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A Statistical Study of Temporal Trends in Rainfall Over New South Wales

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ABSTRACT

The main objective of this study is to carry out trend analysis by using Mann Kendall's tau test in monthly rainfall data of New South Wales over a 99 year period (1912-2010). Trend analysis was performed using non parametric Kendall's tau test to monthly time series of rainfall. This study reveals that the increasing trend dominates the decreasing trend. A total of 492 stations are tested out of which 490 (99.59%) shows a (positive or negative), out of which 202 (41.05%) has negative trend, whereas 288 (58.53%) stations has uptrend. Number of stations with significant increasing or decreasing trends equals to 49 (9.95%), stations with significant increasing trends in data sets dominates over significant decreasing trends over New South Wales. Out of 49 stations, 28 stations have significant increasing trends whereas 21 stations have significant decreasing trends. Two stations were found to have no trend for the month of May and October. Highest number of decreasing trends are found to be in the months of March and April (28 each) while least number of decreasing trends were observed in the month of November (01). Highest number of increasing trends were observed in November (40) out of which 08 are significantly increasing while least number of increasing trends was in April (7) out of which none was significantly increased. Significant increasing trends in cool season were equal to summer season. The highest number of significant decreasing trends was observed in April and June (06 each). This study does not aim to explore the relationship of Climatic indices with rainfall.

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INTRODUCTION

It has been reported in many studies that the climate is changing is due to the both climatic and anthropogenic activities, precisely those activities which are hazardous or can change the chemistry of climate. Climate change is evident by many events from increasing greenhouse gas, extreme events with increased frequency and intensity, variation in temperature globally and locally, and precipitation and hydrological cycle (Durdu, 2010). Deforestation, industrialization, and most importantly burning of fossil fuel are the main factors, which effect most in changing greenhouse gases (UNFCCC, 2007). Increasing Concentration of greenhouse gases is one of the major factor among other factors, which causes increase in temperature (Scavia *et al*., 2002). It has been reported by the intergovernmental panel (IPCC) that mean surface temperature is increased approximately about $0.56\,℃\ to\ 0.92℃$ from 1906 to 2000, which is more than the previous report of IPCC (IPCC, 2001, 2007). These changes may lead to an unexpected and uncertain climatic pattern, as the temperature increased everywhere in the world, some region likely to have less rainfall, therefore these regions may lack availability of fresh water, while some regions may experience more precipitation and storms, which may threaten life of the people in case of extreme flooding (IPCC, 2007).

Numerous studies have been conducted to emphasize on the fact that global warming is related to surface temperature, and to quantify the extent of variability and its influence over different space and terrain. Many studies have shown that this variability is mostly vary from one climatic region to another, however most studies agreed on that it is rising. For example, temperature patterns in Nepal after 1977 is rising with an up slope from 0.03 ℃ to 0.12 ℃ each year (Shrestha *et al*., 1999), Egypt is also experiencing increasing trend from 1941-2000 (Domroes *et al*., 2005).Many studies have shown positive or increasing trends in different parts of the world, however this variability is maximum in winter season (Lund *et al*., 2001; Fan and Wang, 2011).

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For example, in Switzerland, Rebetez (2007) reported that maximum increasing trend in temperature was observed during winter for period 1975 to 2004.

Collins (2000), reported that Australia's mean temperature has increased approximately 0.8 ℃ since 1910, and showed sharp increase after 1950, maximum warming being observed in 1998, while 1990s and 1980s were being the warmest year. Especially, southern part of Western Australia and Queensland experienced most of this variability, while some declining trend was observed in southern Queensland and New South Wales (NSW) (Suppiah *et al*. 2001). Plummer *et al*. (1999) reported that extreme events have been associated with these increasing temperature since 1957 to 1996, while decreased in frequency and intensity of extreme cool events was observed. Stone *et al*. (1996) also reported that increasing trend of temperature is associated also with the reduced frost frequency and its duration. This study is focused on quantifying which regions has significant trends using Mann-Kendall rank correlation test over New South Wales (NSW) in mean temperature time series. This study does not aim to analyze factors that influenced increasing or decreasing trends, however this study is important in a way that it will pave the way for understanding station wise temperature variability and hydrological data.

