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Time Series Analyses of Total Monthly Precipitation and Mean Monthly Temperature for Sustainable Drought Management in Mannar, Sri Lanka

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Abstract: Sri Lanka is a rapidly urbanizing country with 70% of its urban population and 80% of national economic infrastructure concentrated along the coastal cities of the country which are more susceptible for climate change impact and disaster risks. Drought is one of the worst natural disasters that affect Sri Lanka and create numerous problems by making adverse impacts to the economy of the country. Forecasting the drought period before the occurrence and implementation of appropriate drought management strategies may help to reduce the disaster risk and its related impacts mainly in coastal cities of Sri Lanka. Meteorological droughts eventually trigger other forms of droughts in Sri Lanka and it leads to water scarcity due to insufficient precipitation and high evaporation or combination of both. This study analyses the time series characteristics of total monthly precipitation and mean monthly temperature from year 1950 to 2013 for Mannar urban development area located in coastal zone of Sri Lanka to identify specific drought period in Mannar urban development area since it has been changing due to different climate change scenarios.

Brainstorming approach was applied to identify sustainable drought management strategies and to validate the above identified drought period as an outcome of time series analyses and location specific information on drought in ground situation by consulting community and other prospective stakeholders in the area. Weather data was analyzed applying decomposition method of time series analyses which include trend, cycle, seasonal and irregular components. Considering results of time series analyses, high temperature and severe drought situation can be identified in Mannar urban development area from March to September while observing highest rainfall during October to December every year. The total monthly precipitation in Mannar has been increasing by 0.0194 mm while mean monthly temperature is increasing by 0.0004°C. As drought management strategies, the excess water of three months rainy season could be better utilized by developing new irrigation tanks and existing abundant tanks in many parts of the Mannar urban development area. Rain water harvesting and introducing new crops suitable for changing climatic conditions will be encouraged for sustainable dry farming activities in Mannar urban development area. Vertical greenery on walls, greenery on roof tops and green paving are being planned and building design strategies that can be promoted to reduce the heat environment of Mannar urban development area in sustainable Mannar.

Keywords: Drought, Forecasting, Reducing the risk.

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Introduction

The climate and meteorological conditions have changed considerably by their intensity, term and duration with the changing pattern of the human lifestyles. In this, frequently observable meteorological conditions such as rain fall, temperature, wind and sunshine are changing day by day. With the changing weather patterns, intensity of natural hazards of floods, cyclones and droughts, etc. have been increased causing human settlements vulnerable for such cases. Hence, on that point, there is a tight relationship between climate change and the vulnerability of settlements to natural hazards which would increase the disaster risk. Studies on global climatic change have recognized the need of sustainable solutions for these problems. Sri Lanka is a rapidly urbanizing country with 50% of its projected 22 million population expected to be living in urban local authorities by 2020. Besides, around 70% of the urban population and 80% of national economic infrastructure are concentrated along the coastal cities and cities in the intermediate zone of the country which are more susceptible for predicted climate change impact and disaster risks. Drought is one of the worst natural calamities that affect Sri Lanka recurrently and create innumerable problems immediately or over the time as the economy experiences the adverse impacts.

The importance of forecasting of future drought situations and suitable drought managment strategies to be adopted to reduce disaster risk has been realized. Accordingly this study intends to identify specific drought period in Mannar urban development area through time series analysis on total monthly precipitation and mean monthly temperature since the climate conditions in Mannar urban development area have changed and thereby drought periods are changing time to time. Furthermore brainstorming approach applies to identify appropriate sustainable drought management strategies that can be implemented in future and to validate the above identified drought period and location specific information on drought in ground situation by consulting community and other prospective stakeholders in the area.

