SPATIO-TEMPORAL ANALYSIS OF RAINFALL PATTERNS IN THE PHILIPPINES

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ABSTRACT

Spatio-temporal analysis involves models when data are collected across time as well as space and has at least one spatial and one temporal property. An event in a spatio-temporal dataset describes a spatial and temporal phenomenon that exists at a certain time t and location x (Meliker and Sloan, 2011). In this study, the said analysis was used to analyze and predict the rainfall pattern by using the 1990 to 2012 monthly data from Philippine Atmospheric Geophysical and Astronomical Services Administration (PAGASA). The model has been satisfactorily built and was found out that it can predict up to five months (January to May 2013). The predicted pattern was then compared to the real-life rainfall scenarios in the Philippines to verify its validity.

Keywords: predict; rainfall; spatio-temporal analysis

INTRODUCTION

Rain, also known as precipitation, involves the condensation of water in the air. It is part of the never-ending water cycle where fallen rain eventually evaporates, becomes stored by clouds and falls to the earth again to repeat the process. The advantages seen in rainfall contribute to the earth's weather systems, seasons and the survival of all plant and animal life (Stevenson, 2017).

In a study conducted by Geneva-based United Nations Office for Disaster Risk Reduction (UNISOR) in 2016, Philippines is the fourth most disaster prone country in the world. It also revealed that the country is one of the top 10 countries with most number of people stricken by such disasters at shocking 130 billion pesos.

The country is awfully susceptible to the effects of climate change for two main causes: geography and development. Approximately, 20 tropical cyclones enter the Philippine Area of Responsibility (PAR) yearly of which ten will be typhoons with five being destructive (Dela Cruz, 2015). In accordance to this, Brown (2013) stated that Philippines is "the most exposed country in the world to tropical storms". These heavy rainfalls and the associated floods occur frequently in the Philippines and have caused huge economic losses as well as social problems.

Several studies had been conducted about rainfall patterns in different countries, its predictability as well as the effects of these rainfall events to the state. Meliker and Sloan (2011) explained that spatio-temporal data analysis is an emerging research area due to the development and application of novel computational techniques allowing for the analysis of large spatio-temporal databases. Spatio-temporal models arise when data are collected across time as well as space and has at least one spatial and one temporal property. These analyses have the additional benefits over purely spatial or time-series analyses because they allow the

investigator to simultaneously study the persistence of patterns over time and illuminate any unusual patterns. The inclusion of space-time interaction terms may also detect data clustering that may be indicative of emerging environmental hazards or persistent errors in the data recording process.

Considering the vulnerability of the country to extreme rainfall events, this study aims to study the patterns and forecast rainfall given data from different weather stations for the benefit of the citizens residing in the Philippines.

Objectives of the Study

This study aims to::
1. Describe the demographic characteristics of the different locations under certain weather stations;
2. Produce and examine spatial maps and time graphs;
3. Define and model spatio-temporal structure and;
4. Evaluate the model.

Significance of the Study

Extreme rainfall events that happen in the Philippines can be considered as destructive. Prediction information about these events has the potential to reduce the impact of adverse weather events.

Spatio-temporal analysis is of importance with regards to these matters. Through this, rainfall patterns will be studied and will be predicted on certain areas in the country under different weather stations.

Scope and Limitation

This study focused on Philippines. The secondary data was from Philippine Statistics Authority (PSA) - Philippine Food Security Information System (PhilFSIS), monthly rainfall in millimeters recorded on 58 stations in the Philippines. The total number of stations in the country is 76, however, data from 58 stations were only gathered which ranges from 1990 to 2012. This data from PSA was actually collected by Philippine Atmospheric Geophysical and Astronomical Services Administration (PAGASA).

THEORETICAL BACKGROUND

Spatio-temporal

Spatio-temporal database is a database that manages both space and time information. These databases are an extension of spatial databases. This kind of database embodies spatial, temporal, and spatio-temporal database concepts, and captures spatial and temporal

aspects of data and deals with geometry changing over time and/or location of objects moving over invariant geometry (Guting and Schneider, 2005).

In a study entitled "Spatio-temporal Analysis of Extreme Hourly Precipitation Patterns in Hainan Island, South China" conducted by Chen, Li, Xing, Huang, and Wu (2015), the trend stability analysis of several extreme precipitation index suggested that the southern parts of Hainan Island, and especially the city of Sanya should receive more attention to establish the drainage facilities necessary to prevent waterlogging.