1. Seasonality of New South Wales:

New South Wales lies in the middle latitude between 28^{o}S to 38^{o}S of the equator and longitudes 143^{o}E to 154^{o}E of the prime meridian and so the Southern Hemisphere exerts the major influence on its weather. The sub-tropical high pressure system which forms a belt of dry and descending air have great effect on a large part of the Australian continent. The New South Wales average rainfall is about 20 inches of which some 90% is returned to the atmosphere through evaporation and transpiration, while the remaining 10% recharges underground supplies and stream of the state which carry on average about 30 million acre feet per annum. The seasonal movements of rain producing systems across New South Wales follow fairly predictable paths. In general, the annual rainfall decreases with distance from the coast and increases with elevation. Highest rainfalls are experienced along the coastal strip and especially on the north coast where elevated plateau intercept much of the moisture carried by onshore winds. The effect of elevation and uplift produce heavy precipitation over the Snowy Mountains area in the southeast corner of the State. Westwards across the State rainfall diminish roughly in proportion to the distance from the ocean. In these parts of the State lack of reliable water supplies have posed a lot of problems. Due to scanty of water for irrigation agricultural productions have reduced and it has also caused environmental problems. So a lot of efforts have been carried out to assure highly coordinated program of water development to stabilize the rural economy and assist in overcoming drought in these affected areas. Evaporation takes its toll of both soil moisture and streamflow. Together with transpiration from plants and infiltration, it accounts for over 90 per cent of the average annual rainfall over New South Wales. The net amount of rainfall so absorbed, varies in different parts of the State. It is estimated to range from over 60 per cent of the annual rainfall along the coast to more than 96 per cent in the inland, reaching almost 100 percent in the most arid regions. The quantity of annual rainfall that fall into streams also varies widely throughout the State. Runoff ranges from over 1000 mm in some small coastal catchments to 600 mm or so in the Snowy Mountains and is virtually negligible in the extreme far west. Almost 70 per cent of the State's total annual runoff originates east of the Dividing Range and flows towards the Pacific Ocean. The transition in the amount of annual runoff across New South Wales is closely related to the pattern of annual rainfall and evapotranspiration.

The climate of NSW is very different from other Australian State, it depends on the topography of the region, for example, Northwestern part of the region has the hottest part of the state, where maximum temperature of about 51°C was recorded at Bourke. Collins *et al*. reported that since last century Australian rainfall has been increased more in summer than in winter. Australian rainfall variability is different from other countries, for instance, Eastern part of the continent observed 15% increase in rainfall, while western part of Australia has much drier trends only in South west WA has 25% reduced rainfall(Hennessy *et al*. 1999; Hennessy 2000). Increased in rainfall in various state of Australia, is associated with the frequency and intensity of rainfall (Hennessy *et al*. 1999; Haylock & Nicholls 2000). Median coldest Rainfall in north west of the state has minimum value of 200mm, while north east coas has maximum rainfall of 1500mm.Hennessy *et al*. (1999)m reported that almost 10% increase in wet days was observed, regardless of 10% significant decreased was observed in South west of western Australia, however, 20% increase was observed in NSW and Northern territory.

2. Data description and Methodology:

We have obtained Monthly rainfall data of 41 rainfall gauging stations from Department of primary industries NSW Office of Water. These 41 stations were analyzed for a period of 99 years (1912-2010) details given in Table 1. These 41 stations were analyzed and recorded by NSW office of water. Mean Monthly temperature data have been obtained from Australian meteorological department site www.Bom.gov.au.Non-parametric Kendall's tau rank based (Capéràa and Van Cutrem, 1988) tests were applied to rainfall data for

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analyzing monthly trends in NSW. This test has been used extensively in numerous studies relating to hydrological trend analysis. This non-parametric test does not require any assumption about the distribution of the data used and tells the degree of association between two time series of rainfall (R) or mean-sea level pressure (P) and time (T). Alternative and null hypothesis for Kendall's tau are defined as, if the correlation exist τ must not be equal to zero and a perfect correlation exists if τ is equal to 1, i.e. H_o: τ=0, no correlation exist between R and T ; H_1: τ≠0, correlation exist between R and T. Where τ is mathematically defined as

$$\tau = \frac{2S}{n(n-1)}$$

In order to apply this test first Kendall's S has to be calculated by $S = a - b$, Where a is the number of concordant pairs while b is the number of discordant pairs. Null and alternative hypothesis is tested on the basis of significance test $z_\tau = \tau\sqrt{\frac{9n(n-1)}{2(2n+5)}}$, null hypothesis is rejected if z_τ, is greater than a fixed value z_α, for positive trend and incase, if there is a negative trend z_τ, is less than $-z_\alpha$, where α is the level of significance. All values are tested at 95% of significance level.

Table 1: Summary of selected station of New South Wales.

