Analysis of Precise Climate Pattern of Maldives. A Complex Island Structure

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Abstract:

Republic of Maldives is located on the south and south-western region of the coast of India. The country is one of the most geographically dispersed nations in the world, with 1192 coral islands grouped into 26 natural atolls in the middle of the Indian Ocean. A descriptive study of its climatic conditions is presented in this work. We have used geostatistical technique of kriging (described below) for the estimation of meteorological variables. Complexity related to the structure of the region, with diverse distribution of islands of varying sizes, is discussed in connection to the analysis. Climatic characteristics explored in the current work indicate the need for subsequent studies of seasonal patterns in climate change, especially temperatures and precipitation across the country, and also to identify the effect of extreme climatic conditions and natural disasters such as Tsunamis. The results do not show periodicity over the study period. It emphasizes that climatic patterns appearing in the study area must be analyzed more extensively over time, with the inclusion of a greater number of meteorological stations for precise spatio-temporal analysis.

Keywords: Climate pattern, Geostatistics, Kriging, Maldives Islands

I. Introduction

Republic of Maldives is one of the most geographically dispersed nations in the world, with 1192 coral islands grouped into 26 natural atolls in the middle of the Indian Ocean, as shown in Figure 1. Atolls vary in size and number of islands. This variation is related to geographical grouping. Some atolls are huge, like Huvadhu atoll with 255 islands, while the atoll of Gnaviyani is based on only one island. Figure 1 depicts the geographical location, the naturally occurring atolls and the complex island structure forming the atolls of Maldives. The islands are low lying and almost 80% of them are less than 3 feet above the sea level. The archipelago is more than 800 kilometers long and 130 kilometers wide (Ministry of Environment and Energy, 2017). Maldives stretches from north to south and the Equator crosses between Fuvahmulah and Gaafu Dhaalu Atoll in the southern parts of the nation. Ever since its beginning, the tourism industry has represented a growing portion of the GDP share of the country. The main image sold in tourism marketing has been the sunny side of life, representing the climate, beautiful sandy beaches, and the crystal-clear water around these small islands.

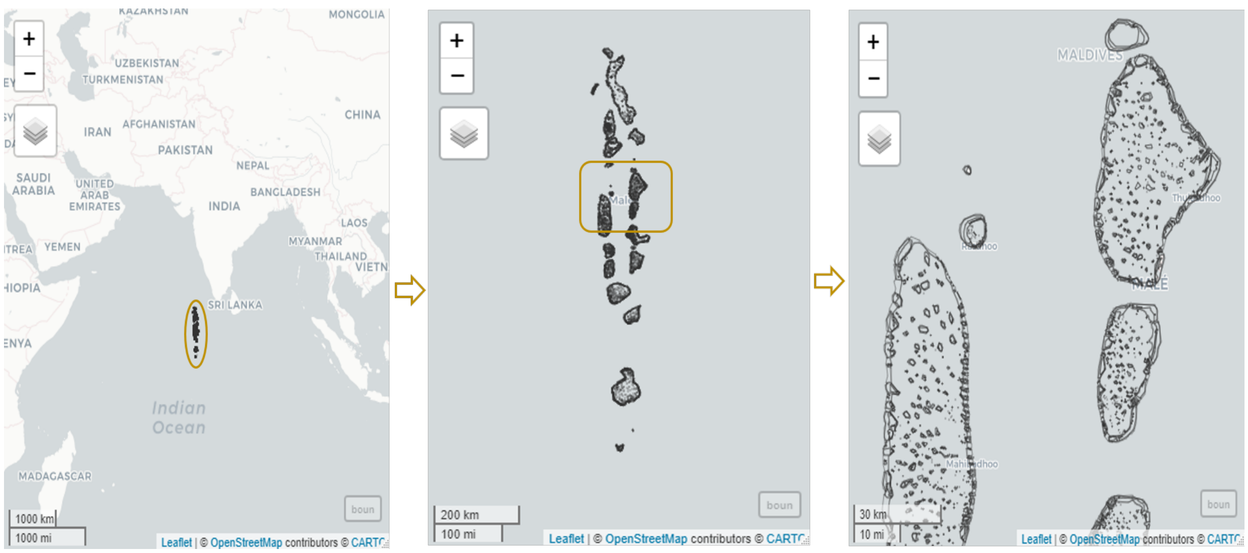

Figure 1: Study area: Maldives geographical location and complex island structure of the atolls

The coral reefs of Maldives represent the most diverse reefs in the Indian Ocean (Naseer, 2007). Due to the nature and structure of the coral reefs, conventional definitions of coastal area applied to continental land do not apply to this island nation. A more appropriate notion of coastal land for Maldives can be seen in Figure 2 which represents Addu atoll, the southernmost atoll of the country. The figure on the left depicts the atoll which includes enclosed lagoon or basin, forereef, subtidal reef, pass reef flat and land on reefs. It appears that the whole area enclosed by the reef and lagoon is land surface. But the figure on the right shows only land on reefs areas of the same atoll. In fact, only five percent of the total reef area of the Maldives is land. Most of the reefs are landless with vast expanses of shallow reef flats and are extremely small islands (size ranges from 0.1 to 5 square kilometers) (Naseer, 2007). As a result of this, only two hundred of the 1192 islands are inhabited.

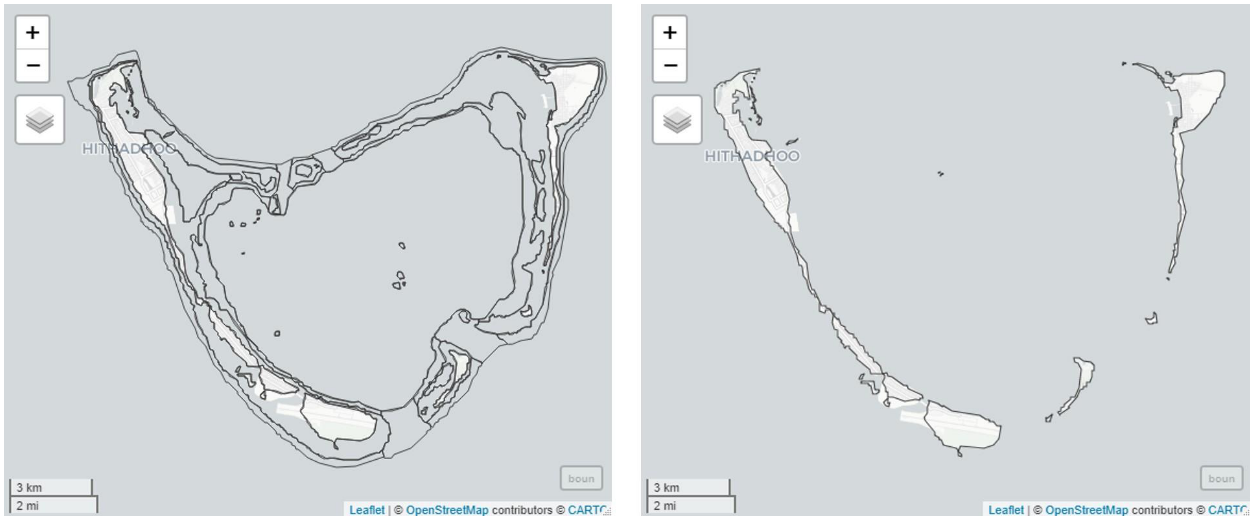

Figure 2: Addu atoll with both lagoon and reef areas and with only land on reefs areas

More than 40 percent of the country's population resides in Male`, the capital city of Maldives. Most of the other inhabited islands are sparsely populated. About 120 islands are assigned exclusively for tourism development as resort sites. The remaining uninhabited islands are used for agriculture and other commercial developments (Shifaza, 2018).

According to the Köppen system, India is characterized by 3 types of climates depending on their location: (1) arid deserts in the west, (2) alpine tundra and glaciers in the north, and (3) humid tropical regions in the tropical forests of the southwest as well as on the islands (Beck et al., 2018). Thus, the climate in the Maldives is characterized as tropical climate. The temperature is moderately high all year round, but influenced by the monsoon winds. Seasonal changes in the direction of the monsoon winds control the weather conditions of the islands. With a stretch of 800 kilometers from north to south and the equator crossing the country, the weather conditions vary considerably in different parts of the archipelago (Climate of Maldives, 2020). In particular, the south-west monsoon (from late April to September), which includes wind, higher humidity, and more frequent cloud cover, is more intense on the northern islands than elsewhere. The north-east monsoon (October to December), located mainly on the southern atolls, is calmer and simply brings rain and thunderstorms in the afternoon or evening. Finally, the driest period, outside the monsoons, runs from January to April and is most felt in the northern atolls (Weather-atlas, 2020). Maldives, being located near the Equator, offers warm and stable temperature throughout the year and protection from cyclones. But there are specific particularities depending on the location of each atoll. In addition, the weather condition is generally humid with a high relative humidity of around 80 percent. Finally, as is common in tropical areas, the rains are torrential and often devastating, being short but intense (Climate of Maldives, 2020). Maldives has been occasionally been hit by tropical cyclones, but the cyclones are not considered to be in any geological system at risk. Even the morphology of the coral reefs helps to prevent cyclonic catastrophe (Naylor, 2015). Due to this morphology of the sea-beds, the gigantic waves of tsunamis, as happened on the December 26, 2004, did not cause disastrous consequences, but only led to notable flood phenomena. In addition, the external eastern coral reef acts as a natural barrier absorbing the impact of the anomalous waves and protects the internal islands (Naylor, 2015).

