasonality and periods of drought for the high carbon emission scenario (i.e. RCP 8.5) for the twenty-first century through using a dimensionless seasonality index, utilising the distribution and timing of monthly rainfall of dry months for regions of Mediterranean type climates such as southern Australia, Northern Africa and southern Europe.

Among the sustainable water resources infrastructures, there have been numerous studies on rainwater harvesting systems and its potential benefits. With the emerging impacts of climate change, several studies investigated the impacts of climate change on changes in

potentials of water savings through rainwater harvesting (Imteaz et al. 2021b; Imteaz and Moniruzzaman 2020; Zhang et al. 2019). Regarding implications of SI on water harvesting and its relationship, there were very few studies. Through analyzing historical rainfall data from several Australian cities and applying daily water balance model, Jenkins (2007) has presented relationship of SI with rainwater tank's water savings efficiency; and shown that rainwater savings efficiency decreases with the increase of SI value. Such relationship was taken to a next level by Imteaz et al. (2021a), who incorporated SI in a generalised equation, which can be used to calculate expected rainwater savings through domestic rainwater tank. However, there is uncertainty on the future applicability of the developed equation under the impact of climate change. To investigate such uncertainly, this study first evaluates future SI values for the largest Australian city, Sydney based on projected future rainfall data. The study also evaluates future expected water savings through roof-connected rainwater tanks. Eventually, the study derives the relationship between future SI and future potential water savings efficiencies and compares it with the earlier developed relationship based on the past data. With the onslaught of climate change, such type of study involving SI was never conducted and/or reported. For a sustainable water resources management under the impacts of climate change, such study outcomes are expected to render significant insights towards future water resources management.

2 Methodology and Data

Due to availability of enough complete data, the largest Australian city, Sydney, which is the capital of New South Wales was selected for this study. Four rainfall stations covering different spatial directions having minimal missing data were selected from the city. Table 1 show the details of the selected rainfall stations in Sydney, where directions are mentioned with respect to city centre. Figure 1 shows the locations of the stations within Sydney metropolitan area. Australian government through its Commonwealth Scientific and Industrial Research Organisation (CSIRO) has commissioned generation and storing of future projected climate data for different regions/states of Australia. For the projection of data, the widely used technique, Statistical Downscaling Modeling (SDSM) was applied, which uses multilinear regression technique and stochastic weather generator to downscale climate variables from original General Circulation Models' outputs. Different states of Australia using different data hub to store the generated data. For Sydney (New South Wales), projected data are available through the NSW Climate Data Portal (https://climatedata.environment.nsw.gov.au/). For the current study, daily rainfall data for the future years for all the selected stations were collected from the mentioned data sources. Projected data is provided for two future periods; near future (2020 - 2039) and distant future (2060 - 2079). All the calculations were performed for both the future periods.

Table 1 Details of the selected rainfall stations

Station name	Site ID	Longitude	Latitude	Elevation(m)	Direction
Sydney Observatory	066062	151.21	−33.86	39.0	Central
Seven Hills	067026	150.93	−33.77	50.0	North-West
Lucas Heights	066023	150.98	−34.05	140	South-West
Badgerys Creek	067108	150.73	−33.90	81.2	West

Fig. 1 Map of Sydney metropolitan showing prominent rainfall stations
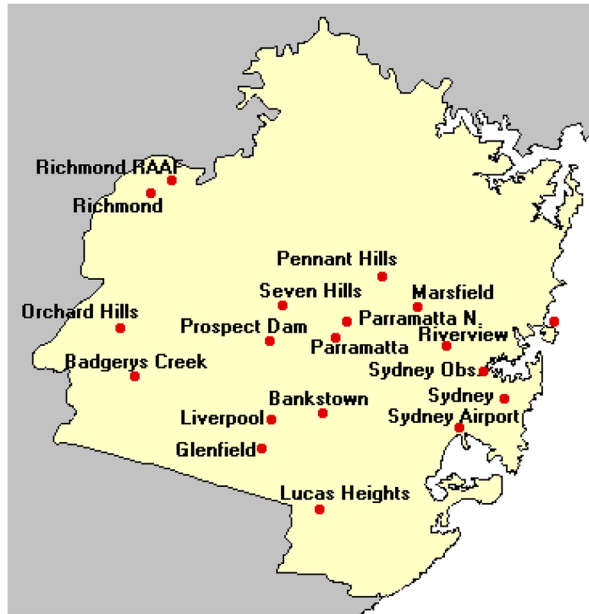
SI values for all the stations in each city were computed using Eq. 1. To investigate any differential effects based on weather conditions, three different weather conditions such as 'dry', 'average' and 'wet' were considered. Dry, average and wet years were determined based on the 10th percentile, median and the 90th percentile values of annual rainfall respectively (Imteaz et al. 2016). As a particular year may exhibit unusual pattern, for each weather condition three years were selected to represent the particular weather conditions. Computations were performed for each of the selected years. Same weather classifications and years based on such classification were considered for both the historical and future rainfalls. Historical and potential future SI values were compared for each selected station.