Station Number	River Name	Longitude	Latitude
46037	TIBOOBURRA POST OFFIC	29.44	142.01
47031	STEPHENS CREEK RESERVOIR	31.88	141.59
47033	Pooncarie (Tarcoola)	33.43	142.57
47039	Umberumberka Reservoir	31.82	141.21
47045	Wentworth (Willow Point)	33.33	141.77
47053	Wentworth Post Office	34.11	141.91
48031	Collarenebri (Viewpoint)	29.55	148.59
48039	Enngonia (Shearer	29.32	145.85
49023	Euston Street Benington	34.45	142.91
50028	Trundle (Murrumbogie)	32.9	147.52
50031	Peak Hill Post Office	32.73	148.19
50052	Condobolin Ag Research Stn	33.07	147.23
51049	Trangie Research Station Aws	31.99	147.95
52019	Mogil (Benimora)	29.35	148.69
53003	Bellata Post Office	29.92	149.79
53018	Croppa Creek (KruiPlains)	28.99	150.02
54003	Barraba Pos	30.38	150.61
58012	Yamba Pilot Station	29.43	153.36
58063	Casino Airport	28.88	153.05
61010	Clarence Town	32.59	151.78
61014	Branxton(Dalwood Vineyard)	32.64	151.42
61071	Stroud Post Offic	32.41	151.97
62021	Mudgee (George Street)	32.6	149.6
62026	Rylstone (Ilford Rd)	32.81	149.98
63005	Bathurst Agricultural Station	33.43	149.56
64008	Coonabarabran (Namoi Street)	31.27	149.27
65022	Manildra (Hazeldale)	33.16	148.59
68016	Cataract Dam	34.27	150.81
69006	Bettowynd (Condry)	35.72	149.78
69018	Moruya Heads Pilot Station	35.91	150.15
72150	Wagga Wagga Amo	35.16	147.46
73012	Harden (Dunolly)	34.75	148.3
73038	Temora A.R.S	34.41	147.52
74007	Leeton (Bents Hill)	34.48	146.55
74128	Deniliquin Post Office	35.55	144.95
75012	Wakool (Calimo)	35.42	144.6
75050	Naradhan (Uralba)	33.61	146.32
75056	Ramsa	34.94	144.73
76031	Mildura Airport	34.23	142.08
54004	Bingara Post Office	29.87	150.57
54036	Wallangra (Wallangra Station)	29.24	150.89

Results:

Trend analysis was performed using non parametric Kendall's tau test to monthly time series of rainfall. Analysis showed that rainfall distribution over NSW is dependents on the topography of the region. In Fig 5 (a &b) increasing trend dominates over the decreasing trend, while in March-April decreasing trends grows stronger for almost all stations except for some station over southern coast which show an increasing trend. For the winter season, almost all stations showed an increasing trend. These increasing or decreasing trends in rainfall should be further investigated because it depends on several factors for example, number of rain days, the intensity of rainfall and its duration, for if any station shows an increasing trend it may be because of the

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increased number of rainy days or it may be because of less rain days but of higher intensity. Other variable like El Nino southern oscillation index (ENSO), southern annular mode, Pacific Ocean high pressure system and Indian Ocean high pressure system may also be the possible reasons for this increasing trend, however this study does not aim to answer this question.

Discussion:

Overall trends are shown in Table 2, 492 stations are tested out of which 490 (99.59%) shows a (positive or negative), out of which 202 (41.05%) has negative trend, whereas 288 (58.53%) stations has uptrend. Number of stations with significant increasing or decreasing trends equals to 49 (9.95%), stations with significant increasing trends in data sets dominates over significant decreasing trends over New South Wales (See Fig. 5 (a) to 5 (l)) . Out of 49 stations, 28 stations have significant increasing trends whereas 21 stations have significant decreasing trends. Two stations have no trend out 492 stations for the month of May and October. In March and April number of stations with decreasing trends are 28 while least number of decreasing trends were observed in the month of November (01). Maximum number of increasing trends was observed in November (40) out of which 08 are significantly increasing while least number of increasing trends was in April (7) out of which no trend was significantly increasing. In cool season i.e. May to August number of significant increasing trends was equal to summer season. The highest number of significant decreasing trends was observed in autumn (April and June (06) each).This declining trend in autumn is due to the fact that the ground water level has fallen due to the less intensity of rainfall in autumn see (fig 1).

Table 2: Summary of selected station results of New South Wales.

Months	No. of Station tested	No. with decreasing trends	Number with significant decreasing trends	Number with increasing trends	Number with significant increasing trends	Number of significant trends	Percent with significant trends	No trends
January	41	19	2	20	0	2	4.87	0
February	41	6	0	32	3	3	7.31	0
March	41	28	2	11	0	2	4.87	0
April	41	28	6	7	0	6	14.62	0
May	41	11	0	29	0	0	0	1
June	41	21	6	14	0	6	14.62	0
July	41	22	1	14	4	5	12.19	0
August	41	11	1	29	0	1	2.43	0
September	41	12	3	18	8	11	26.82	0
October	41	10	0	26	4	4	9.75	1
November	41	1	0	32	8	8	19.51	0
December	41	12	0	28	1	1	2.43	0
TOTAL	492	181	21	260	28	49	9.95	2