There are some important objectives that we have discussed in the current study. Firstly, the limited number of descriptive studies on identifying the spatial and seasonal patterns of the climate in this region demands more extensive spatio-temporal research work. Since Maldives is a popular tourist destination, the seasonal patterns of weather conditions can cause recurrent fluctuations in tourism demand. A second objective is to identify the correlations among the meteorological parameters like precipitation, temperature, atmospheric pressure, and relative humidity (RH). This can help us to better understand how typical local atmospheric phenomena or extreme climatic conditions develop and influence the seasonal pattern of the climate. A third objective is to analyze individual meteorological parameters to interpret the climatic patterns or seasonality in the region, and at the same time to identify the impact on the seasonality because of extreme climatic conditions and natural hazards like Tsunami. A final objective is to illustrate the complex island structure of the archipelago and the computational issues involved in geostatistical studies. This paper presents a geostatistical study on an island region that differs from other studies as the land structure and distribution of the islands are unique. There are a few existing useful works on the analysis and description of elements on islands (Bland, Konar, Edwards, 2019; Brushett et al., 2014; Kabir, et al., 2020; Riyas et al., 2020; Staniec & Vlahos, 2017). However, in the current study, it is important to highlight the complex archipelago structure of the Maldives since it hinders the usual methodological and technical development. Because of the advantages of kriging over traditional interpolation techniques, the current study can help future researchers to identify other study areas having similar or more complex land structures where similar methodology can be applied.

The rest of the paper is organized as follows. In Section II we present the locations of the five Meteorological (MET) Stations of Maldives and the meteorological parameters used in the current study. We briefly highlight some details of the exploratory data analysis and kriging method used to develop geostatistics in Section III. Section IV reports the results with graphical representations. Section V contains a discussion about the exploratory analysis and kriging as well as the comparison with other similar results in the literature. The paper ends with the principal conclusions on the absence of common seasonal periodicity in the study area during the study period in Section VI.

II. Data settings

The original data is collected from the Maldives Meteorological Service (MMS), Republic of Maldives ("Maldives Meteorological Service," 2020). MMS is responsible for the seismological and meteorological services in the country. The dataset provides monthly weather reports from five MET stations under MMS namely, Gan, Hanimaadhoo, Hulhule, Kaadedhdhoo and Kadhdhoo. The offices are located in different atolls covering the full stretch of Maldives from north to south as depicted in Figure 3.

Figure 3: Locations of five meteorological offices under MMS

(*Source: Locations of five Climate Observatories (MET stations) collected from Maldives Meteorological Service,* "Maldives Meteorological Service," 2020*)*

The current dataset from five individual MET stations includes monthly average records of four meteorological parameters: precipitation, temperature, atmospheric pressure (atm. pressure) and RH. The time frame of the present study is from January 2000 to December 2015. The sampled dataset is divided into four independent sets for each meteorological parameter having 960 observations in each case.

Table 1 reports the minimum, maximum and average value of each of the meteorological parameters from individual MET stations. It allows the identification of differences between the five stations as well as comparing the range of values for each parameter. For instance, the maximum value of precipitation was recorded in the month of November in Kaadedhdhoo office (624.9 mm) while Hanimaadhoo had the lowest precipitation value during the study period. Temperatures range from 25.1 to 30.3 degree Celsius in all the offices. In this case, Kaadedhdhoo is the one with the lowest values. The other two variables show little differences among the MET stations. Therefore, the data presented in Table 1 shows that there are considerable variations between the northern, central, and southern regions. For this reason, more methodological studies are needed in the area.

MET Station	Precipitation (mm)			Atm. Pressure (hPa)			Temperature (deg. Cel)			RH (percentage)		
	Min	**Mean**	**Max**	**Min**	**Mean**	**Max**	**Min**	**Mean**	**Max**	**Min**	**Mean**	**Max**
Gan	0.6	187.3	530.7	1008	1011	1014	27	28.17	29.3	75	80.72	86
Hanimaadhoo	0	142.09	511.7	1008	1010	1013	26.9	28.46	30	73	79.73	86
Hulhule	0	166.06	568.9	1008	1010	1013	27.4	28.71	30.2	71	79.05	85
Kaadedhdhoo	0	181.28	624.9	978.4	1010.6	1004.2	25.1	28.46	29.9	72	79.7	86
Kadhdhoo	0.1	174.67	542.5	1009	1011	1013	27.3	28.61	30.3	72	79.11	84
Summary	0	170.3	624.9	978.4	1010.7	1014.2	25.1	28.48	30.3	71	79.66	86

Table 1. Principal descriptive values about the four meteorological parameters for each MET station

(*Source: Collected from Maldives Meteorological Service,* "Maldives Meteorological Service," 2020)

III. Methods

The methodology used in the current study is, first, an exploratory data analysis to inspect the datasets and summarizes the characteristics and distribution of the data, supported by graphical plots. Subsequently, we have implemented geostatistical techniques of kriging. The type of dataset used in the current study is clearly geostatistical data. Geostatistics is the science that studies phenomena that fluctuate in space and/or time and offers a collection of statistical tools for the description and modelling spatial (and temporal) variability (Boer, De Beurs, & Hartkamp, 2001); (Bostan, Heuvelink, & Akyurek, 2012); (Juan Verdoy & Mateu, 2009). Geostatistical methods have a wide range of applications, for example, in soil science, meteorology, and ecology (Jordan, et al. 2004); (Serra, Juan and Varga, 2017). The objectives of a typical geostatistical analysis are estimation and prediction. Estimation refers to inference about the parameters of a stochastic model for the data, and prediction refers to inference about the realization of the unobserved signal. It was the South African mining engineer (Krige, 2015) who pioneered work in the field geostatistics and presented the basic equations for optimal linear interpolation of spatially correlated variables. The name Krige was immortalized by Matheron, (1962) in a series of books and papers that used the French term Kriging. An important tool in geostatistics is kriging, which refers to a least square linear predictor that, under certain stationarity assumptions, requires at least the knowledge of covariance parameters and the functional form for the mean of the underlying random function. The modern development of spatial methods came from Besag, (1974). For the description of the climate data of the Maldives, the geostatistical technique of kriging has been used, employing variograms. The basic paradigm of predictive Geostatistics is both the characterization of the unknown value z as a continuous random variable Z, and the associated uncertainty defined by the corresponding probability distribution. In the context of Geostatistics, the random variable Z shows a significant dependence on the spatial location, denoted by $Z(u)$, where u is the spatial location. The cumulative distribution function (cdf) of this continuous random variable depends on the spatial location $Z(u)$ and is defined by:

$$F(u;z) = P\{Z(u) \leq z\} \qquad (1)$$

being P the associated likelihood function. In this case, we can work with the conditional cumulative distribution function (ccdf) given by:

$$F(u;z \mid n) = P\{Z(u) \leq z \mid n\} \qquad (2)$$

In Geostatistics, it is important to model the correlation or dependence between a certain variable $Z(u_i)$, $i=1,...,n$, and other potential covariates in other sampling points $Y(v_j)$, $j=1,...,n$. A random function defines a set of random variables defined on the field of interest (Cressie, 1993). In most applications, only one sample is possible in each spatial location u, so you need to use the condition of repeatability, which is guaranteed under the assumption of stationarity. A random variable $Z(u)$, $u \in A$ is stationary in the region A, if the multivariate cdf is invariant under any translation C made about locations, this is:

$$F(u_1,...,u_k; Z_1,...,Z_k) = F(u_1 + C,...,u_k+C;Z_1,...,Z_k) \qquad (3)$$

for any translation vector C.

Next, we focus briefly on semivariogram and kriging. The basic object we consider is a stochastic process $\{Z(u),\ u \in D\}$ in which D is a subset of R^d (Euclidean space d-dimensional), although normally $d=2$. Assuming that the average value in a location u expressed as μ(u) is a constant, which we assume as zero without loss of generality, we can define:

$$2\gamma(u_1\text{-}u_2) = \text{var}\{Z(u_1) - Z(u_2)\} \qquad (4)$$

The function $2\gamma(.)$ is called variogram and $\gamma(.)$, semivariogram. The semivariogram represents a rate of change showing a variable (attribute) with distance. Its shape pattern describes spatial variation in terms of size and general shape. The maximum value that a semivariogram reaches is called sill, or prior variance, and indicates the low-level data which defines a stationary second-order process. The lag or distance, for which the sill is reached, is called range and defines the limit of the spatial dependence. Finally, a semivariogram with a separate variance term defined is called nugget, and it defines the intrinsic variability in the data that has not been captured by the range of distances analyzed or any purely random variation (Juan Verdoy & Mateu, 2009). After testing a variety of models, for our data, the best one was the Spherical Model for our data, defined by a current range a, a prior variance (sill) c_1 and a nugget effect c_0,

$$\gamma(|h|) = \begin{cases} c_0 + c_1 \cdot 1.5\frac{|h|}{a} - 0.5(\frac{|h|}{a})^3] & si\,|h| \leq a, \\ c_0 + c_1 & si\,|h| \geq a \end{cases} \tag{5}$$

Thereafter, we will focus on the main element in Geostatistics using spatial covariance models to predict and interpolate spatial processes, the Kriging. An important problem is the following: given a set of observations of a spatial attribute $Z(u_1), Z(u_2),...,Z(u_n)$, the goal is to predict the value $Z(u_0)$ for some $u_0 \notin \{u_0,...,u_n\}$. All Kriging estimates are variants of the basic linear regression estimates which predict the value of Z in the location attribute u_0, denoted by $Z^*(u_0)$, and is defined by:

$$Z^*(u_0) - m(u_0) = \sum_{\alpha=1}^{n(u_0)} \lambda_\alpha(u_0)\left[Z(u_\alpha) - m(u_\alpha)\right] \tag{6}$$

Where $\lambda_\alpha$defines the weighting assigned to the data involved in the summation weight, and $m(u_0)$ and $m(u_\alpha)$ are the corresponding expected values of $Z(u_0)$ and $Z(u_\alpha)$ respectively. Note that only those neighboring locations u_α are required to operate the localization prediction u_0.