Literature Review

United Nation Framework Convention on Climate Change has identified that climatic variations and changes are becoming the cause for increasing natural disaster occurrences as well as other associated issues such as epidemics, environmental degradation etc. On the other hand, urbanization trends and their pressure on urban cities have also risen up many environmental issues due to pollution, eco system losses, deforestation, etc. making all cities highly vulnerable for natural hazards. Weather forecasting helps to understand the relationship of disaster occurrence with the changes of the weather patterns for a series of time period (Firozi et al., 2013). Further, community of those vulnerable cities for natural hazards may be resilient for disaster risk if the time period of the occurence of natural hazards in future can be forecasted as an early warning strategy.

Drought is one of the worst natural calamities that affect Sri Lanka when compared to other natural hazards. Drought leads to water scarcity due to insufficient precipitation and high evapo-transpiration. Meteorological drought will eventually trigger other forms of droughts (Mosaad et al., 2009). This is because rainfall as the main input into the hydrological cycle provides water for recharging surface runoff, which in turn serve as a source of water for irrigation and subsequently such water will be required for various socio-economic activities which will in turn create wealth. Drought event always leaves behind massive economic loss, degradation of environment, and food and fodder shortage in addition to starvation. The primary source of water in Sri Lanka is rainfall, which, varies spatially and temporally. The variability of rainfall is indeed greater in the dry zone than in the wet zone in Sri Lanka. The significance of high rainfall variability is possibly the high risk that cultivators have been facing in dry zone of Sri Lanka. Sri Lanka experienced serious drought in 1899, 1913, 1916, 1918, 1945, 1950, 1968, 1974, 1976, 1980, 1983, 1988, 2001, 2004 and 2007 (Disaster Event and Impact Profile of Sri Lanka, 2014). Generally once in 3-4 years a drought is possible in Sri Lanka. Therefore forecasting of future drought situations and implementation of sustainable drought management strategies is needed to mitigate the disastrous effects in future. Various methods are used to forecast weather such as Time series analysis (Box and Jenkins, 1976), Autoregressive (Hurrel, 1995) and Moving Average Model (Kaushik and Singh, 2008), Autoregressive-Moving-Average Modeling (Walker, 933), Seasonal ARIMA Model (Aziz et al., 2013), etc. Considering previous studies and the mathematical complexity of other models, Time series analysis was selected for this study to examine the characteristics of total monthly precipitation and mean monthly temperature for Mannar urban development area during last 63 years with a view of understanding specific drought period that has been changing time to time under different climatic variations.

Time series is a collection of quantitative observations that are evenly spaced in time and measured successively (Box and Jenkins, 1970). Time series analysis is generally used when there are 50 or more data points in a series. Time series are analyzed in order to understand the underlying structure and function that produce the observations. It is assumed that a time series data set has at least one systematic pattern. The most common patterns are trends and seasonality. Trends are generally linear or quadratic. To find trends, moving averages or regression analysis is often used. Seasonality is a trend that repeats itself systematically over the time. Understanding the mechanisms of a time series allows a mathematical model to be developed that explains the data in such a way that prediction or monitoring can occur. Examples include prediction/forecasting which is widely used in weather forecasting, economics and business etc. There are numerous software programs that will analyze time series, such as SPSS, JMP and SAS/ETS, and Excel can be used for a analysis if linear regression analysis is considered.

Methodology

Weather data on total monthly precipitation and mean monthly temperature from year 1950 to 2013 recorded at Mannar weather station was obtained from the Metrological Department of Sri Lanka. In Sri Lanka at past and even present situation most of districts have only one weather station that covers entire district area and Mannar urban development area which is to the extent of 216.94 sq.km also has only one weather station which is located in middle part of the area. According to Aziz (2013), weather station data provide accurate information on weather condition around the vicinity of the instrument. Therefore it is assumed that the data recorded from Mannar weather station are perfectly very similar to the weather conditions of Mannar urban development area since the entire area is geographically located in flat terrain as an island protected by Indian Ocean.