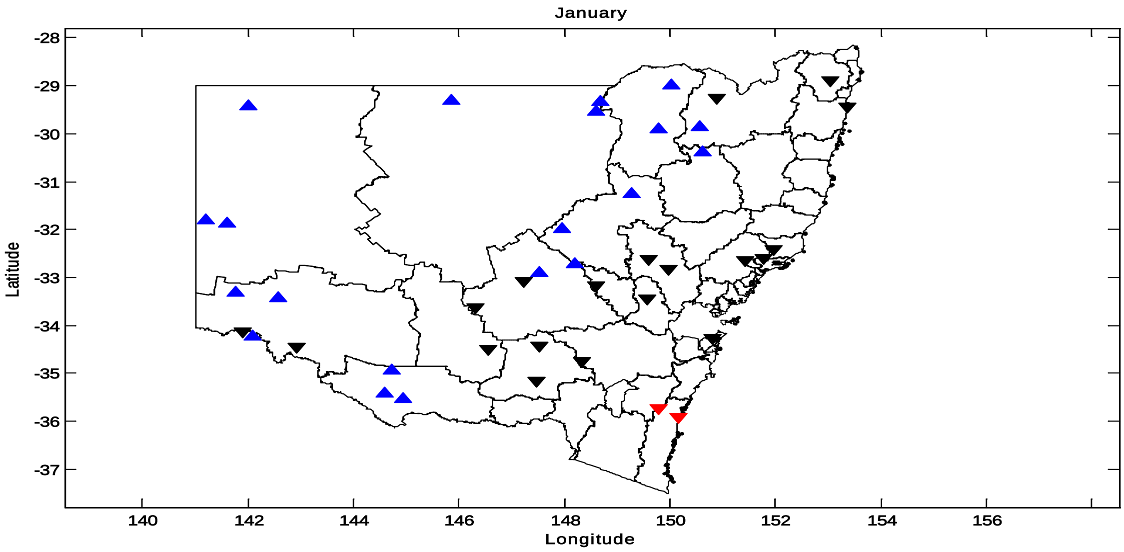

Fig. 5(a): Spatial Distribution of trends in monthly rainfall for January where (▲) represents significant increasing trend (▲) Non significant increasing trend (▼) significant decreasing trend (▼) non-significant decreasing trend.

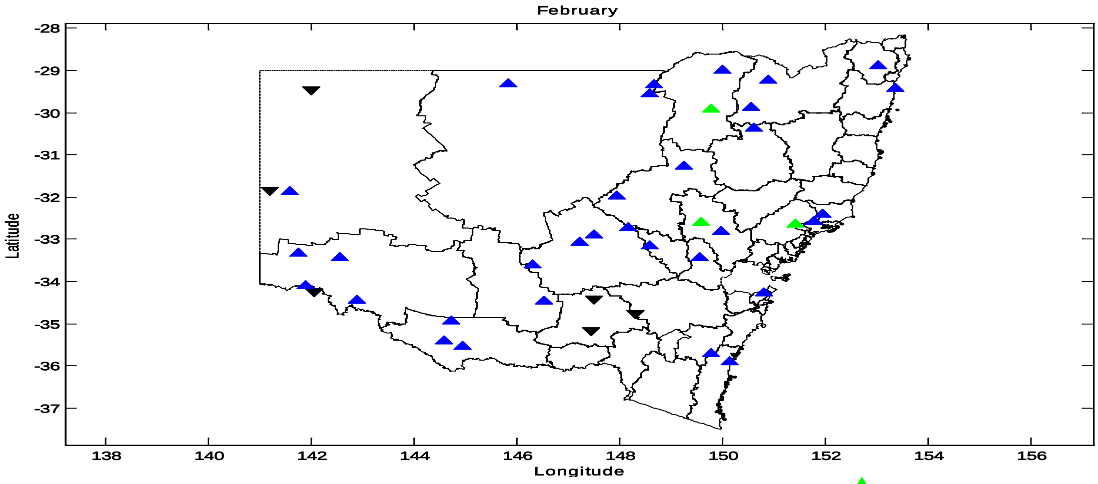

Fig. 5(b): Spatial Distribution of trends in monthly rainfall for February where (▲) represents significant increasing trend (▲) Non significant increasing trend (▼) significant decreasing trend (▼) non-significant decreasing trend.

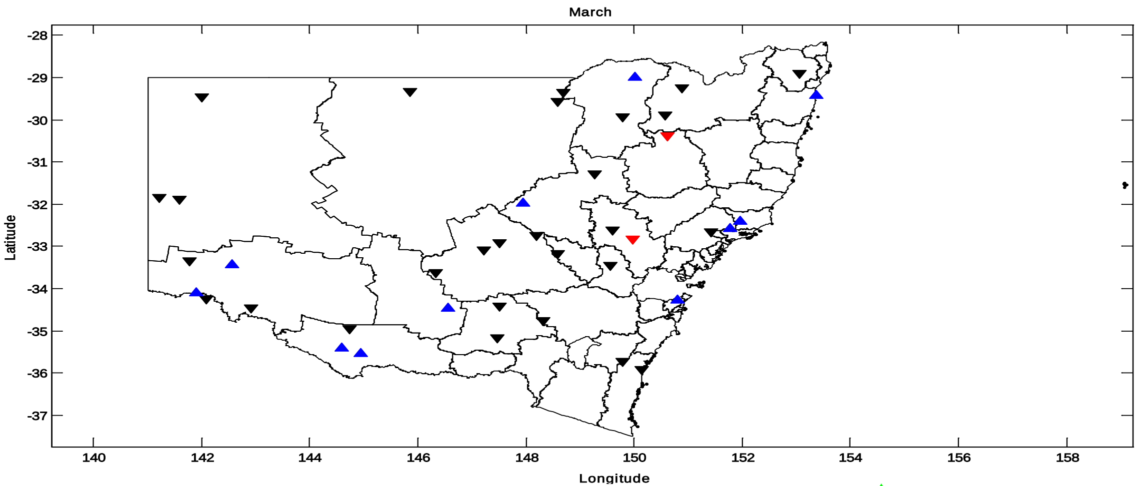

Fig. 5(c): Spatial Distribution of trends in monthly rainfall for March where (▲) represents significant increasing trend (▲) Non significant increasing trend (▼) significant decreasing trend (▼) non-significant decreasing trend.