In response to the serious implications of changes in the local climate, based on a study entitled "An Analysis of the Spatio-temporal Variability of Rainfall in the Philippines" conducted by Castillo, Cruz, and Villarin (2004), the temporal and spatial rainfall variability in the Philippines were analysed. Results indicate that among the three major islands, the rainfall in Luzon is more spatially variable during the wet and dry seasons.

Rainfall Forecasts

World Meteorological Organization (2015) elaborated that rain is measured in units of depth per unit time, typically in millimeters per hour. The "depth" being measured is the depth of rain water that would accumulate on a flat, horizontal and impermeable surface during a given amount of time, typically an hour. One millimeter of rainfall is the equivalent of one liter of water per square meter.

PAGASA have their own way of rainfall forecasting using a probabilistic model approach to predict rainfall where

Percent of normal = $\frac{Forecast\ rainfall}{Normal\ rainfall}$ x 100%.

A different approach was made in a study by Luk, Ball, and Sharma (2001) entitled "An application of artificial neural networks for rainfall forecasting". Artificial neural networks (ANNs), which perform a nonlinear mapping between inputs and outputs, are one such technique.

In a study conducted by Viana (2016), "Monthly and Seasonal Rainfall Forecasting in Southern Brazil Using Multiple Discriminant Analysis", they used this analysis to forecast monthly and seasonal rainfall in southern Brazil. The definition of key regions (feature extraction step) was performed using spatial principal component analysis. The results revealed that one-third of the predictors are associated with atmospheric pressure and also emphasized the role of atmospheric circulation over the Antarctic region and its surroundings.

Theoretical Framework

Notation: Spatio-temporal Process

$$\{Y(s;t): s \in \mathbf{D_s} \subset \mathbb{R^d}, t \in \mathbf{D_t} \subset \mathbb{R}\}$$

where D_s is the spatial domain of interest

D_t the temporal domain of interest,

s is a spatial location,

t a time and,

$\mathbb{R}$ is a real number from 0 to ∞.

Spatial Autocorrelation

Tobler (2018) defined spatial autocorrelation as how much close objects are in comparison with other close objects. Moran's I can be classified as positive, negative and no spatial auto-correlation. Positive spatial autocorrelation is when similar values cluster together in a map. Negative spatial autocorrelation is when dissimilar values cluster together in a map.

Temporal Autocorrelation

Alexandru (2016) defined temporal correlation as a normal correlation only that is computed on data that fluctuates according to time, like signals, time series, etc.

METHODOLOGY

Source of Data

The data used in this study was from Philippine Statistics Authority (PSA) - Philippine Food Security Information System (PhilFSIS). It is an open data accessible to everyone without fees. The data about rainfall (in millimeters) was in terms of monthly and annual data recorded from 58 stations in the Philippines.   There are 36 stations in Luzon, 11 stations in Visayas, and 11 stations in Mindanao.

The PAGASA datasets have the following features: First, there are several provinces that host multiple weather stations. Second, there are several provinces in which no weather station is present but it is possible to assign a weather station on the basis of the relative distance (in kilometers) between the province and the location of the weather station (Dacuycuy 2016).

Statistical Software

This study used Microsoft Excel 2013, EViews, GeoDa, SPSS version 23 and ArcGIS 10.5. Microsoft Excel was used for data encoding and organizing purposes that served as the database. MS Excel was also used for descriptive statistics and EViews for preliminary graphs.