The general time series plot of weather data on total monthly precipitation and mean monthly temperature from year 1950 to 2013 recorded at Mannar weather station indicates a cyclical pattern due to the effect of seasonality component. At the same time data are distributing in an irregular way indicating an increasing trend. Weather data subjected to time series tests were analyzed applying decomposition method which include trend, cycle, seasonal and irregular components using Microsoft Excel 2010. First, Moving Average (MA_{12}) and Centered Moving Average (CMA_{12}) methods were applied sequentially to make the time series in to smooth curve reducing the impacts on seasonality and irregularity. This CMA series can be named as ‘base line’ which shows the amount of fluctuation to up and down from the base line. Decomposition Method [$Y_t = f(S_t, I_t, T_t)$] was used with multiplicative model to identify trend cycle and seasonal analysis. When applying decomposition method, the patterns of seasonal and irregular component (S_t, I_t) were identified by dividing the original observation by the CMA values. The average seasonal data (S_t) for each month were calculated later on. Then the seasonally adjusted data are computed by dividing the original observation by the seasonal component which can be known as ‘de-seasonal data’ ($Y_t/S_t = T_t \times I_t$). The trend line equation was derived applying simple linear regression analysis and trend values (T_t) were calculated considering original observation of weather data as dependent variable and time (t) as independent variable. Multiplicative Model ($Y_t = S_t \times I_t \times T_t$) was applied for forecasting weather data from year 2014 to 2018. Pearson correlation coefficient value was calculated in order to identify the reliability and the accuracy of the forecasted values comparing them with original observation of weather data from 1950 to 2013.

The identified drought period through time series analysis for Mannar urban development area was verified at real ground situation by consulting stakeholders who live in the area. Three stakeholder workshops were conducted at Mannar Urban Council with the participation of 20 local communities and 30 stakeholders including institutions, civil society, the private sector, development partners, council members and government officers who live in Mannar urban development area. Each of the five groups consisted of 10 participants who were provided information on prevailing drought period, drought prone areas, hazard history, frequencies and magnitudes of drought situations, most threatened communities, vulnerable elements and infrastructural needs based on the provided structured questionnaire under several brainstorming sessions. Each group of participants prepared drought hazard prone area map and finally all maps were digitized and overlapped applying Arc GIS 10.2 software by the researchers to identify drought affected area whether the level of impact is low, moderate, high and very high even the entire Mannar urban development area has been identified as “Very high” drought affected area under

Table1: Example of application of multiplicative model for forecasting rainfall

			Y_t			$Y_t/CMA(12)$		Y_t/S_t	SLR	St × Tt
t	*Year*	*Month*	*Total monthly rainfall mm*	*MA(12)*	*CMA(12)*	S_t,I_t	S_t	*De-seasonal data*	T_t	*Forecast*
1	**1950**	JAN	28				0.72	38.7	88.80	64.19
2		FEB	24.6	66.6	68.4	0.36	0.32	76.9	88.83	28.40
3		MAR	17	70.3	71.0	0.24	0.29	59.3	88.85	25.49
4		APR	11.2	71.7	73.4	0.15	0.64	17.5	88.88	56.72
5		MAY	18.9	75.1	79.4	0.24	0.38	49.4	88.90	34.00
6		JUN	0	83.7	83.3	0.00	0.19	0.0	88.93	17.11
7		JUL	9.1	82.8	82.8	0.11	0.25	37.1	88.96	21.80
8		AUG	21.8	82.8	83.1	0.26	0.37	58.2	88.98	33.35
9		SEP	87	83.3	82.8	1.05	0.53	164.1	89.01	47.20
10		OCT	278.7	82.3	81.8	3.41	2.37	117.8	89.04	210.64
11		NOV	162.5	81.3	77.8	2.09	3.49	46.6	89.06	310.49
12		DEC	140.7	74.3	83.6	1.68	2.36	59.7	89.09	209.90
13	**1951**	JAN	71.5	92.9	91.6	0.78	0.72	98.9	89.12	64.42

Source: Author constructed

the drought ranking index of Hazard profile of Sri Lanka 2014 (Figure 1). This level of impact was identified by the community according to their past experience on drought situations and affected level for each area.