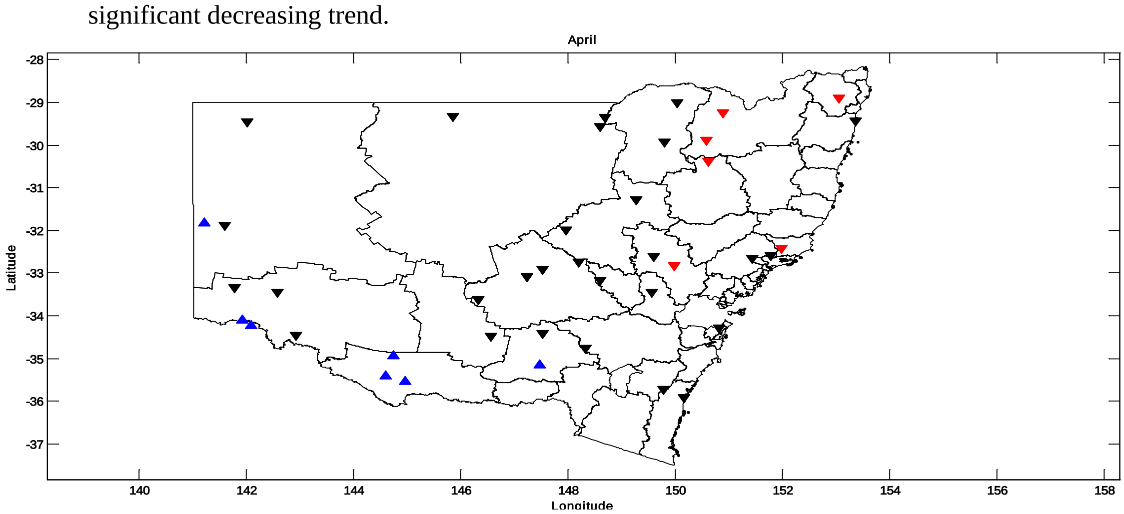

Fig. 5(d): Spatial Distribution of trends in monthly rainfall for April where (▲) represents significant increasing trend (▲) Non significant increasing trend (▼) significant decreasing trend (▼) non-significant decreasing trend.

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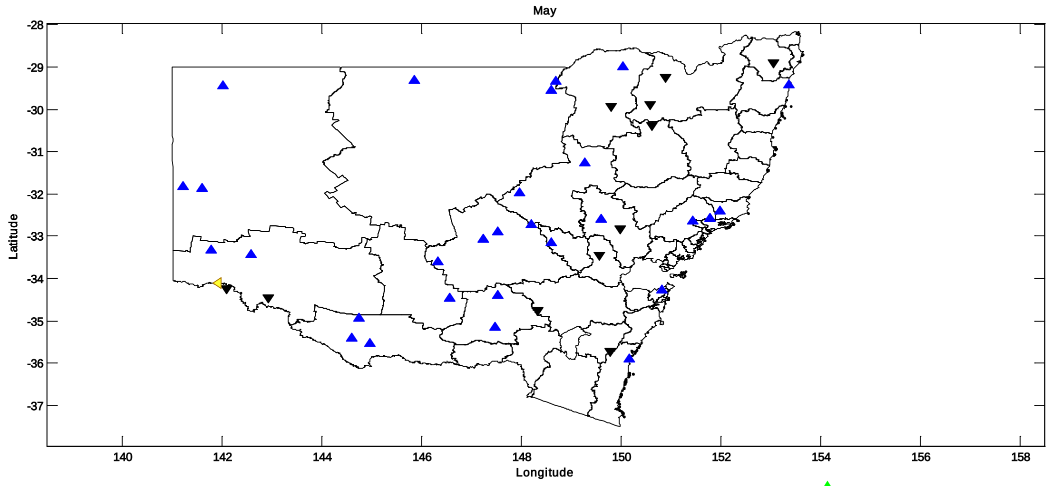

Fig. 5(e): Spatial Distribution of trends in monthly rainfall for May where (▲) represents significant increasing trend (▲) Non significant increasing trend (▼) significant decreasing trend (▼) non-significant decreasing trend.