The error variance σ_E^2 (u) in its general form is given by:

$$\sigma_E^2(\mathrm{u}) = \mathrm{Var}[\mathrm{Z}^*(\mathrm{u}) - \mathrm{Z}(\mathrm{u})] \tag{7}$$

where the superscript * indicates the estimated value for that location. Furthermore, in this expression the variance is minimized under the constraint of unbiasedness, $[Z^*(u) - Z(u)] = 0$.

According to the model considered for the trend, we can consider two variants of Kriging: simple kriging (SK) with known and constant trend over the entire area of study and ordinary kriging (OK) that considers the possible local fluctuations of the trend or average (Cressie, 1993). When we introduce more covariates, the cokriging regression methods take part in which multiple attributes are involved. Suppose then that we have two variables Z and Y defined in the same locations. The equation for estimating the value of the main variable in the location u_0 is given as:

$$Z^*_{COK}(u_0) = \sum_{\alpha_1=1}^{n_1} \lambda_{\alpha_1}(u_0) Z(u_{\alpha_1}) + \sum_{\alpha_2=1}^{n_2} \lambda^*_{\alpha_2}(u_0) Y(u^*_{\alpha_2}) \tag{8}$$

It requires a model for the covariance matrix of features, including covariance of *Z*, $C_z(h)$, covariance of *Y*, $C_Y(h)$, cross-covariance of *Z*-*Y*, $C_{ZY}(h)=Cov\{Z(u),Y(u+h)\}$, and cross-covariance of *Y*-*Z*, $C_{YZ}(h)$.

The final step is the cross-validation. General statistical modelling requires a posteriori validation of the results and re-estimation based on the known values under the same conditions the constructed models were subject to. These include variogram models, the type of kriging and the choice of the general modelling strategy. The cross-validation technique (CV) is used to compare estimated models with actual values. The idea consists in an iterative process where, each time real data is deleted, it is estimated with the remaining data.
In the current study, the R programming language (version R 3.6.1) ("R Core Team", 2020) has been used for the exploratory and graphical analysis and, for computing kriging plots, ArcGIS Pro (version 2.4.1) ("ArcGIS Pro Resources", 2020) geographic information system application. RStudio (version RStudio 1.2.1335) integrated development environment has been used to implement R ("RStudio", 2020).

IV. Results

In this section we first report the results of exploratory analysis. Annual and monthly data are displayed for the four meteorological parameters, and then for each MET station. In addition, the kriging maps include different time points that will be of interest to better understand the behavior of the meteorological parameters considered. The kriging results are divided into two categories: (1) three years in which Tsunami took place (from 2003 to 2005), and (2) another three observation years (2000, 2009 and 2015) covering the entire study period.

Annual and monthly plot of meteorological elements

- *Average Annual Records (for all MET stations)*

Individual plots depict the average annual records for four meteorological parameters combinedly for all MET stations. Thus, the value is comparable to the average annual climate records for the entire country of Maldives.

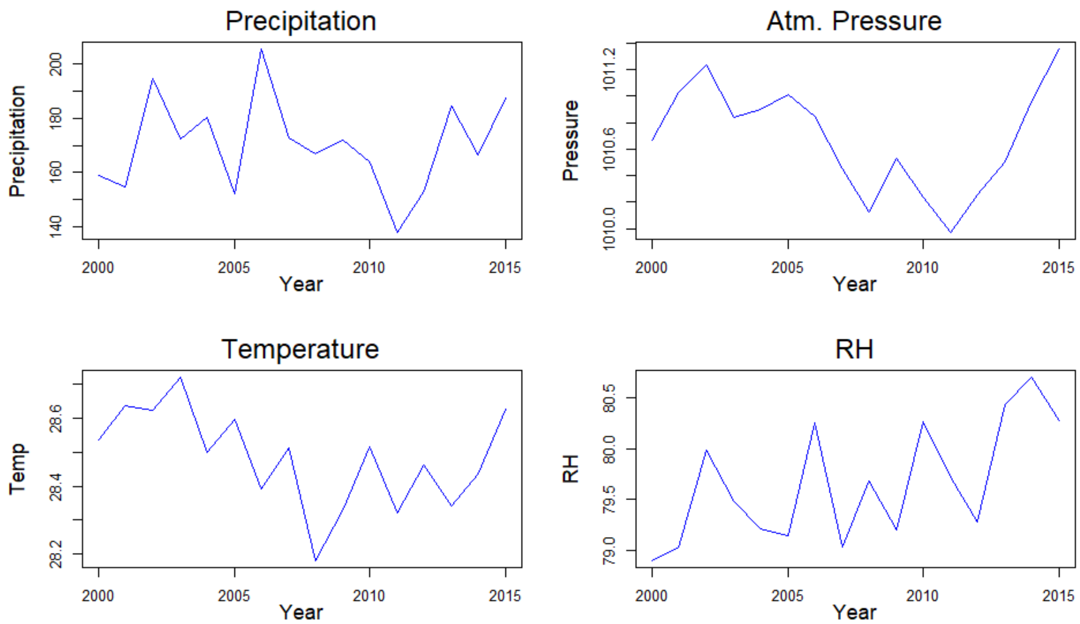

Figure 4: Average annual meteorological records (for all MET stations)

- *Average Monthly Records (for all MET stations)*

Individual plot depicts the average monthly records for four meteorological parameters combinedly for all MET stations. Thus, the value is comparable to the average monthly climate records for the entire country of Maldives.

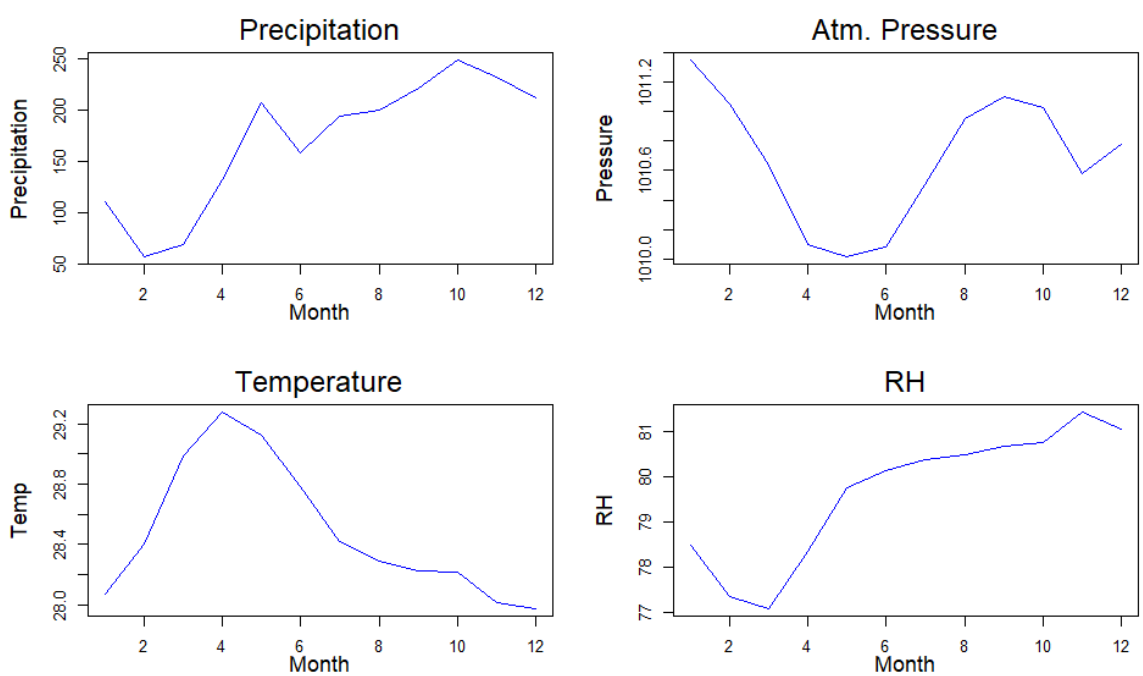

Figure 5: Average monthly meteorological records (for all MET stations)

While analyzing the average annual climate data some variability is observed throughout the analyzed time window although the general trend is quite stable (Figure 4). Furthermore, the variability seems to be important, although if we look at the scale of the y axis, we see that the differences over time are minimal. On the other hand, when we analyze the monthly behavior, the data shows practically no seasonality pattern (Figure 5). This is because the equator crosses the study area, so the climate is quite stable throughout the year. However, it is possible to observe some unique trends in the meteorological parameters. For example, in case of precipitation, like the case of RH, it is observed that it increases as the year progresses, with December being the month with the highest amount of rainfall. The temperature, on the other hand, shows a peak in the month of April and then it decreases again until the end of the year. Finally, with respect to atmospheric pressure, the behavior is more variable throughout the year, decreasing to minimum values between April and June, increasing again to another peak in September and decreasing slightly in the last months of the monsoon.