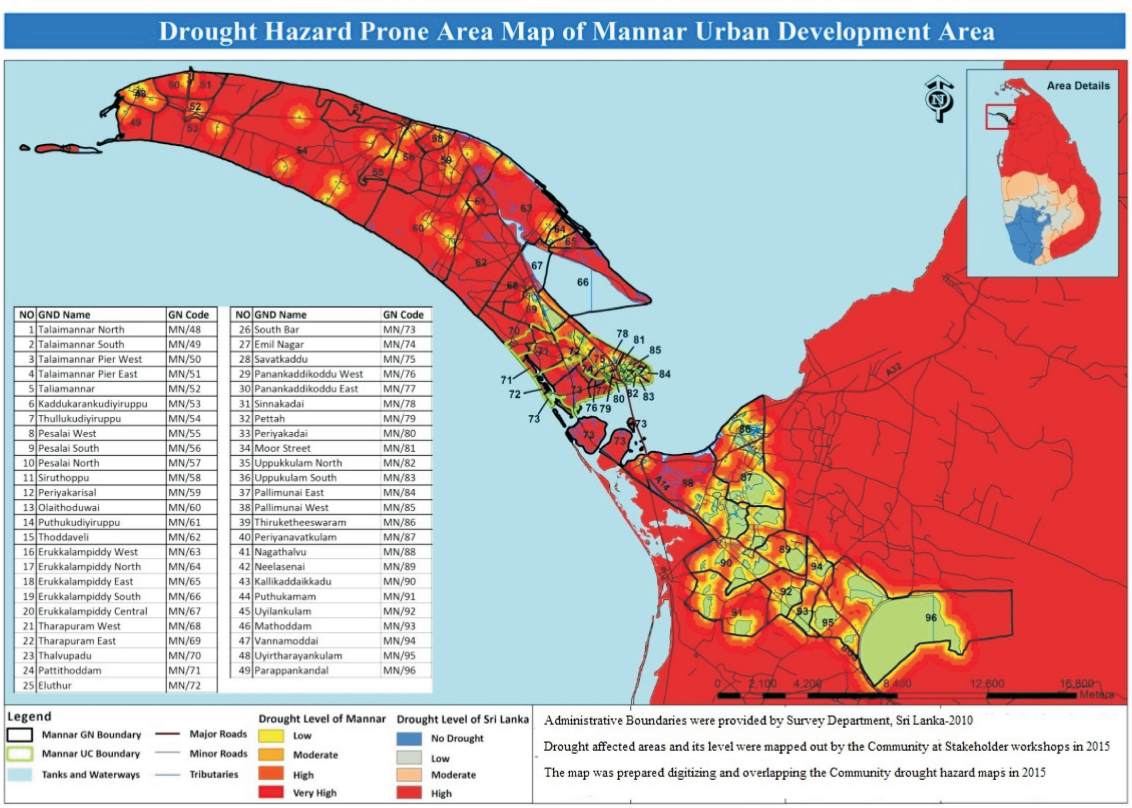

Figure 1: Drought hazard prone area map of Mannar urban development area.

This map and the information provided by community were validated through several field investigations by the researchers. Further, community was consulted for suitable solutions to overcome issues due to drought situation and possible drought management strategies according to their knowledge and the past experience on drought incidents by adopting the bottom up decision making process based on brainstorming sessions to ensure and maximize participation of the local folks.

Study Area

For this study, Mannar urban development area was selected because more than 15,000 people in the area were affected by drought annually (Disaster Inventory Hazard Profiles of Sri Lanka, 2014). The Urban Development Authority (UDA) has declared Mannar urban development area under section 3 of the Urban Development Authority Law No. 41 of 1978 through the government gazette 38/68 in 1979. Mannar urban development area includes the administrative boundaries of Mannar urban council and Mannar pradeshiya sabha. Total land area of this urban development area is 216.94 sq km consisting of 49 Grama Niladhari divisions as shown in Figure 1 with their GN codes.