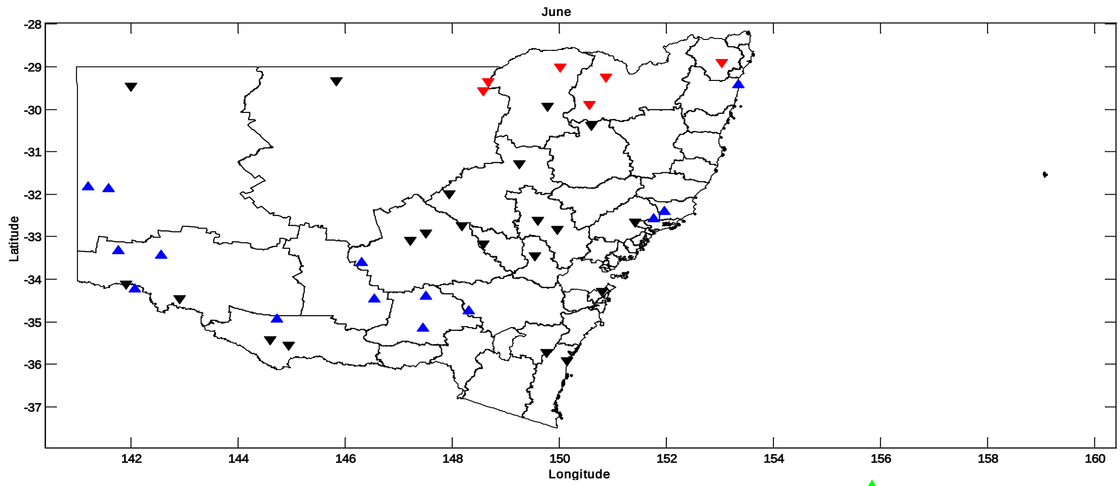

Fig. 5(f): Spatial Distribution of trends in monthly rainfall for June where (▲) represents significant increasing trend (▲) Non significant increasing trend (▼) significant decreasing trend (▼) non-significant decreasing trend.

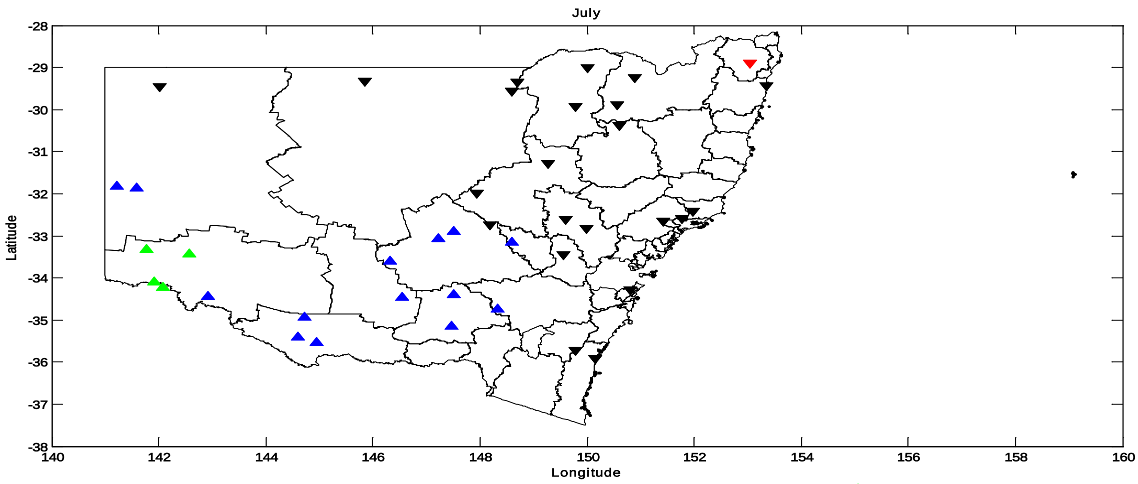

Fig. 5(g): Spatial Distribution of trends in monthly rainfall for July where (▲) represents significant increasing trend (▲) Non significant increasing trend (▼) significant decreasing trend (▼) non-significant decreasing trend.

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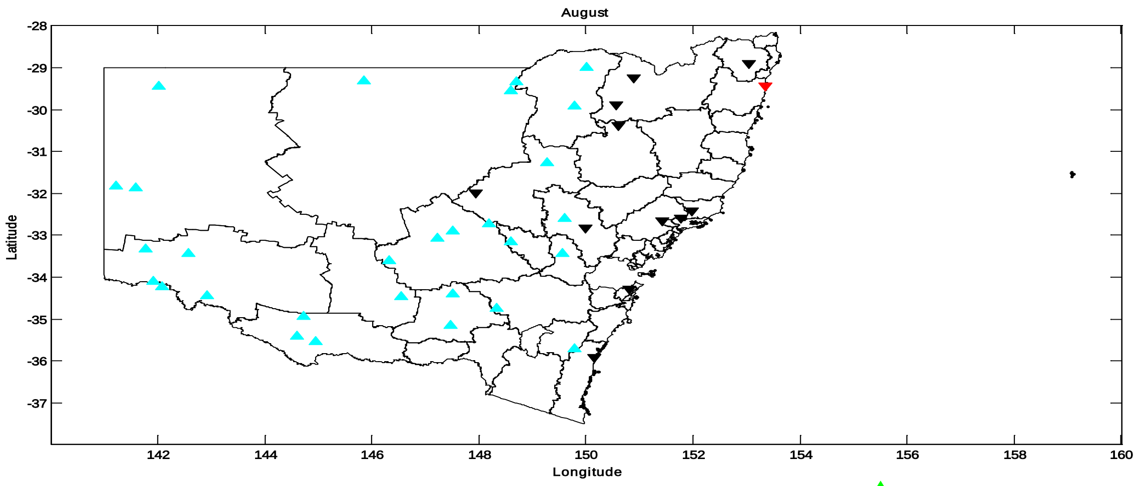