Potential future water savings under climate change scenario were calculated using an earlier developed daily water balance model, eTank (Imteaz et al. 2017b). eTank was widely used for different Australian cities such as Melbourne (Imteaz et al. 2016), Sydney (Moniruzzaman and Imteaz 2017), Adelaide (Paudel et al. 2018) and Canberra (Imteaz et al. 2014), as well as for Nigeria (Imteaz et al. 2012) and Nepal (Imteaz et al. 2017a). In brief, eTank considers daily rainfall as input and a certain portion of the rainfall is deducted as losses (evaporation and spill). After deduction of losses, the remaining portion will enter into the rainwater tank, volume of which is preselected. If the tank is already full from rainwater inflows of earlier days, then the subsequent inflows will be bypassed as overflows. From the accummulated water in the tank, daily expected usage amount will be deducted. Model calculates cumulative rainwater uses in a year. In addition, the model also calculates reliability of expected demand, cumulative overflows and cumulative augmented supply from main source when rainwater is unable to fulfill the intended demand. Imteaz et al. (2017b) provided details of theoretical concepts, mathematical algorithms and comparisons with other contemporary tools. While for the applications in different cities, numerous different combinations of climatic conditions, roof areas, tank volumes and rainwater demands were considered. For the current study, as the salient focus was to assess climate change impacts in relation to historical rainwater savings, to compare with an earlier study, the input parameters used in the earlier study was used for the current study, which are: roof size (100 m^2),

rainwater demand (200 L/day), tank volume (5000 L) and a rainfall loss (due to evaporation, leakage and spillage) 15% is considered. Also, to assess the effect of roof size and rainwater demand, other scenarios were evaluated for the roof size of 200 m^2 and demand of 300 L/day.

3 Results and Discussions

3.1 Impacts on Seasonality Index

Table 2 show the selected years from the past as well as for the futures, along with their corresponding annual rainfall amounts and calculated SI values for all the selected stations. For each station, each period and each weather condition three years were selected. Figure 2 (a-d) show the average SI values of these three years for all the periods and weather conditions in all the stations. From the figures it is clear that compared to historical values, SI values are likely to increase in future years, except in dry years. In all the stations, future dry years' SI values are likely to decrease, except for the station of 'Badgerys Creek'. As under the climate change scenario, the dry years are likely to be drier, the monthly spread of rainfalls is likely to be more uniform resulting in lower SI value. For average years, in all the stations SI values are likely to increase in the far future. However, in the near future the scenario is different; for all the stations except Lucas Height SI values are likely to decrease. For wet years, in the near future in all the stations the SI values are likely to remain similar, except Lucas Height, where it is expected to increase. However, for far future in the wet years, in all the stations SI values are likely to increase. As per general climate impact predictions, wet years are likely to be wetter and this study predicts that the monthly distribution of wet years' rainfalls are likely to be more sporadic.

3.2 Effects on Water Saving Efficiency

To assess the effects of future SI values under climate change scenario, eTank model was used for calculating potential annual water savings for all the selected years. For the selected years, daily projected rainfall amounts were downloaded from the mentioned data source and fed as input data in the model. Other model parameters are mentioned in the 'Methodology' section. Calculated potential annual water savings in the corresponding years along with the annual rainfall amounts and water saving efficiencies are shown in Table 3. Rainwater saving efficiency was defined as the ratio of expected annual water savings and annual rainfall amount (Imteaz et al. 2021a). For the sake of comparison, except the daily rainfall data, other input data were considered same as those were considered in the study of Imteaz et al. (2021a).