Mannar has a dry climate throughout the year being located in the dry zone in Sri Lanka. Mannar area consists of rich ancient cascade system. But at present, most of the reservoirs and tanks are abandoned. The Giants tank is a significant element in the cascade network of Mannar. Apart from the inland part of the area, there are few tanks in the Thalai Mannar island area in small scale including the Kora Kulam and Nellun Kulam. In addition, there are 38 irrigation tanks located within Mannar DSD area. Those tanks feed 4765 acres of agricultural land being as water retention areas. Uppukulam, Amman Kovilkulam, Eluthurkulam and Tharavankottaikulam used to retain rainwater during the monsoon period and people reuse this water during dry season. Further, most of the rural areas obtain water from ground water sources using tube well and dug well. But salt water intrusion has contaminated the ground water. Most of the areas in Mannar are consisted of red-yellow-latosols soil. Regosols on recent beach and sand dunes are common features in the area. The inland part of the area is mostly contained with solidized solonets and solonchaks. 38% of the land in Mannar urban development area is used for paddy cultivation while 40% is used for other cultivations. Water bodies represent 10.5% of the total land while home gardens have covered 9.5% of the total land.

Results

Mannar receives high rainfall from the North-East Monsoon from October to December (total monthly rainfall: 200 mm-600 mm) and March to September it mostly experiences severe drought situation due to the lowest monthly precipitation (total monthly rainfall: 10 mm-60 mm). Total annual rainfall varies from 300 mm to 1500 mm during last 63 years. Average total annual rainfall during last 63 years is recorded as 904 mm. Total annual rainfall has varied from 300 mm to 700 mm in 13 years, from 700 mm to 1000 mm in 30 years and from 1000 mm to 1500 mm in 20 years from 1950 to 2013. The equation of $Y_t = 0.0194x + 78.211$ implies that the total monthly precipitation has been increasing by 0.0194 mm (Figure 2). Multiplicative model is more accurate since there is a strong correlation between actual and forecasted total monthly precipitation values indicating Pearson correlation coefficient value as $r = 0.727$. These forecasted values can be used to identify the rainfall pattern in coming years and same pattern is expected to be continued in the future. This rainfall pattern effects on changing the level of ground water. This situation can be considered as one of the major factors that affects occurring drought situation in Mannar area. Further, the higher rainfall pattern in some periods causes to create floods and storm surge, taking the advantage of low flat topography of the area.

Average annual temperature in Mannar area varies from 27.7 to 28.6 during last 63 years. Monthly mean temperature varies from 26.4 to 29.7 being high in March to September of most of years while the temperature is bit low during October to December which is the northeast monsoon period. The equation of $Y_t = 0.0004x + 27.731$ implies that mean monthly temperature is increasing by 0.0004°C (Figure 3). The accuracy of the multiplicative model indicates a very strong correlation between actual and forecasted values indicating Pearson correlation coefficient value as $r = 0.906$. It shows that the forecasted values of temperature pattern are having a similarity with the actual temperature pattern. These forecasted values can be used to identify the temperature pattern in coming years and same pattern is expected to be continued in the future. There is a negative moderate linear relationship between total monthly precipitation and monthly mean temperature indicating Pearson correlation coefficient value as $r = -0.469$. This implies that temperature has been decreased when there is high precipitation in Mannar area. Further seasonality and irregularity pattern of above time series analyses indicate that severe drought situation can be observed in Mannar once in 2-3 years.