RESULTS AND DISCUSSIONS

Figure 1 shows the location of weather stations. The red triangles represent the said stations scattered throughout the country. There are 58 of these stations: 36 from Luzon, 11 from Visayas, and 11 from Mindanao.
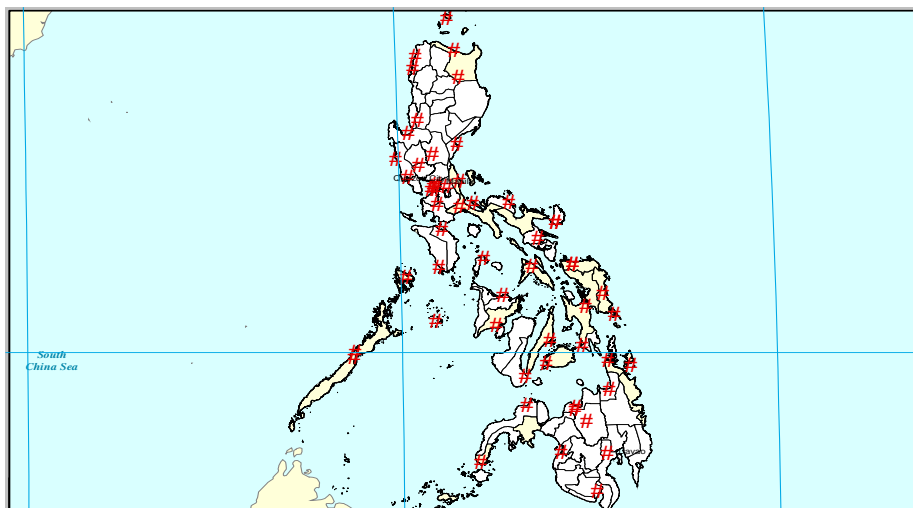

Figure 1. Philippine map with the location of weather stations

**Rainfall amount in provinces grouped into respective k-nearest neighbors**

The following graphs were constructed by grouping the provinces into their respective k-nearest neighbors. For Figures 3 to 17, the x-axis represents the month 01-12 (January to December) and y-axis represents amount of rainfall in mm.
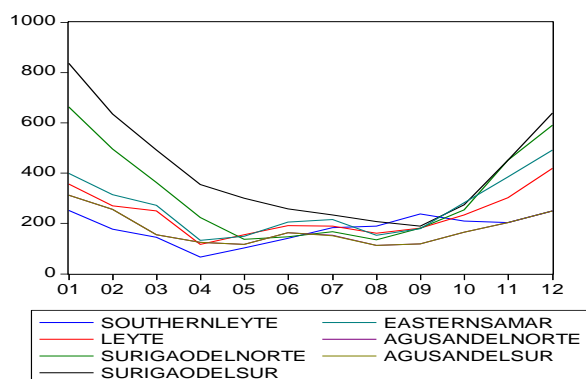
Figure 3. Monthly mean rainfall of Surigao del Norte (focal point) and its nearest neighbors
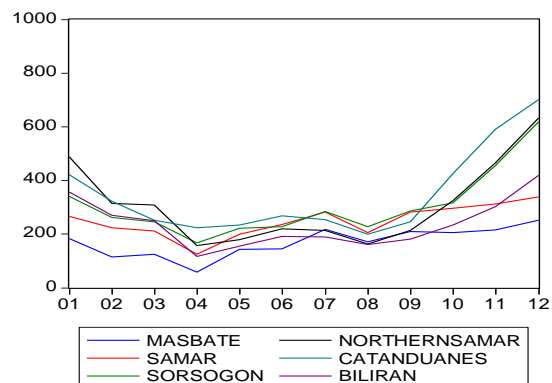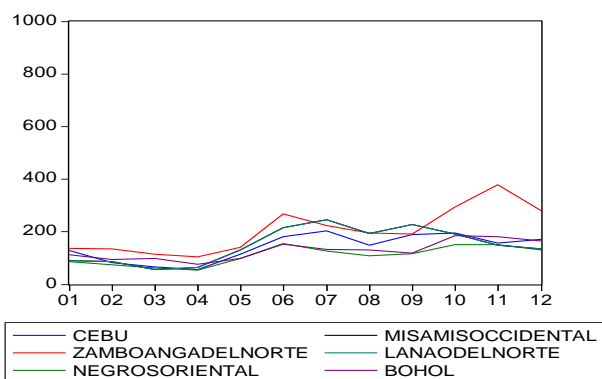