Figure 3 shows the scattered plot of calculated SI values with the corresponding water savings efficiency values. As obvious, a general trend is that with the increase of SI values, water savings efficiency decreases and trendline drawn on the plot aligns with this. Figure 3 also shows the line which depicts the earlier established relationship between SI value and water savings efficiency based on historical rainfall data from several Australian cities (Imteaz et al. 2021a), which is outlined below:

$$WSE = -34.788 \times SI + 79.928$$

Table 2 Calculated SI values for the selected years

Location	Period	Dry Year		Average year		Wet year	
		Year	SI	Year	SI	Year	SI
Sydney Observatory	Past	1994	0.48	1912	0.67	1919	0.67
		1946	0.73	1953	0.76	1974	0.59
		1997	0.80	1995	0.63	1952	0.65
	Near Future	2025	0.56	2020	0.78	2023	0.64
		2032	0.62	2034	0.6	2026	0.58
		2024	0.66	2038	0.57	2030	0.62
	Far Future	2075	0.67	2062	0.88	2069	0.53
		2078	0.69	2071	0.82	2065	0.64
		2072	0.55	2060	0.72	2067	0.73
Badgerys Creek	Past	1997	0.6	2000	0.81	2008	0.65
		2002	0.9	2016	0.9	2012	0.78
		2018	0.67	2017	0.88	2013	0.74
	Near Future	2024	0.79	2031	0.71	2026	0.61
		2028	0.67	2035	0.66	2030	0.95
		2032	0.62	2036	0.73	2037	0.56
	Far Future	2072	0.64	2071	0.96	2065	0.8
		2075	0.69	2073	0.99	2069	0.79
		2079	0.87	2077	0.74	2070	0.77
Lucas Heights	Past	1994	0.71	2010	0.74	1988	0.56
		1982	0.85	2003	0.71	1976	0.63
		1965	0.81	1991	0.69	1990	0.59
	Near Future	2022	0.56	2034	0.74	2031	0.71
		2028	0.55	2039	0.76	2026	0.73
		2024	0.66	2020	0.79	2036	0.74
	Far Future	2060	0.70	2072	0.52	2070	0.72
		2079	0.78	2073	0.81	2065	0.77
		2075	0.58	2071	0.85	2068	0.73
Seven Hills	Past	1982	0.78	1953	0.86	1955	0.73
		1994	0.60	1964	0.80	1976	0.73
		2002	0.89	2001	0.56	1978	0.82
	Near Future	2022	0.61	2021	0.69	2023	0.61
		2025	0.68	2035	0.65	2026	0.69
		2032	0.55	2038	0.65	2036	0.89
	Far Future	2072	0.59	2071	0.91	2067	0.86
		2075	0.63	2074	0.81	2069	0.72
		2079	0.89	2077	0.68	2070	0.76

where, '*WSE*' is the water saving efficiency in "L/mm". From the figure, it is clear that the future trendline (under climate change scenario) follows exactly similar trend having same slope of the trendline, however magnitudes of water savings efficiency are lower than the trendline based on historical values. This reveals that with the impending climate change,
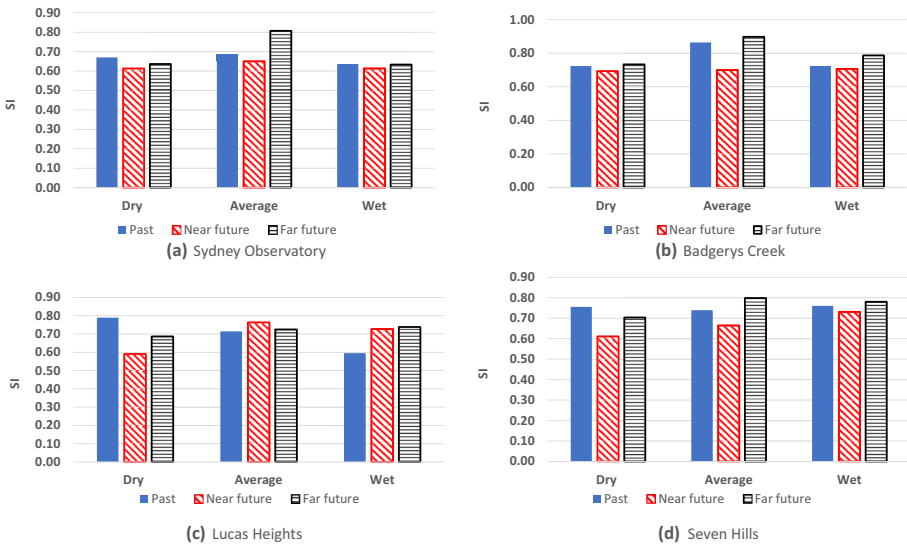
Fig. 2 Past and future SI values for **a** Sydney Observatory, **b** Badgerys Creek, **c** Lucas Heights and **d** Seven Hills