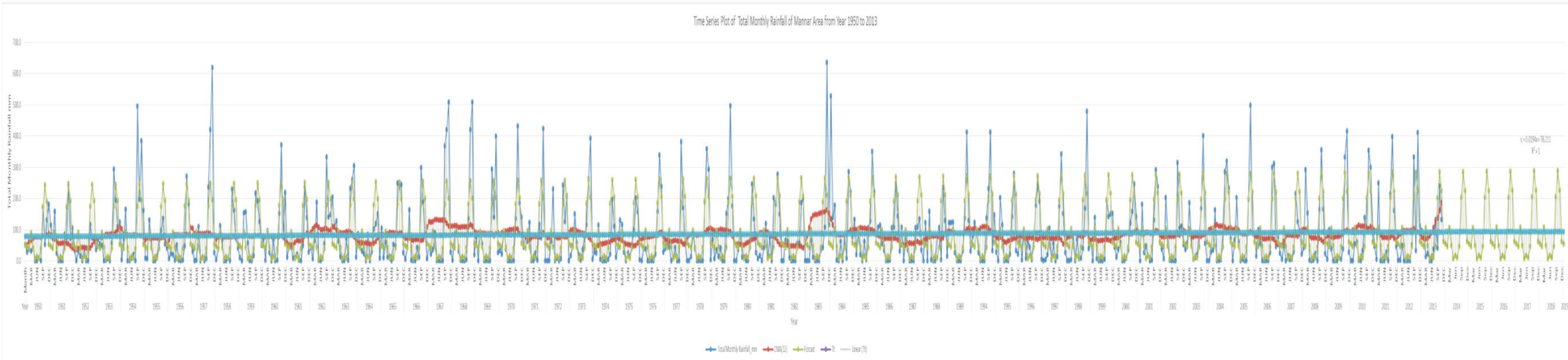

Figure 2: Time series analysis of total monthly precipitation pattern of Mannar urban area 1950-2013.

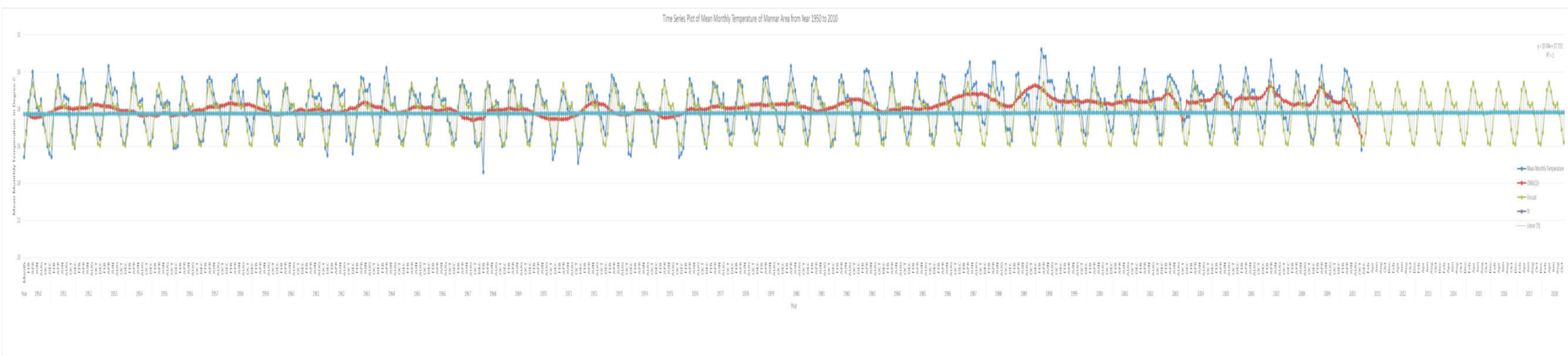

Figure 3: Time series analysis of mean monthly temperature pattern of Mannar urban area 1950-2013.