- *Annual Records (for individual MET station)*

Individual plot depicts the annual records for four meteorological parameters records separately for each MET station.

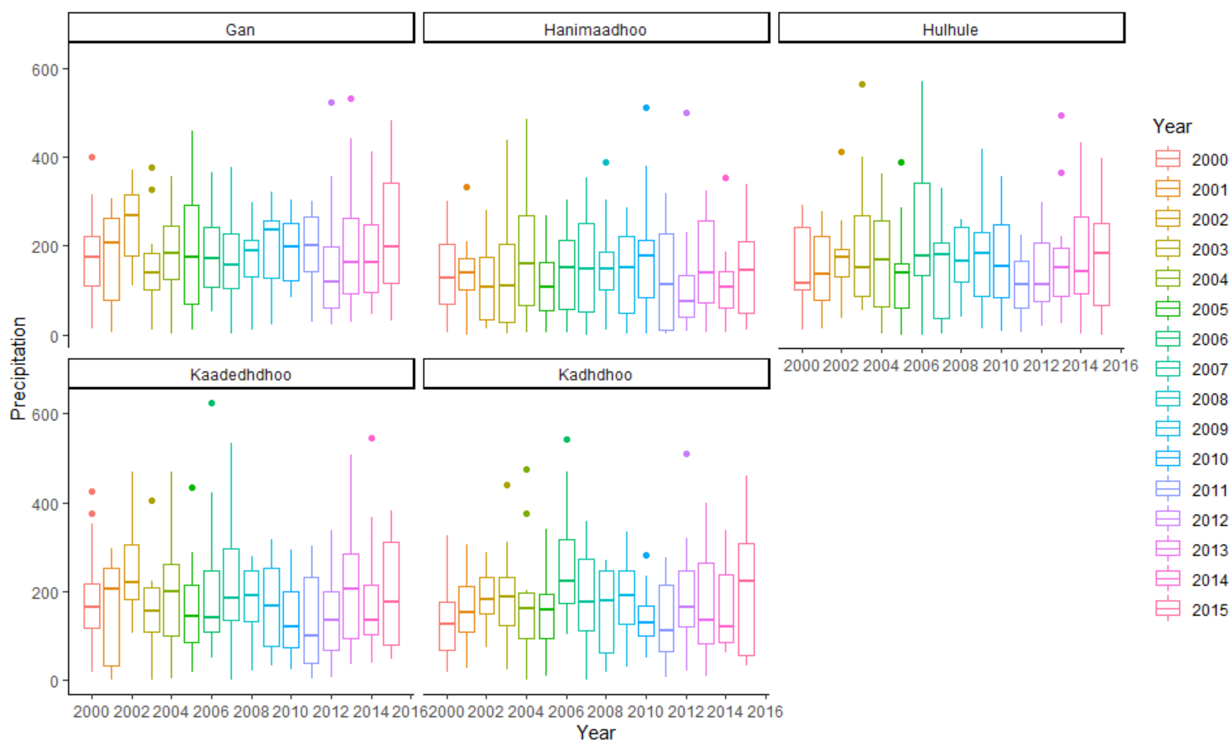

Figure 6: Annual precipitation records (for individual MET stations)

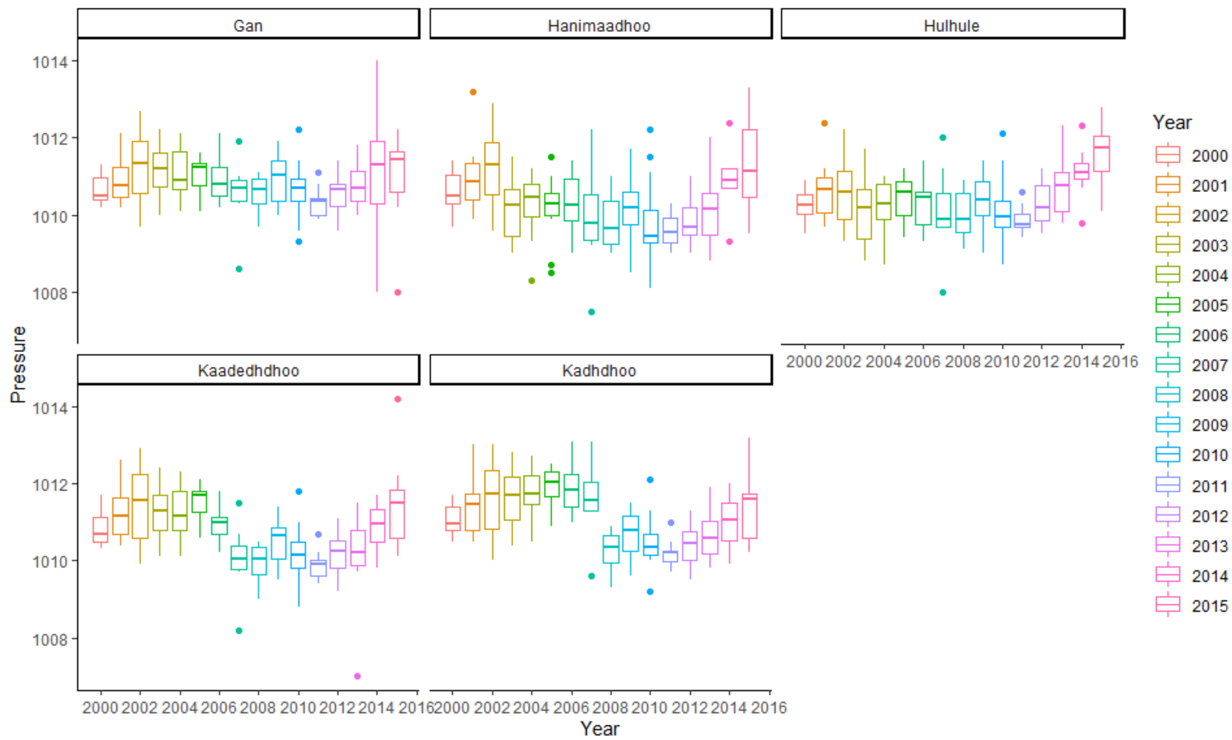

Figure 7: Annual atmospheric pressure records (for individual MET stations)

Figure 6 depicts annual precipitation records for each MET station. Clearly, in all cases, from Gan to Kadhdhoo, the values are very similar. In addition, 2002, 2005 and the last study years, 2014 and 2015 experience the highest rainfall with mean records close to 200 mm. On the contrary, Figure 7 shows clear variations in terms of atmospheric pressure. In general, for all MET stations, there is a rise until 2002, a drop in pressure until 2011 and a rise again with the highest value recorded in 2015. Another clear distinction from precipitation is that there are years where wide variations of atmospheric pressures are observed among different MET stations. A clear example is 2014 in Gan, with distinct variation of data having very high values, which are not recorded in other MET stations.

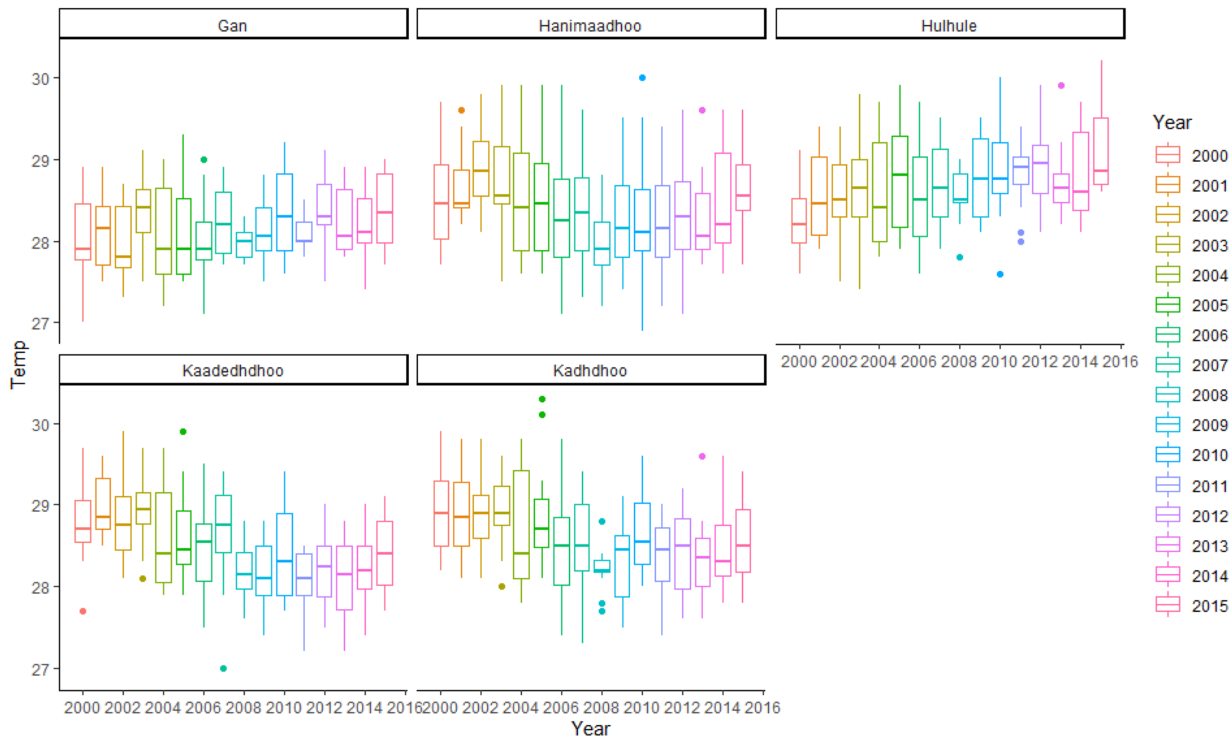

Figure 8: Annual temperature records (for individual MET stations)