not only the SI values are likely to increase (in average and wet years), also for the same SI overall water saving efficiency will be lower under future scenario. This is due to the fact that was predicted by several climate studies, which predict that under climate change scenario rainfall will be more sporadic. Such nature of sporadic rainfall causes to reduce the water savings efficiency, as frequent bursts of higher magnitude rainfall causes rainwater tank to overflow and hence more loss from the roof-collected rainwater.

Figure 3 does not reveal any spatial difference within the city, however Moniruzzaman and Imteaz (2017) demonstrated that significant spatial variabilities exist in regard to rainwater savings within Sydney. As such, Figure 4 present the SI versus water savings efficiency scatter plots separately for all the selected locations. For more clarity, a separate figure (Figure 5) shows separate best-fit trendlines for all the four locations, which reveals significant spatial variations. From the figure it is found that overall 'Badgerys Creek' location is having highest water saving efficiency. It is to be noted that Imteaz and Moniruzzaman (2018) also reported the highest water saving efficiency for the 'Badgerys Creek' location based on historical data and eTank simulations. However, this observation is quite different for 'Seven Hills'; as per historical data it was having second highest water saving efficiency, whereas based on future climate change data the same is showing worst water saving efficiency. An interesting phenomenon is likely to happen for 'Lucas Heights'. As per historical data the 'Lucas Heights' was having worst water saving efficiency (Imteaz and Moniruzzaman 2018). However, under the climate change scenario, the same location is likely to render highest water saving efficiency for lower SI values (< 0.52) and lowest water saving efficiency for very high SI values (> 0.92). For all other locations the SI versus water savings efficiency curves follow same pattern having almost same slope. However, for 'Lucas Heights' it is following very steep slope. From the above-mentioned results, it can be concluded that climate change is not only likely to

Table 3 Expected water savings along with corresponding annual rainfall amounts for the selected years

| Location	Period	Dry Year			Average year			Wet year		
		Year	Water Saving (L)	Rainfall (mm)	Year	Water Saving (L)	Rainfall (mm)	Year	Water Saving (L)	Rainfall (mm)
Sydney Observatory	Near Future	2025	51814	743	2020	47216	914	2023	49777	1280
		2032	48108	708	2034	52435	908	2026	54588	1267
		2024	44540	772	2038	50578	928	2030	43643	1258
	Far Future	2075	52731	784	2062	42353	1056	2069	65925	1498
		2078	49277	844	2071	44962	1056	2065	59968	1532
		2072	52504	929	2060	49865	1020	2067	54491	1441
Badgerys Creek	Near Future	2024	33289	469	2031	50032	693	2026	50978	1040
		2028	36935	453	2035	47771	683	2030	42495	1304
		2032	38274	479	2036	42314	676	2037	58511	1009
	Far Future	2072	39175	536	2071	37201	754	2065	52306	1034
		2075	43818	557	2073	36268	767	2069	54706	1060
		2079	37667	517	2077	43336	788	2070	50753	1088
Lucas Heights	Near Future	2022	48241	594	2034	52635	757	2031	53380	985
		2028	52432	607	2039	51307	826	2026	56314	1004
		2024	46797	645	2020	43501	846	2036	54765	1099
	Far Future	2060	50773	886	2072	51494	713	2070	54102	1252
		2079	41903	690	2073	47064	921	2065	59351	1261
		2075	51750	705	2071	43309	928	2068	46228	1314
Seven Hills	Near Future	2022	32,983	573	2021	36300	724	2023	31817	957
		2025	27474	469	2035	25918	707	2026	31855	970
		2032	29614	608	2038	39767	831	2036	32678	1120
	Far Future	2072	31871	630	2071	43219	841	2067	37262	1102
		2075	26500	673	2074	34485	828	2069	33765	1156
		2079	31421	967	2077	26174	888	2070	38582	737
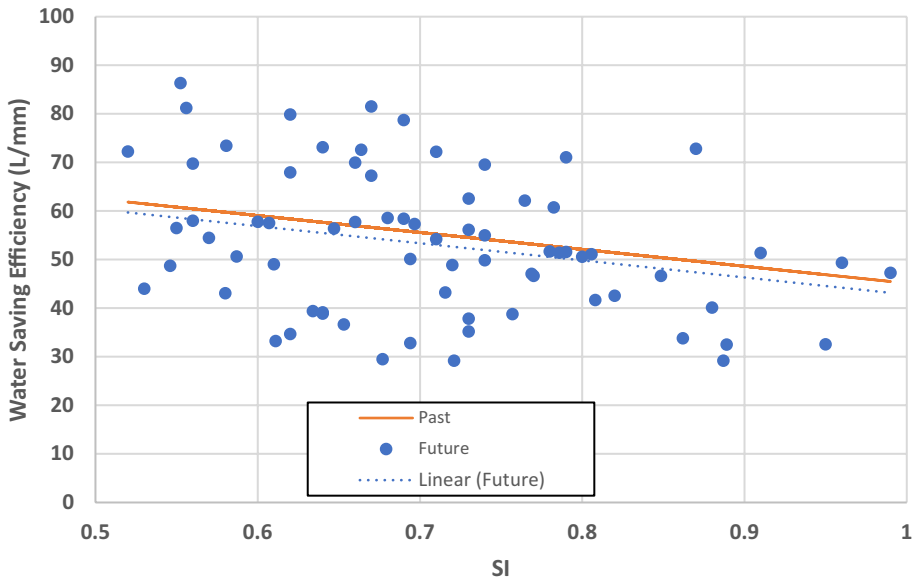
Fig. 3 Past and future relationships of SI value and water savings efficiency