Discussion

The communities who live in Mannar urban development area and who suffered by the war during last 30 years in Sri Lanka and after the dawn of the peace in 2009 are gradually trying to come out from the war wounds and willing to live peaceful life. But this community is frustrating due to the sudden extreme disaster situations which have severely affected their day to day life in Mannar area. Disaster recovery activities are also not functioning well due to existing bureaucratic process. Drought is a severe natural hazard in Mannar area due to long dry period from March to September while observing higher rainfall during October to December in every year and making severe drought situations once in 2-3 years that is evidenced by the above time series analysis as the main outcome. At stakeholder workshops, the community shows that drought situation is rapidly increasing making a big water scarcity for paddy and other crops cultivation and other day to day water needs in the Mannar area and continually setting back the efforts of the poorest communities to develop their economies. Knowing about the causes and occurrence of severe drought situations once in 2-3 years and current severe damages for them to identify future drought situations and to reduce future disaster risk due to drought through sustainable drought management strategies is therefore becoming essential. This study mainly focused to identify suitable drought management strategies through participatory decision making process that leads to find appropriate strategies according to their past experiences on drought at real ground situation. Therefore most of the strategies mentioned in this paper may be general without any scientific background and not based on any feasibility studies. But this will be a starting point to identify those drought management strategies that can be improved later on with proper feasibility studies.

As a drought management strategy, building of rainwater harvesting systems to the community who live in Savatkaddu, Panankadikoddu, Eluthur, Emil Nagar, Periyakadai, Thalvupadu, Thoddaveli and Uppukulam Grama Niladhari divisions where safe drinking water is lacking due to droughts and salt water intrusion was proposed in order to introduce a well-developed mechanism to store and harvest water for the day to day activities of people. This is a technique used for collecting, storing and using rainwater for landscape irrigation and other uses which brings so much of environmental as well as economical beneficiaries. On the other hand, since these areas have more building density and thereby flash flood situations occur due to low run off rate of storm water during rainy season, these rainwater tanks will support to store rain water making the storm water flow smooth. As most of the people who live in Kadukarankudiyiruppu, Thullukududiyiruppu, Pesali and Periyakarisa are farmers and due to less access to pipe-born water facilities it raises a higher demand for domestic rain water harvesting system. The excess water of three months rainy season in Mannar could be better utilized by renovating the existing 38 irrigation tanks in Mannar urban development area. Uppukulam, Amman Kovilkulam, Eluthurkulam and Tharavankottaikulam tanks (Figure 4) should be designed to take into cognizance the high rate evaporation in the region. For example, they should be deep and should have smaller surface areas. For the purposes of potable water supply in the period of dry season, a bigger reservoir will be required to store excess water of the rainy season. This could be done by increasing the dam size of Giant Tank (Figure 4) in Mannar and by constructing more underground reservoirs in strategic area in Thullukududiyiruppu and ThalaiMannar of northern part of Mannar. These reservoirs will be for strategic use in the seven months of dry season.

Meanwhile, during the seven months of dry season, dry farming should be encouraged. Dry farming can be practiced in this area under slight or insufficient rainfall conditions without irrigation by planting drought-resistant crops or by employing moisture-enhancing techniques such as planting seeds deep in the ground or using and maintaining a fine surface tilts or mulch that delays evaporation. Successful dry farming is possible with as little as 230 mm of precipitation a year (Rockeleau et al., 1988). Since the Mannar receives total annual rainfall that varies from 300 mm to 1500 mm, dry farming is possible. The choice of crop is influenced by the timing of the predominant rainfall in relation to the seasons and type of soil. Crops such as chilli, onion, peanut, tobacco, orange, wheat, small grains, potatoes, sugar beets, vegetables, bulbous plants and cashew can be cultivated in red yellow latosol soil that is common in many parts of Mannar area. The area has Regosol soil with less organic materials, nitrogen and phosphorous contents; coconut and cashew can be cultivated. According to the community point of view, this would only be sustained in the face of appropriate government incentives on appropriate farm inputs, water pump subsidy programme and fair access to fertilizers, introducing new crops suitable for changing climatic conditions and storage and preservation facilities for rain water harvesting since they are running the cultivation under many barriers.