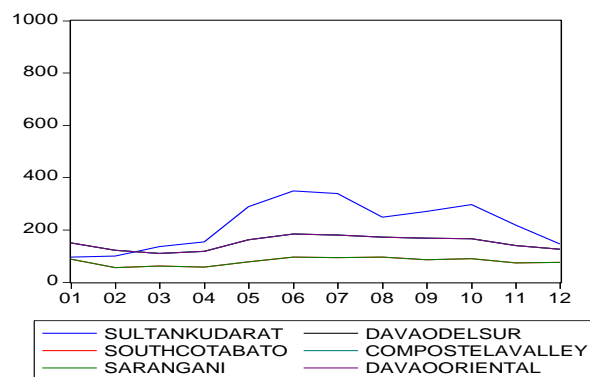**Figure 4.** Monthly mean rainfall of Sorsogon (focal point) and its nearest neighbors
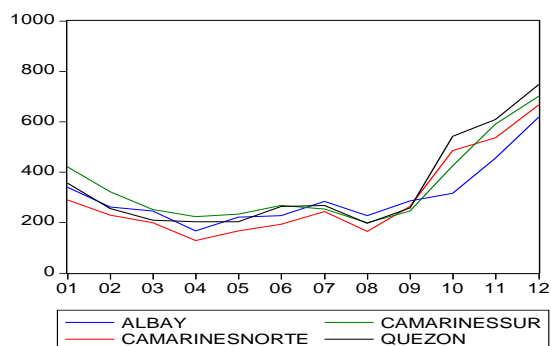
Figure 5. Monthly mean rainfall of
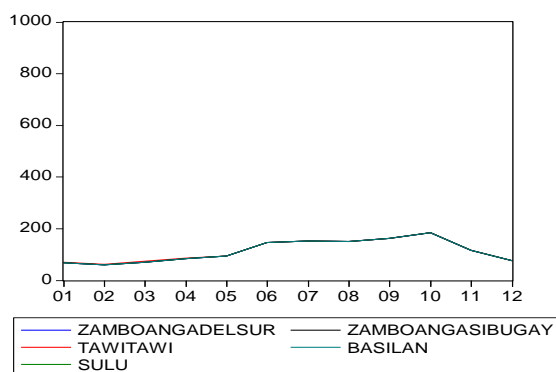Albay (focal point) and its
nearest neighbors

Figures 3 to 5 shows similar pattern which resembles convex structure. It can be noticed that the provinces in the figures above are all located at the southern part of the country. Each figure has their maximum rainfall at about 800 mm, either January or February.
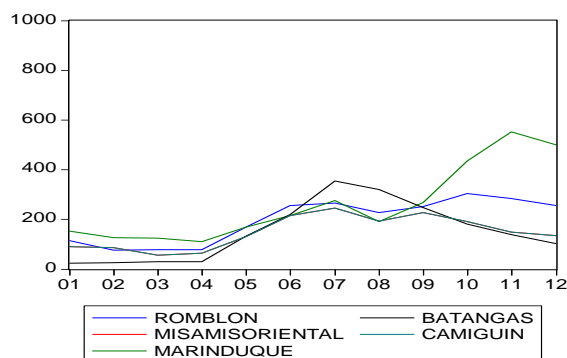

Figure 6. Monthly mean rainfall of Bohol
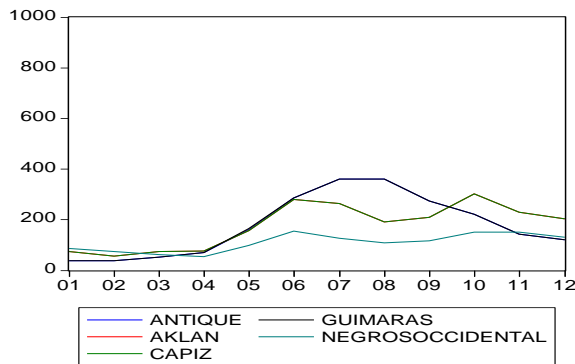(focal point) and its nearest
neighbors

Figure 7. Monthly mean rainfall of South
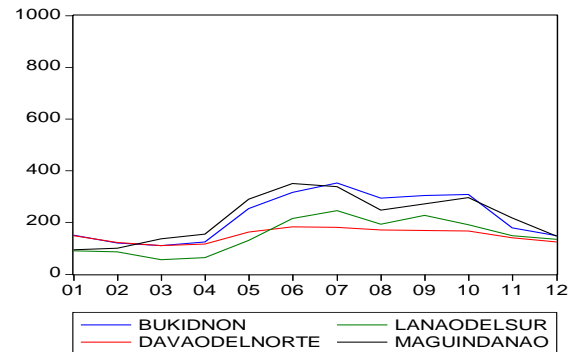Cotabato (focal point) and its
nearest neighbors