impact rainfall magnitude and intensity, but will also impact intra-annual rainfall pattern, which will eventually impact waters savings efficiency through rainwater tanks. Moreover, such impacts will not be spatially uniform. Rather, impacts and magnitude of deviances are likely to be different for different areas, even within a large city.
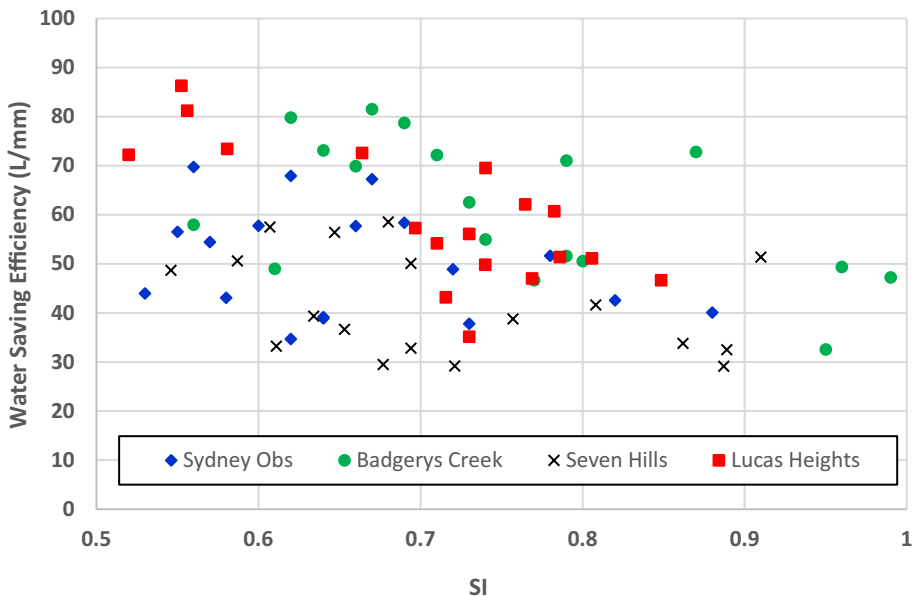