Apart from that Mannar being a city with tropical dry climate, it is important to promote sustainable planning and building design strategies to avoid the impact of high temperature. Drought Resistive Green Home Gardening Model is an action that was proposed by the communities who have technical knowledge about built environment to reduce drought risk attached to individual housing units by increasing its resistance to disasters. This is kind of policy that can be implemented with very less financial resources. Houses and home gardens are constructed by people without having notions to make them safe from heat and act as insulators for reducing energy needed to provide cooling and improving indoor comfort and lower heat stress associated with heat waves. This model may reduce air pollution and greenhouse gas emissions by lowering air conditioning demand; green roofs can decrease the production of associated air pollution and greenhouse gas emissions. Permeable paving which have hollows for infiltration can be introduced with high infiltration rate for home gardens, road pavements and local roads to increase the ground water level by recharging from storm water during rainy season. Finally drought forecast and early warning centre at local level by participation of irrigation department and farmer organization to establish early warning communication network were proposed.

Conclusions and Recommendation

With climatic changes and variations, intensity of natural hazards of floods, cyclones and droughts, etc. have been increased causing mainly urban areas highly vulnerable for such cases due to high population and buiding density. Sri Lanka being a small island in the Indian Ocean in the path of two monsoons is mostly affected by weather related hazards. Floods mostly due to monsoonal rain or effects of low pressure systems and droughts due to failure of monsoonal rain are the most common hazards experienced in Sri Lanka. Drought is one of the worst natural calamities that affect Sri Lanka when compared to other natural hazards. The variability of rainfall is indeed greater in the dry zone than in the wet zone in Sri Lanka. The importance of forecasting of future drought situations and suitable drought management strategies to be adopted to reduce disaster risk has been identified as a current need of built environment industry in Sri Lanka. Accordingly this study was carried out to identify specific drought period through time series analysis on total monthly precipitation and mean monthly temperature for Mannar urban development area as one of the major urban areas in Sri Lanka which is severely affected by meteorological droughts every year. Furthermore brainstorming approach was applied to identify appropriate drought management strategies that can be implemented in future and to validate the above identified drought period and location specific information on drought in ground situation by consulting stakeholders in the area. This study reveals that there is seven months of severe drought period in Mannar from March to September while observing three months of very short rainy period from October to December every year making flood situation in the area. Furthermore trend lines indicate that mean monthly temperature has been increasing by 0.0004°C while total monthly precipitation has been increasing by 0.0194 mm only for rainy periods. Seasonality and irregularity pattern of above time series analyses indicate that severe drought situation can be observed in Mannar once in 2-3 years.

In this background, the rainwater received during three months rainy season would be better utilized by

Figure 4: Drought hit tank and the Giant Tank during dry season. (*Source:* Field visit snapshots)

renovating existing 38 irrigation tanks and the abundant tanks in many parts of the Mannar urban development area. Meanwhile, during the seven months of dry season, dry farming should be encouraged since Mannar receives enough rainfall (300 mm-1500 mm) and has suitable soil types for prospective crops cultivations. This would only be sustained in the face of appropriate government incentives on appropriate farm inputs, water pump subsidy programme and fair access to fertilizers, introducing new crops suitable for changing climatic conditions and storage and preservation facilities for rain water harvesting. For the purposes of potable water supply in the period of dry season, Giant tank could be expanded to store enough water during the rainy season. Apart from that Mannar being a city with tropical dry climate, it is important to promote sustainable planning and building design strategies to avoid the impact of high temperature. Drought Resistive Green Home Gardening Model is an action that was proposed to reduce drought risk attached to individual housing units by increasing its resistance to disasters. Establishment of drought forecast and early warning centres at local level was proposed as a solution to understand the severity of future drought situation before the occurrence since it may help to reduce the risk and its related impacts. As the recommendation, this time series analysis can be used to identify the flood periods, its frequency and magnitude and the brainstorming approach that was applied here can be followed to identify disaster risk reduction and preparedness strategies for mitigating the impacts of floods as well.

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