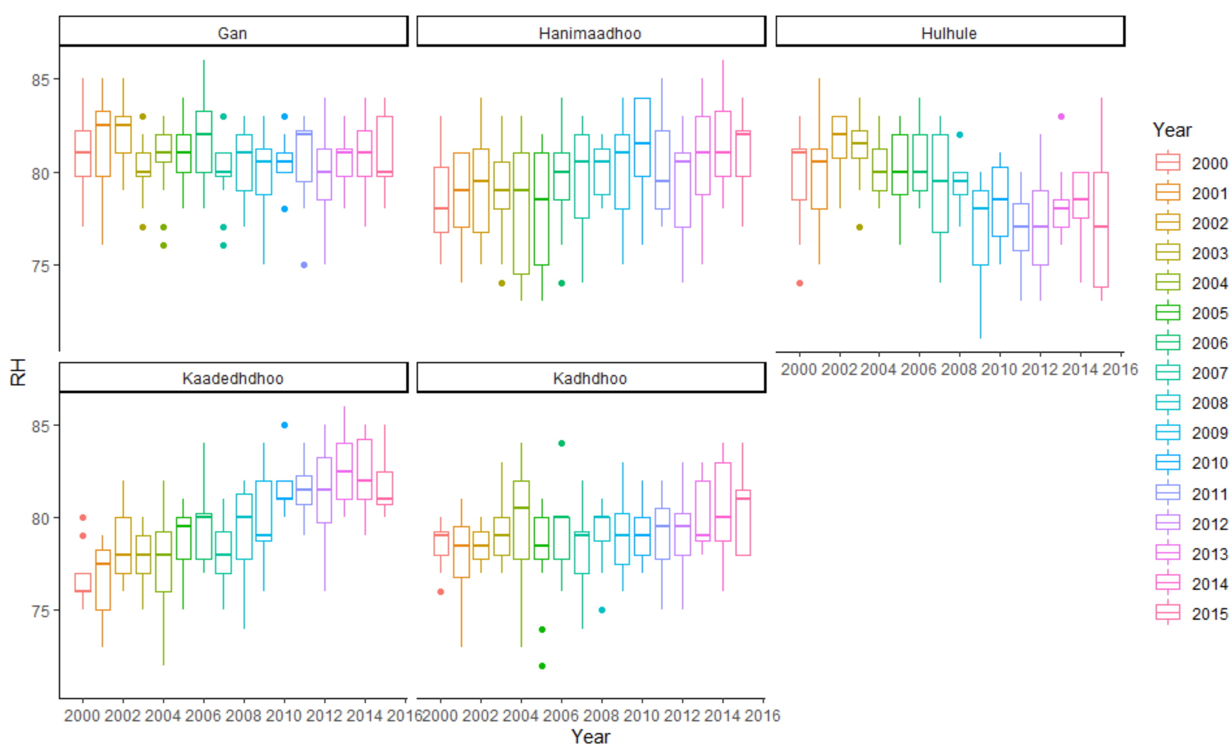

Figure 9: Annual RH records (for individual MET stations)

Figure 8 clearly depicts variations of temperature patterns in all the MET stations. In addition the mean value records are different in each case, much lower in Gan and Kadhdhoo and higher values in Hanimaadhoo and Hulhule. All this accompanied by a pattern of similarity in temperatures over the years in Gan with a slow gradual increase. In case of Kaadedhdhoo, a decreasing trend is noted, similar trend is observed in Kadhdhoo. While Hulhule experiences a slow but gradual increase in annual temperature. Figure 9 illustrates the annual records of RH in each MET stations. The records clearly show a reverse trend with respect to temperature. It is noted that, the stations where the annual temperatures have been increasing, as in Hulhule, the RH is found to be decreasing. On the other hand, Kaadedhdhoo and Kadhdhoo experience gradual increase in RH values. In case of Gan, the temperature values have been regular, similar trend is observed for RH with some occasional outliers.

- *Monthly Records (for individual MET* stations*)*

Individual plot depicts the monthly records for four meteorological parameters separately for each MET station.

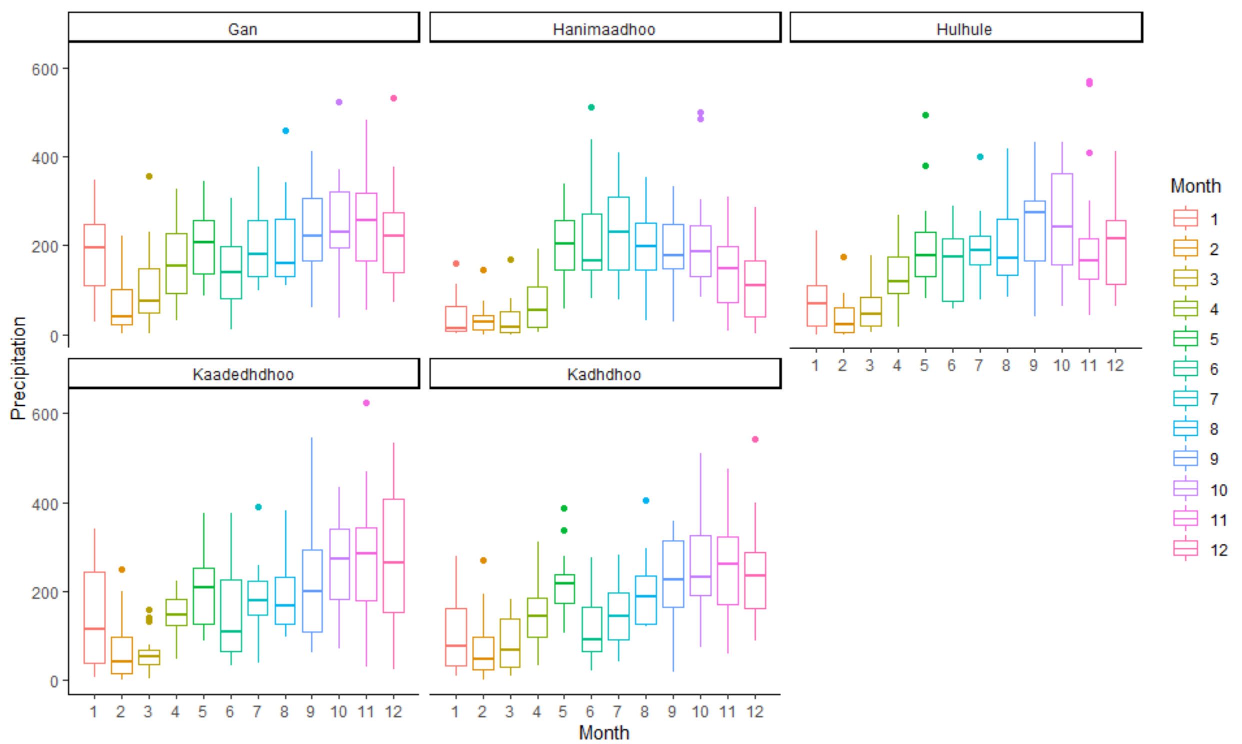

Figure 10: Monthly precipitation records (for individual MET stations)