Figure 8. Monthly mean rainfall of Tawi
tawi (focal point) and its nearest
neighbors

Figure 9. Monthly mean rainfall of
Marinduque (focal point)
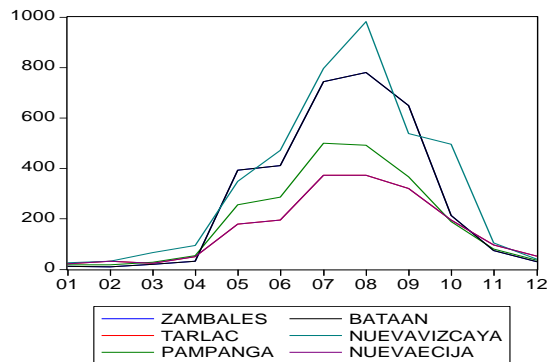and its nearest neighbors

Figure 10. Monthly mean rainfall of Antique (focal point) and its nearest neighbors
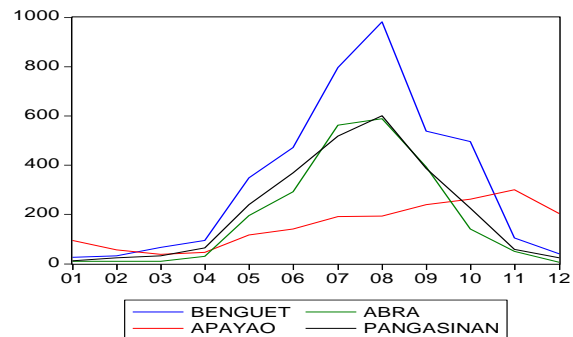

Figure 11. Monthly mean rainfall of Bukidnon (focal point) and nearest neighbors

Figures 6 to 11 shows almost flat lines not exceeding 600mm. All the figures also show that in the second half of the year, the rainfall amount slightly increases and decreases in December. The provinces mentioned in the figures are located in southern part of Luzon, Visayas, and Mindanao.
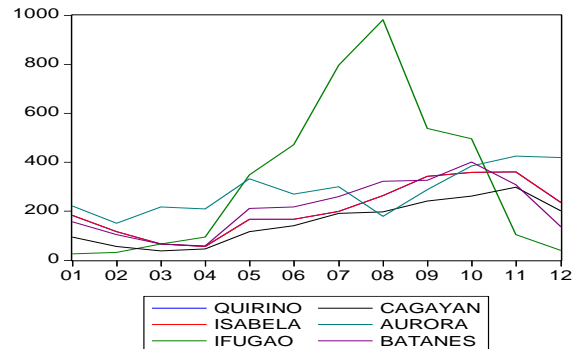

Figure 12. Monthly mean rainfall of Zambales (focal point) and its nearest neighbors
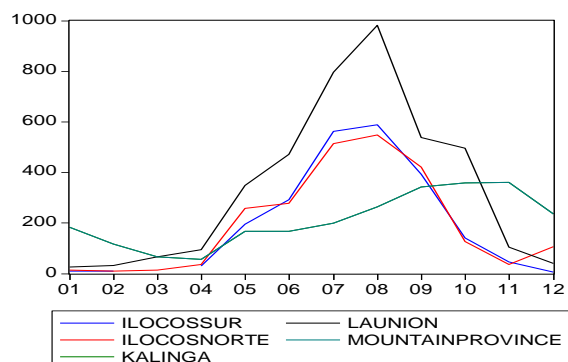