Fig. 5(h): Spatial Distribution of trends in monthly rainfall for August where (▲) represents significant increasing trend (▲) Non significant increasing trend (▼) significant decreasing trend (▼) non-significant decreasing trend.

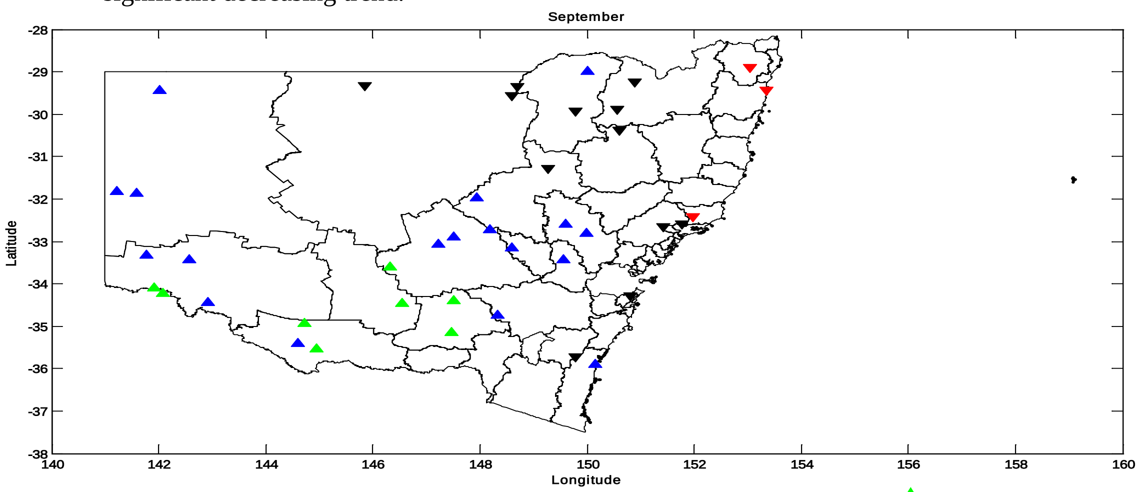

Fig. 5(i): Spatial Distribution of trends in monthly rainfall for September where (▲) represents significant increasing trend (▲) Non significant increasing trend (▼) significant decreasing trend (▼) non-significant decreasing trend.

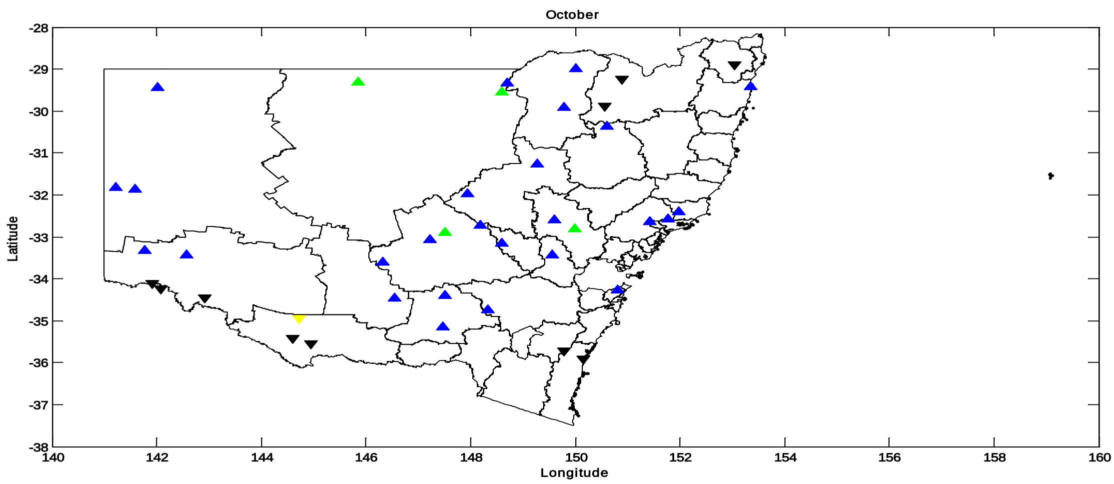

Fig. 5(j): Spatial Distribution of trends in monthly rainfall for October where (▲) represents a significant increasing trend (▲) Non significant increasing trend (▼) significant decreasing trend (▼) non-significant decreasing trend (▼) no trend.