Fig. 4 Scatter plots of SI value and water savings efficiency showing four locations separately
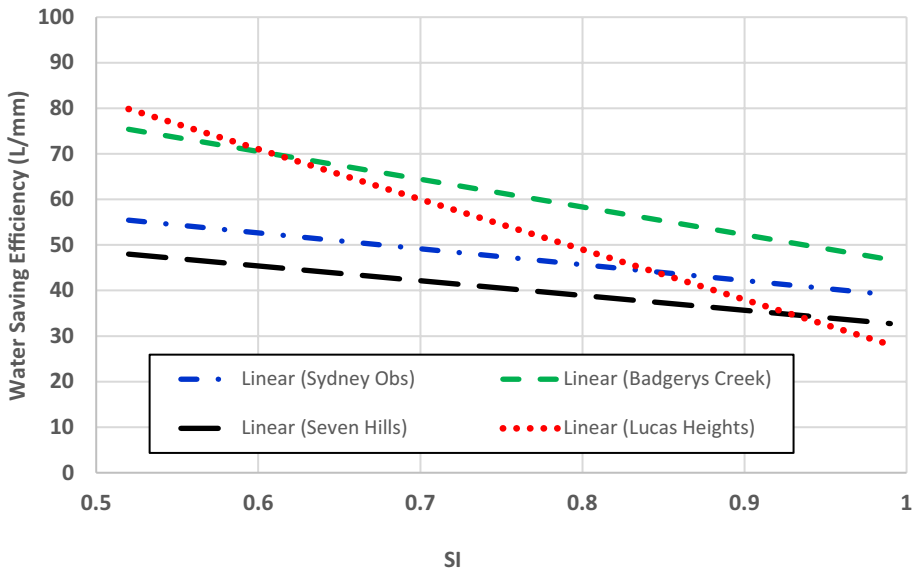
Fig. 5 Trendlines for SI value versus water savings efficiency for four locations

3.3 Effects of Roof Area and Water Demand

This section describes the effect of roof area and rainwater demand on potential water savings efficiency and its relationship with the SI. For this investigation, to avoid repetition of similar things, calculations from only one station are shown. The selected station is 'Badgerys Creek', for which rainwater savings and water savings efficiencies were calculated for the same selected years. For the assessment of effect of roof area, demand was assumed as 200 L/day and two roof areas considered are 100 m² and 200 m². For the assessment of demand, roof area was assumed as 200 m² and two demands considered were 200 L/day and 300 L/day. Figure 6 shows the effect of roof area on water savings efficiency versus SI relationship. From the figure it is clear that both the curves follow the same pattern, while an overall 20% increase in water savings efficiency with a roof area of 200 m² compared to a roof area of 100 m². It is to be noted that such increase in water savings efficiency is not likely to be linear with the increase of roof area, as it was demonstrated by Moniruzzaman and Imteaz (2017) that the effect of roof area gets flatten with the increase of roof area and after a threshold size further increase in roof area does not provide any additional benefit. Figure 7 shows the effect of rainwater demand on water savings efficiency versus SI relationship. It is evident that both the curves follow linearly decreasing pattern which is almost same, having an average 27% increase in water savings efficiency with a demand of 300 L/day compared to a demand of 200 L/day. In this case, it can be seen that the best-fit lines are converging with the increase of SI value.
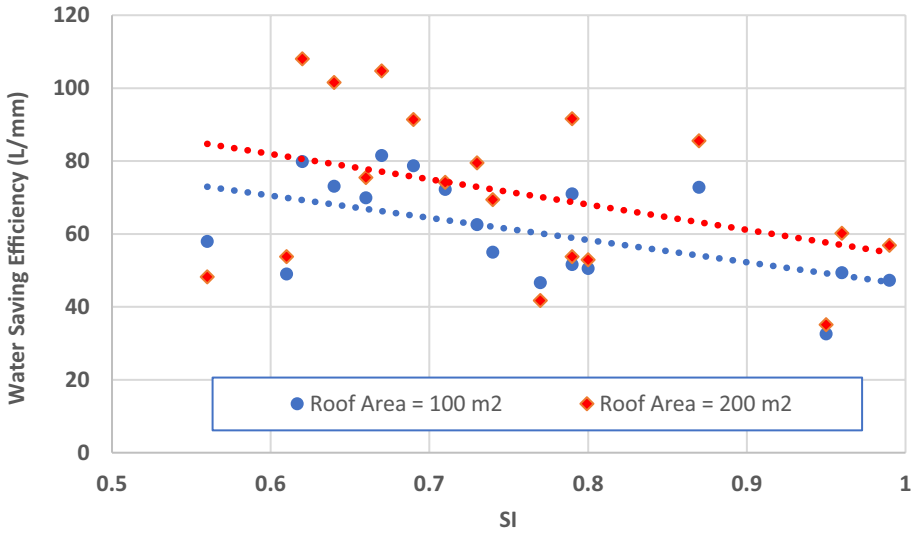
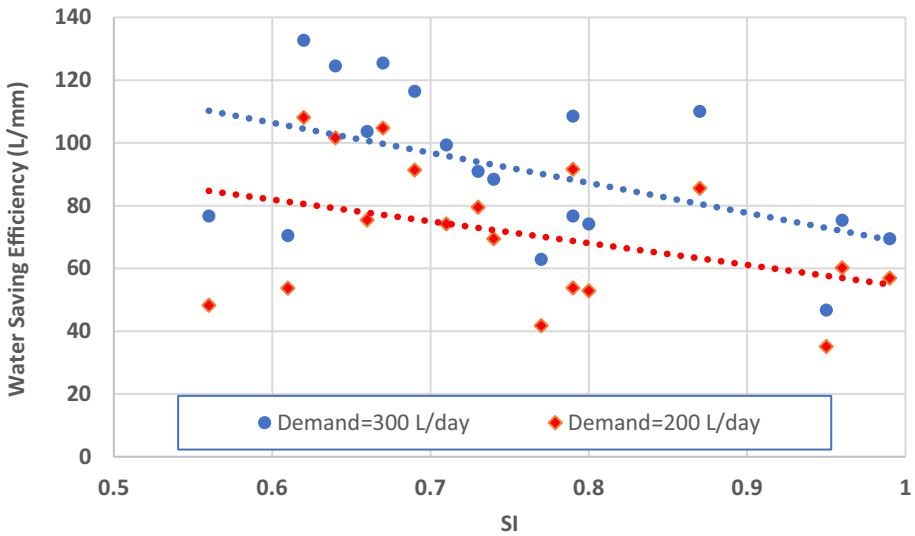**Fig. 6** Effect of roof area on SI-water savings efficiency relationship