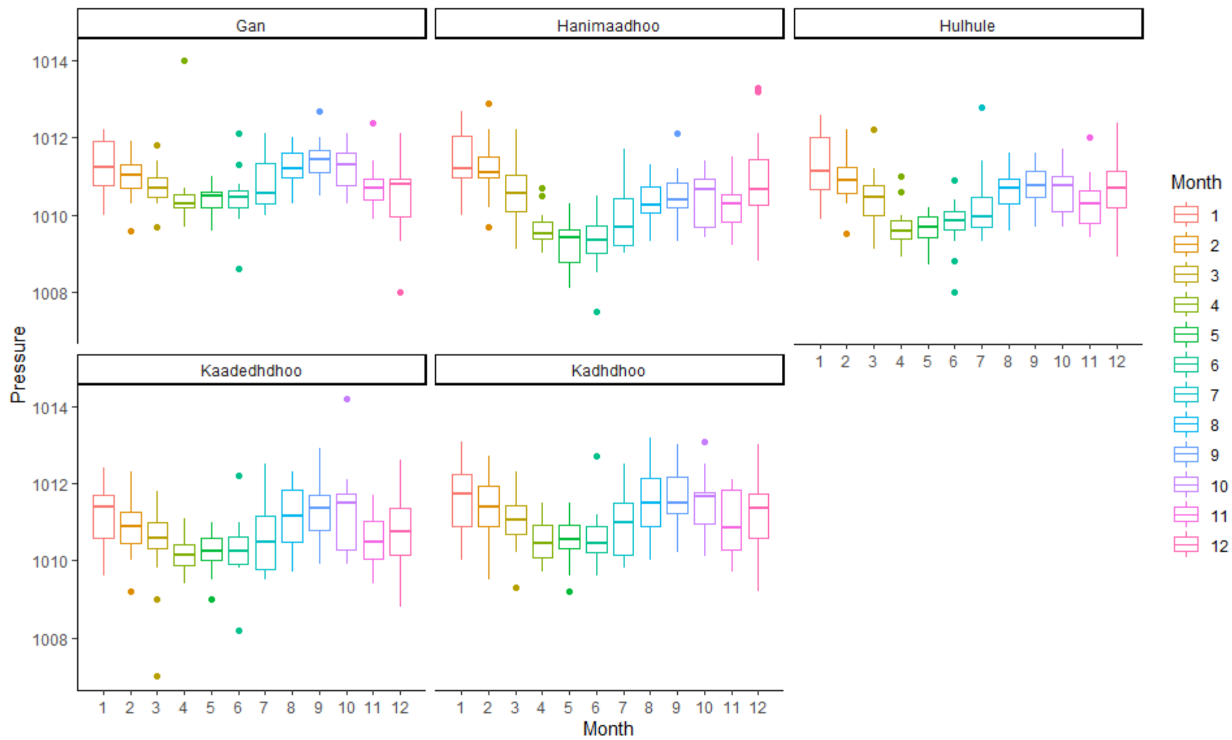

Figure 11: Monthly atmospheric pressure records (for individual MET stations)

Figure 10 depicts the monthly precipitation records in individual MET stations. The patterns are similar, where early each year there are low precipitation values, an increase in the central months and high to intermediate values in the last months. Hanimaadhoo and Hulhule experience the driest months in the beginning of the year compared to other three MET stations. Except for Hanimadhoo, all other MET stations record high monthly rainfall in the last two months of the year. Figure 11 illustrates that the atmospheric pressure follows a sinusoidal pattern having higher value in the beginning of the year. It is noteworthy to mention in this context that monthly variation in atmospheric pressure is noted to be relatively low in all MET stations.

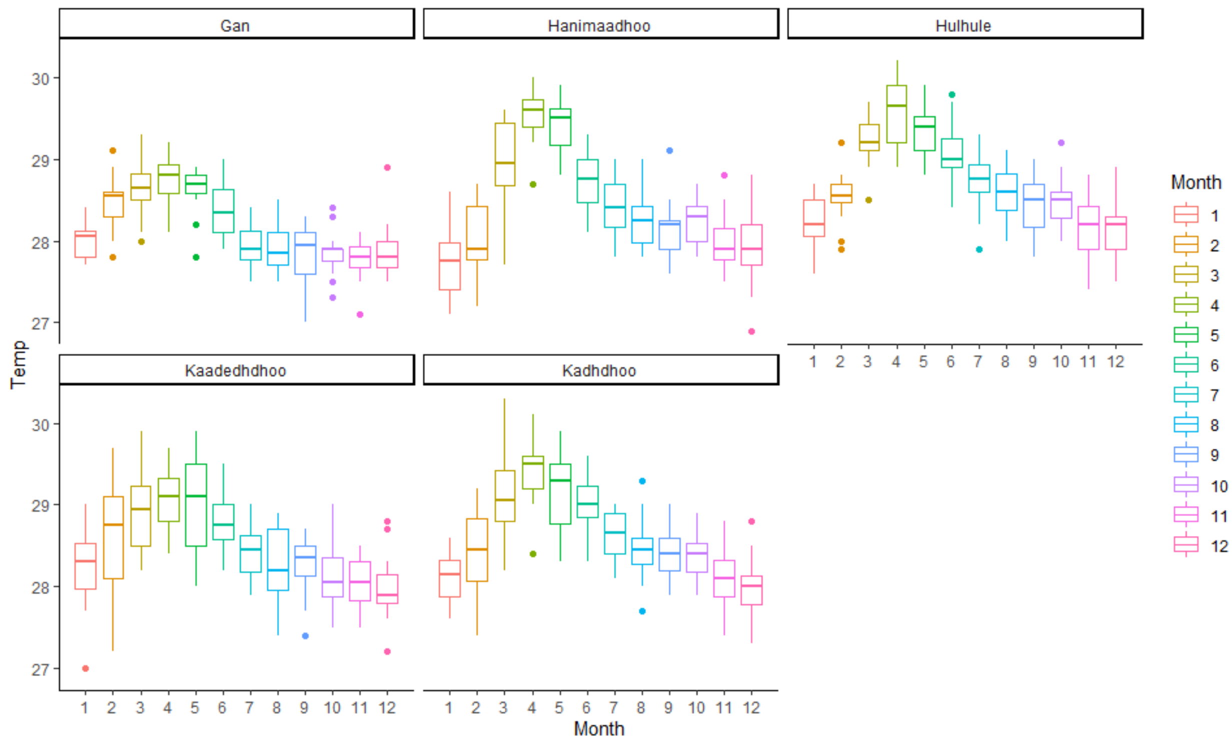

Figure 12: Monthly temperature records (for individual MET stations)

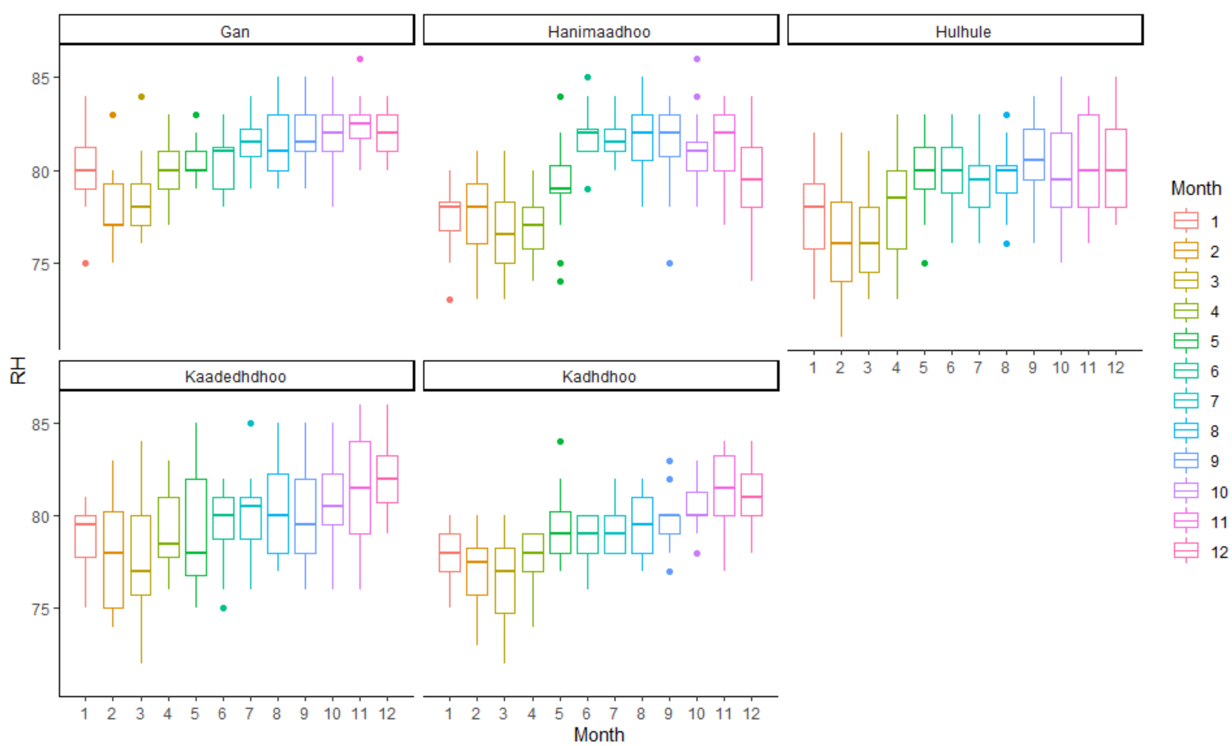

Figure 13: Monthly RH (for individual MET stations)

In Figure 12, the records of monthly temperatures follow the similar trend in all MET stations, an annual increase until April and May and a pronounced decrease until the last months of the year. Though Gan experiences a similar trend, its temperature values are comparatively low with respect to other four MET stations. Figure 13 illustrates the pattern of RH for each MET station are not at all correlated with temperature, it occurs, but not in such pronounced way as in Figure 12.

Next, a very important element in the description of similar datasets is the correlation values among four meteorological parameters overall and separately for each meteorological office data. Overall correlation among the four parameters for the entire study period has been reported in Figure 14. Individual MET stations correlation results are not illustrated in the current study. The results shown in Figure 14 depicts a positive relationship between RH and precipitation. On the other hand, a negative relationship exists between RH and temperature. Also, there is a negative relationship between precipitation and temperature, but the value is relatively small. Among the rest of the parameters, no clear relationships are identified.

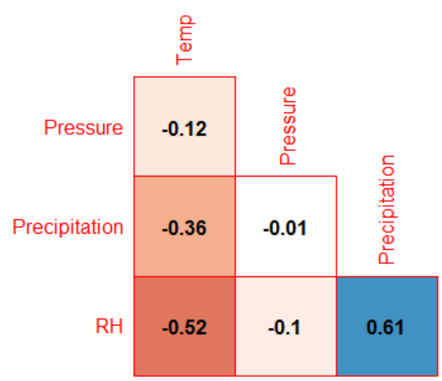

Figure 14: Correlations among meteorological parameters

Figures 15-18 illustrate the maps of the study area using kriging for the four meteorological parameters considered. In each figure different temporal moments of the kriging result have been depicted. On one hand, three years that coincide with the Tsunami that took place in the study area are presented. On the other hand, maps of another three years representing the complete study period from initial year (2000), intermediate and post Tsunami year (2009) and final study year (2015) have been depicted.