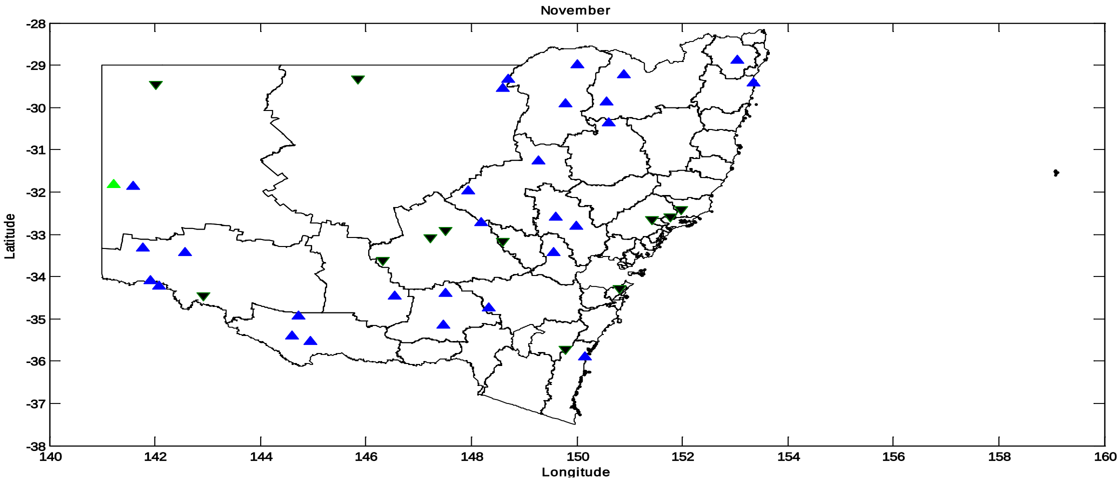

Fig. 5(k): Spatial Distribution of trends in monthly rainfall for November where (▲) represents significant increasing trend (▲) Non significant increasing trend (▼) significant decreasing trend (▼) non-significant decreasing trend.

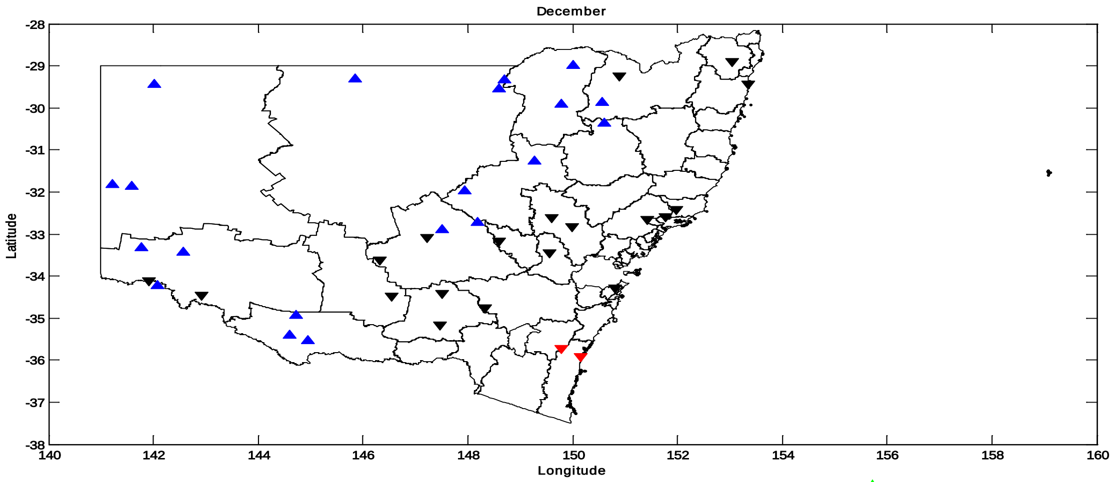

Fig. 5(l): Spatial Distribution of trends in monthly rainfall for December where (▲) represents significant increasing trend (▲) Non significant increasing trend (▼) significant decreasing trend (▼) non-significant decreasing trend.

Conclusion:

The trend detection technique was applied to monthly mean rainfall in New South Wales and to identify trends in rainfall all over New South Wales during the last 99 years (1912-2010) for 41 stations. The direction of trends is mostly increasing 58.53%% and the decreasing trend was 41.05% of the total stations. Systematic patterns were found in the trends of mean monthly rainfall of New South Wales. These trends might be resultant of climate variability. Land use or anthropogenic activities may have contributed to the trends. Therefore detail study is required to enlist all factors responsible for increasing trend of rainfall. In separate study we have planned to investigate the influence of El-Nino southern oscillation indices and South Pacific High Pressure system on this increasing trend of rainfall of most of the Stations.

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