Fig. 7 Effect of rainwater demand on SI-water savings efficiency relationship

4 Conclusion

Impending impacts of climate change are not only limited to magnitudes of climate variables, rather frequency and distribution of climate components are also likely to be affected. An important climate parameter, seasonality index (SI), which is the representation of variability of monthly rainfall amounts within a year, has received scant focus in regards to its potential behaviour under climate change scenario. As it has significant influence on

water resources planning and management in regards to agriculture, flood protection and drought management, this study investigated the impacts of climate change on SI value considering rainfall data from the largest Australian city, Sydney. Also, the consequences of expected changes in SI values under climate change scenario on potential rainwater savings are investigated. Four rainfall stations covering the whole metropolitan Sydney having good length of rainfall data were selected for this purpose. Future rainfall data was extracted from New South Wales government climate data portal. As it was delivered from the data portal, the future data was analysed under two categories; near future and far future. Moreover, available data was segregated under three weather conditions; dry, average and wet. From the calculation of historical and future SI values, it can bee seen that in dry years compared to historical SI values, future SI values are expected to reduce. However, in future wet years the SI values are expected to increase compared to historical wet years, which certainly will have consequences on water resources infrastructures. In average years, the SI values are likely to increase, especially during far future.

To assess the impacts of such changing SI values on potential rainwater savings, an earelier developed daily water balance model was applied to evaluate expected rainwater savings in future years. Then those calculated future years' rainwater savings were plotted with the corresponding SI values. It is found that the overall relationship between the potential rainwater savings and SI values remains at the same pattern, however under the climate change scenario the average rainwater savings will be slightly lower compared to historical rainwater savings for the same SI values. This is due to the fact that under climate change scenario projected rainfall will have more sporadic bursts compared to historical bursts. It is shown that an increase in connected roof area from 100 m^2 to 200 m^2 is likely to cause an average 20% increase in annual water savings. Also, with an increase in demand from 200 L/day to 300 L/day, an overall average increase of annual water savings would be 27%. However, these rates of increases will not be uniform for further increases of roof area and/or demand. Rather, the rates of increases will be reduced with further increases of roof area and/or demand.

Declarations

Ethical Approval Not required as no animal/human was involved in the study.

Consent to Participate Authors agreeing to participate any survey or feedback tasks.

Consent to Publish Authors providing consent publication of the manuscript to the journal publisher.

Competing Interests There is no competing interest in regard to the study.

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