Figure 13. Monthly mean rainfall of Benguet (focal point) and its nearest neighbors
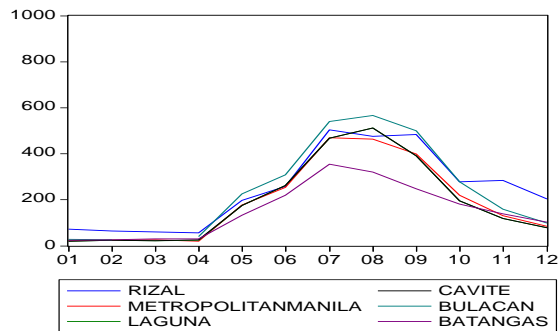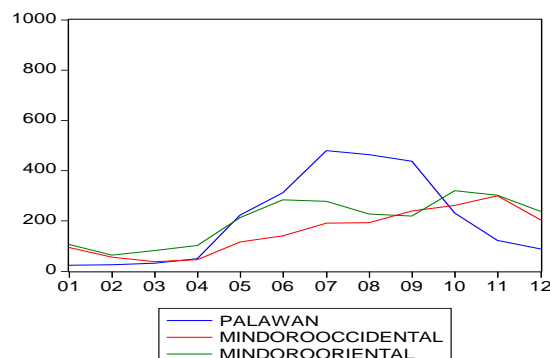

Figure 14. Monthly mean rainfall of Laguna (focal point) and its nearest neighbors

Figure 15. Monthly mean rainfall of Isabela (focal point) and its nearest neighbors

Figure 16. Monthly mean rainfall of Ilocos Norte (focal point) and nearest neighbors


Figure 17. Monthly mean rainfall of Palawan (focal point) and nearest neighbors

Figure 12 to 17 shows inverted "V-like" pattern with the maximum rainfall not exceeding 1000mm. In each figure, it can be observed that the rainfall amount increases in the third quarter of each year and decreases in the fourth quarter. All the provinces in the said figures are located in the Northern part of the country.

The following provinces overlapped due to the same reference of weather station: Bataan and Zambales (black line) (Figure 12).

In Surigao del Norte and its nearest neighbors (Figure 19), all provinces exhibit seasonal pattern. Surigao del Sur and Surigao del Norte clearly displays highest peaks among the provinces at some point in 1998 (Typhoon Norming) and 2011 (Tropical Depression Ramon) respectively which is about 1500mm.
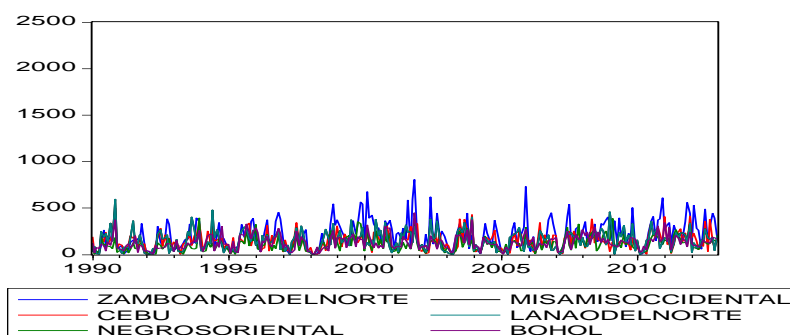
Figure 20. Time graph of rainfall (mm) in Bohol and its nearest neighbors

For Bohol and its nearest neighbors (Figure 20), Zamboanga del Norte evidently received high rainfall and its maximum almost reached 800mm at 2001 (Tropical Storm Nanang). All provinces showed a seasonal pattern.
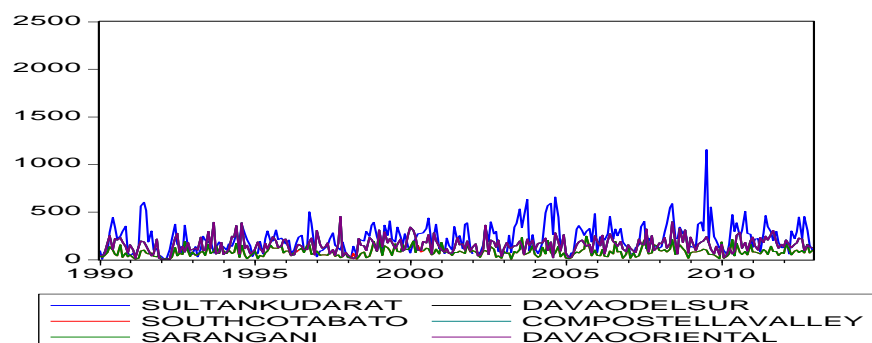
Figure 21. Time graph of rainfall (mm) in South Cotabato and its nearest neighbors