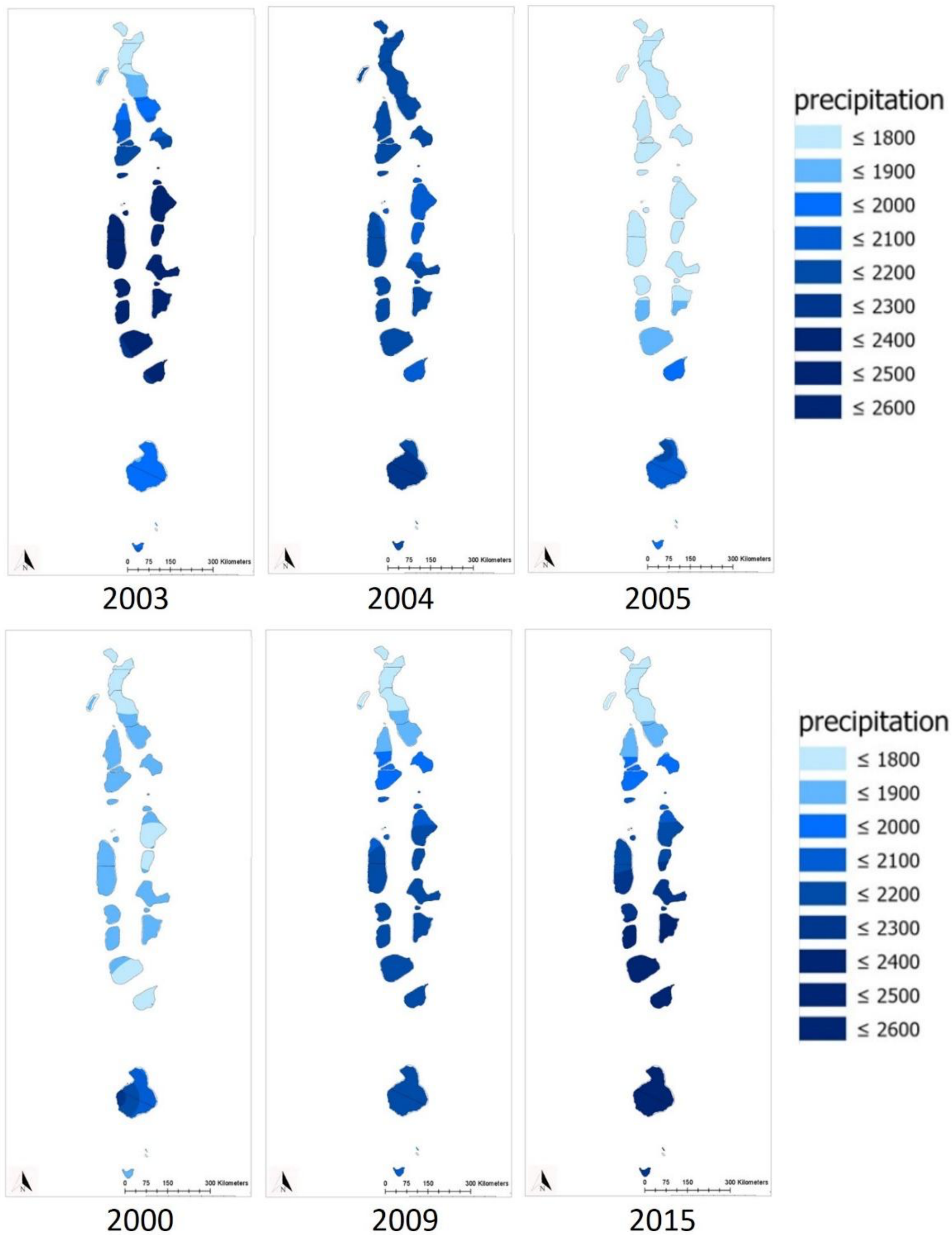

Figure 15: Kriging result of precipitation
Top: Tsunami years, 2003, 2004, 2005
Down: 2000 (before Tsunami), 2009 and 2015 (after Tsunami)

In the case of precipitation as depicted in Figure 15, the values are very low for the year 2000, with only slightly higher values in the south (Gan). In the years of the Tsunami, the values began to increase, especially in the central part of the study area in 2003, showing high values for the entire territory in 2004. In 2005 the same pattern was repeated as in 2000. Finally, in the years 2009 and 2015, we again observed high values, mainly in the central and southern parts of the territory.

Figure 16: Kriging result of atmospheric pressure
Top: Tsunami years, 2003, 2004, 2005
Down: 2000 (before Tsunami), 2009 and 2015 (after Tsunami)

In relation to atmospheric pressure, maximum values stand out throughout the entire territory in 2015. During the time of the Tsunami, however, high values occurred only in the central-southern part of the study area (Figure 16). While 2000 and 2009 experienced similar relatively low atmospheric pressure. It is noteworthy to mention in this context that annual variations are relatively low.

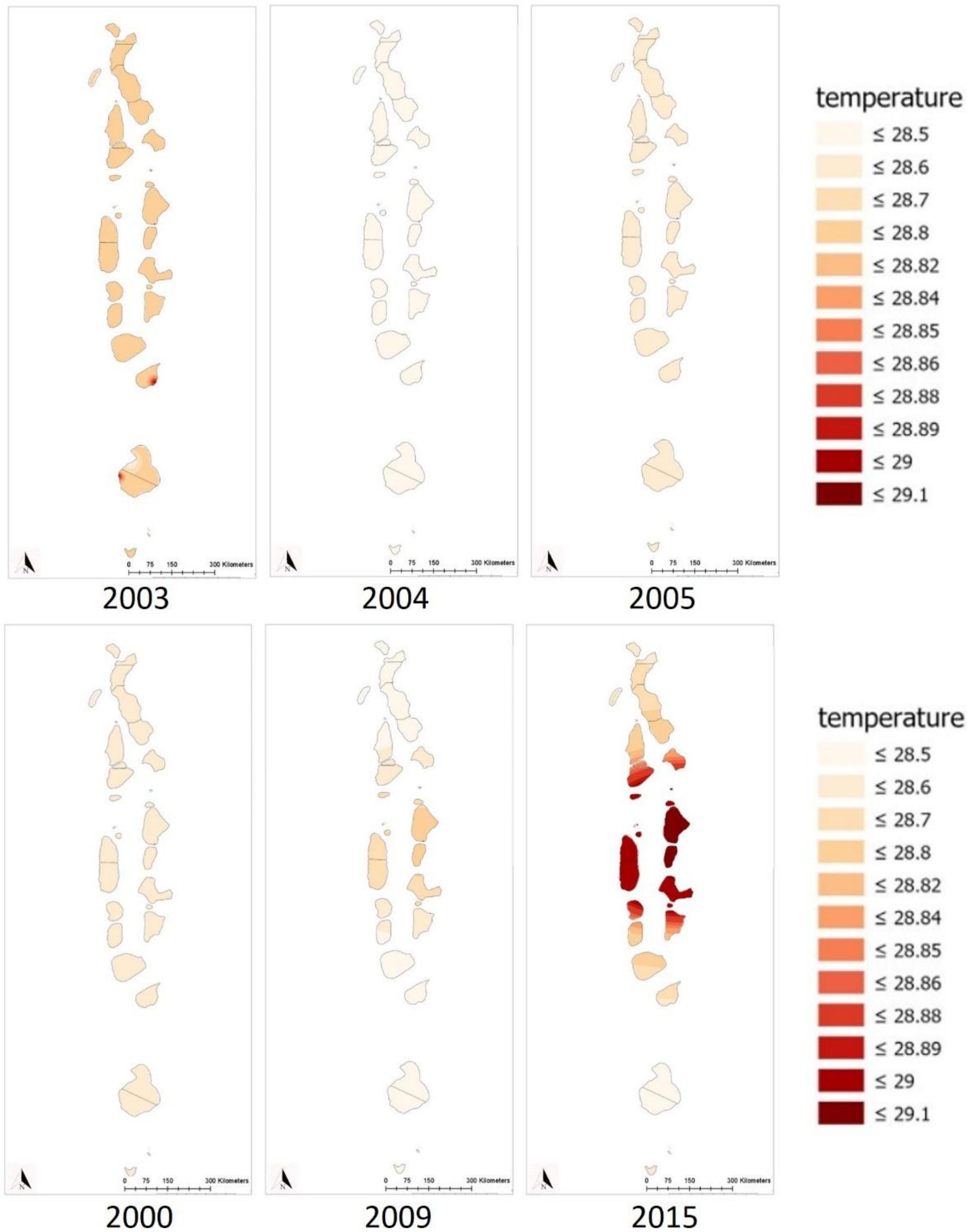

Figure 17: Kriging result of temperature
Top: Tsunami years, 2003, 2004, 2005
Down: 2000 (before Tsunami), 2009 and 2015 (after Tsunami)

In the case of temperature, Figure 17 shows an increase in temperature for the entire territory at the beginning of the Tsunami period (2003) which returns to low values in 2004 which are maintained until 2009, when the central region of the country recorded higher temperature compared to previous years. The same trend persists, and the central region experienced maximum values temperature in 2015.