South Cotabato and its nearest neighbors (Figure 21) shows that they all have seasonal pattern but Sultan Kudarat has evidently shown higher spikes than the others and the maximum peak is at 2009 which nearly reached 1200mm (Tropical Depression Jolina).
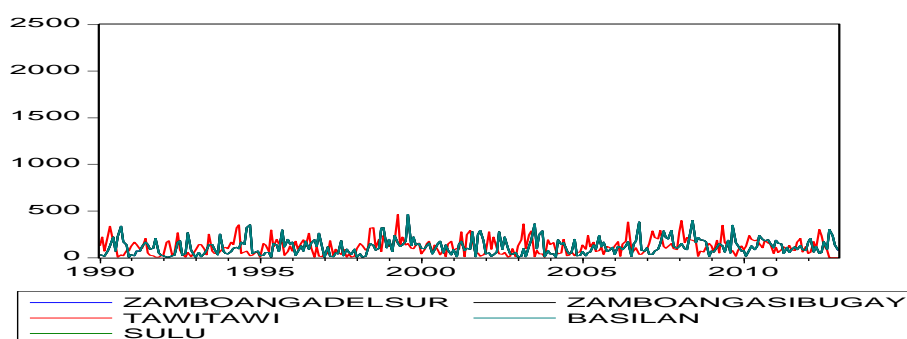
Figure 22. Time graph of rainfall (mm) in Tawi-tawi and its nearest neighbors

Tawi-tawi and its nearest neighbors (Figure 22) illustrates that Zamboanga del Sur, Sulu, and Zamboanga Sibugay (blue-green line) overlapped because they have the same reference of weather station, and the same case for Tawi-tawi and Sulu (red line). All provinces have similar and seasonal pattern.
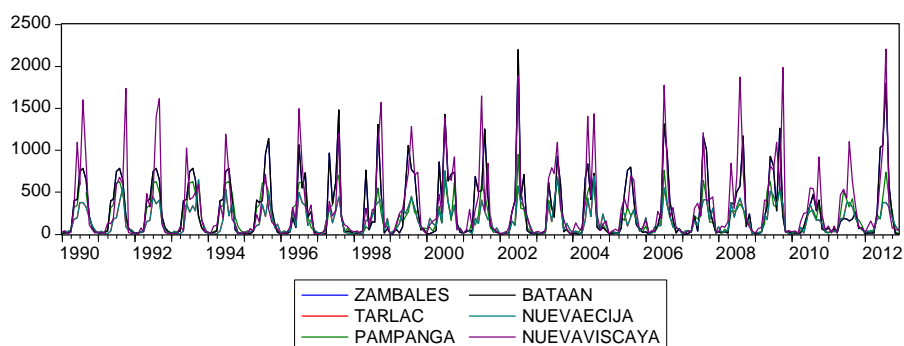
Figure 23. Time graph of rainfall (mm) in Zambales and its nearest neighbors

Zambales and its nearest neighbors (Figure 23) clear displays that Nueva Viscaya has higher spikes than the rest and has its maximum at 2002 (Tropical Depression Milenyo) and 2012 (Tropical Depression Dindo) which nearly reached 2000mm but all of the provinces exhibit seasonal pattern.
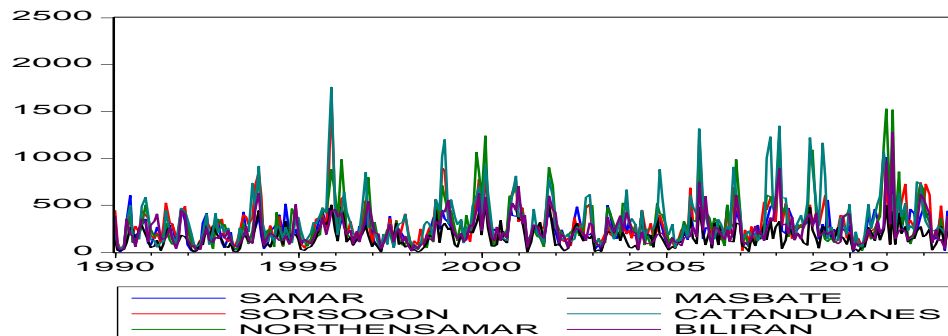
Figure 24. Time graph of rainfall (mm) in Sorsogon and its nearest neighbors