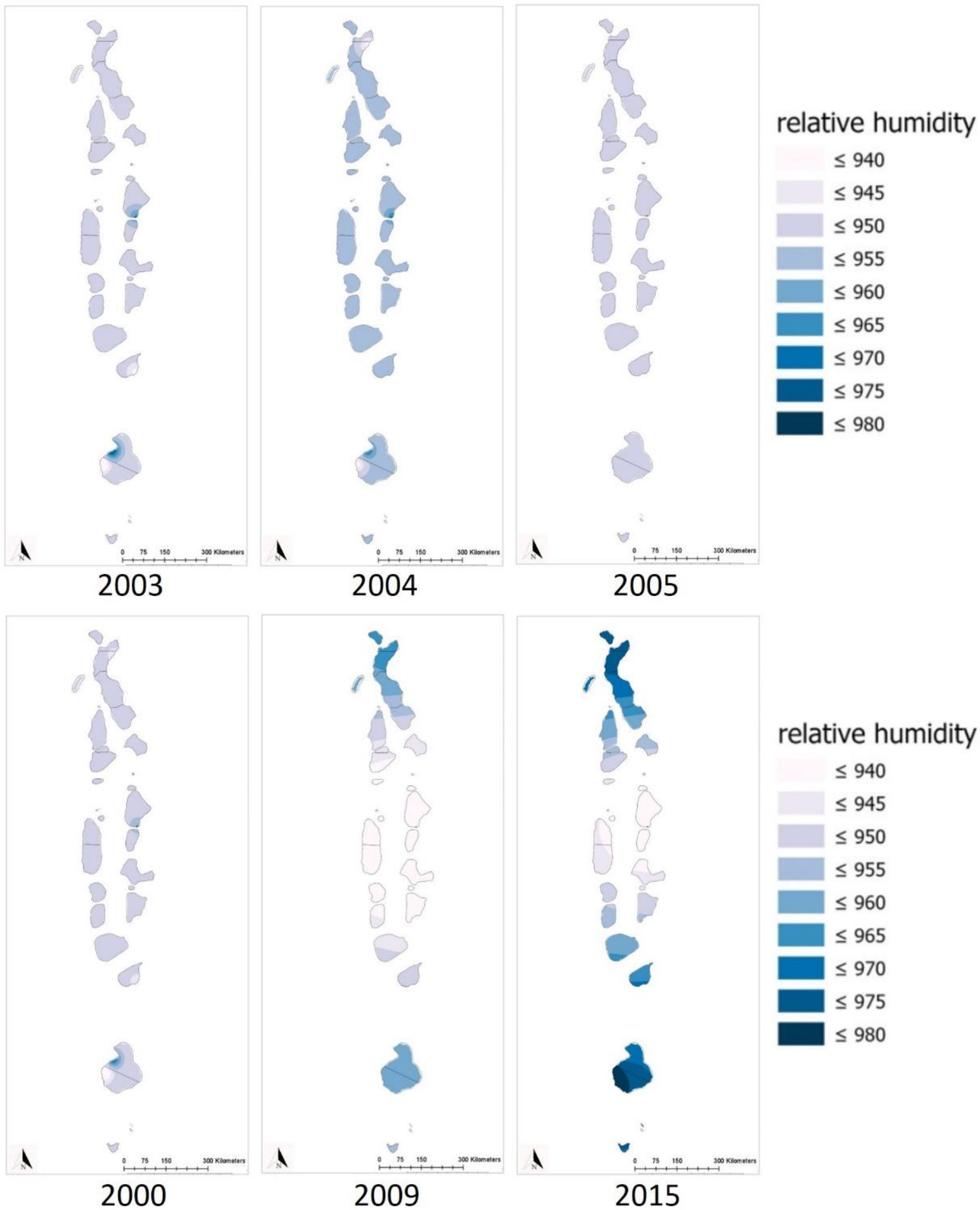

Figure 18: Kriging result of RH
Top: Tsunami years, 2003, 2004, 2005
Down: 2000 (before tsunami), 2009 and 2015 (after Tsunami)

Finally, for RH, records in 2000 and 2003 are similar. But in the Tsunami year an increase in value is observed throughout the study region. 2005 experienced a similar pattern as in 2000. In 2009 there is an increasing trend in the north and south of the territory with maximum values in these same areas in 2015 (Figure 18).

In general, the maximum values appear in 2015 and the lowest in 2000. More specifically related to precipitation pattern and Tsunami, the study shows that the central islands of the Maldives have relatively less rainfall in the year of the Tsunami (2004) than the rest of the region. In addition, in the same year the islands most affected by this natural catastrophe (northern Maldives region) (Naylor, 2015) experienced much more precipitation than the central region (Figure 15).

V. Discussion

The results presented above allow us to explore the climatic variation in the island nation of Maldives and provide a foundation for further studies of this region. In fact, the current study contributes to the relatively small amount of literature on seasonal patterns in climate for dispersed island nations, with emphasis on the effect of extreme climatic conditions and natural disasters like Tsunamis. In general, the application of geostatistical tools like kriging is more appropriate for implementation in areas with continuous land surfaces. There is limited research where kriging has been implemented in dispersed land surface (Cantet, 2015). The current study suggests the appropriate application of geostatistical techniques to analyze the spatial distribution of meteorological parameters in complex island structures.

Since 1972, Maldives has been a major global tourist destination. Tourism in this pristine archipelago is categorized by water sports, sunbathing, and street shopping. Thus, an understudied and unpredicted seasonal climate pattern of the country can have an impact on the tourist inflow. As tourism is the largest economic industry in Maldives, it might affect the overall economy of the nation. The present study focuses on analyzing and identifying spatial and seasonal patterns in climate especially for temperature and precipitation across different atolls of Maldives. This can help in strategic tourism management and promotion for the country. Literature shows there are few research works using geostatistical tools to analyze spatial and temporal patterns of different meteorological factors in island nations (Agou, Varouchakis & Hristopulos, 2019; Longobardi et al., 2016). Thus, the current study illustrates that geostatistical techniques can be applied effectively in complex island settings. Also, this initial step is important for future precise analytical tools of clustering like finite mixture models (Scrucca et al., 2016) to further analyze and identify climatic patterns among different atolls.

A few limitations need to be recognized in the current study. Maldives has overall five meteorological stations under MMS located in different atolls covering the full stretch from north to south of the territory. To carry out this study we had to work with this limited number of meteorological stations. In general, kriging precision can be improved with increasing data density and more regular spatial distribution (Krige, 2015). However, in this case the limited number of meteorological stations indicates low spatial resolution for kriging. Higher spatial distribution would have helped to better analyze and identify the spatio-temporal variation of the meteorological parameters in the study region. However, analyzing the optimal number of stations and determining their ideal positions is beyond the objectives of the current study. Related literature (Lane et al., 2013; Nunn and Kumar, 2017) have analyzed dispersed islands having complex land structures, but none of them have studied the optimal number or locations of weather stations. Thus, the limited number of meteorological stations is a limitation of this study. After analyzing the current results, it can be stated that an increase in the number of meteorological stations distributed over the entire study area would improve the kriging performance and help in precise prediction. Therefore, further research along these lines, to identify the optimal spatial distribution of meteorological stations to implement kriging and similar geostatistical tools, can provide better understanding of the climate pattern for all the atolls of Maldives. On the other hand, the temporal resolution of four meteorological parameters (precipitation, temperature, atmospheric pressure and RH) for a study period of sixteen years is sufficient to conduct the study. The substantial time frame of the dataset facilitates performing initial investigations to identify distinct patterns, to diagnose hypotheses and to examine assumptions.

VI. Conclusions

Among all the elements discussed in the current study, it is worth noting the distinct spatio-temporal variability of the meteorological parameters presented. Maldives differs from the regular seasonal behavior observed in other areas where winters, summers and rainy seasons are distinctly identified annually. The common periodic seasonal pattern is clearly missing in the current study area. In other words, the periodicity is not observed during the study period of 2000 to 2015, making it difficult to predict the seasonal impact on socio-economic factors of Maldives, especially on the tourism industry. For this reason, a clear and concise description of four important meteorological parameters with emphasis on precipitation and temperature of the region, is explored. In addition, possible prediction maps are depicted for the areas where there are no sampling nodes available. The analysis shows low seasonality in the region, something that future researchers can study in more detail to analyze its impact on tourism and the economy in the region. Moreover, the meteorological description in the time frame before, during and after the Tsunami is another addition for future researchers to analyze if there is any impact on the seasonality because of natural disasters like Tsunami. On the other hand, the complex island structure of the atolls of Maldives acts as a challenge to implement spatial and spatio-temporal geostatistical techniques in the region. The complication in finding precise climatic patterns in this dispersed land structure, together with the drawback of having limited number of meteorological stations, especially while performing geostatistical analysis provides additional reasons for scientific researchers to conduct future research works using innovative analytical techniques. In summary, the current description of the Maldives islands region highlights the complexity in the land structure and the non-periodicity of the climatic patterns. This may complicate the process of strategic planning in terms of tourism management and development. Thus, from this point, an accurate cluster analysis would allow determining the spatially distributed regions grouped by similar seasonal patterns.

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