Sorsogon and its nearest neighbors (Figure 24) displays a seasonal pattern but Catanduanes evidently shows the highest peak among them at 1995 about 1500mm (Typhoon Babs and Typhoon Toyang).
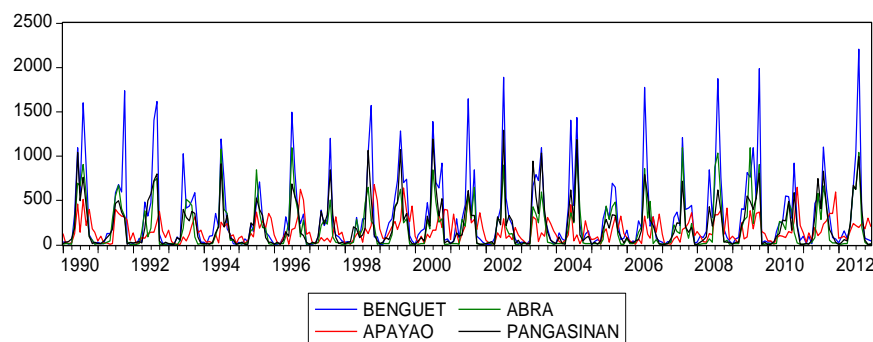
Figure 25. Time graph of rainfall (mm) in Benguet and its nearest neighbors

Benguet and its nearest neighbors (Figure 25) clearly shows that Benguet has higher amount of rainfall through the years especially in 2012 in which, its peak exceeds beyond 200mm (Tropical Depression Dindo). On the other hand, Apayao seems to have low amount of rainfall with its maximum only about 500mm. Also, all of the provinces exhibits seasonal pattern.
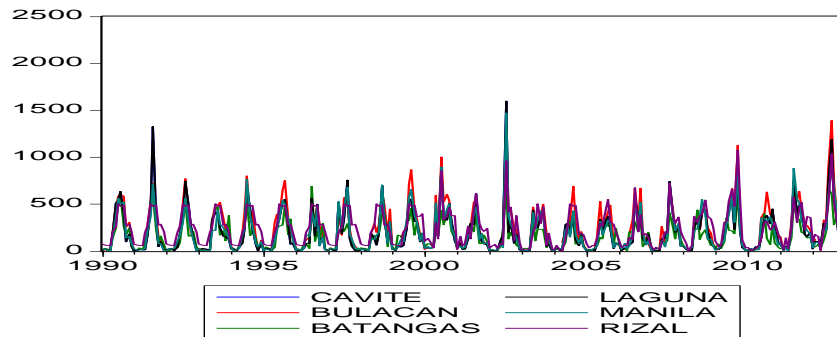
Figure 26. Time graph of rainfall (mm) in Laguna and its nearest neighbors

Laguna and its nearest neighbors (Figure 26) follow similar pattern only that, Laguna has the highest peak among them at year 2002 which is about 1500mm (Tropical Depression Milenyo).
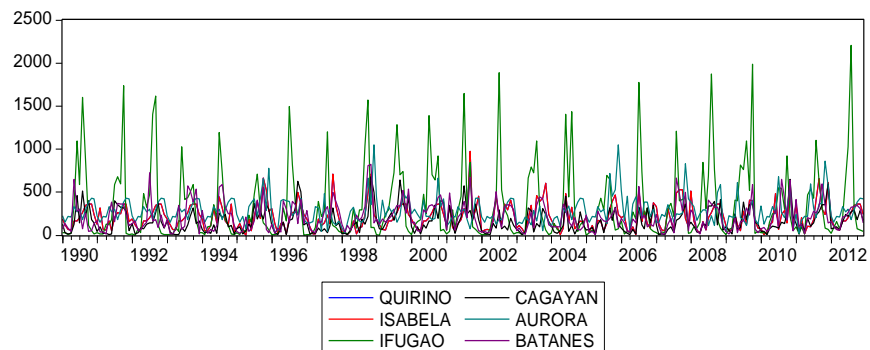
Figure 27. Time graph of rainfall (mm) in Isabela and its nearest neighbors

For Isabela and its nearest neighbors (Figure 27), Quirino, Isabela, Cagayan, Aurora, and Batanes obviously has lower spikes than Ifugao. Ifugao has a very high amount of rainfall every year with its peak exceeding 2000mm at 2012 (Tropical Depression Dindo).
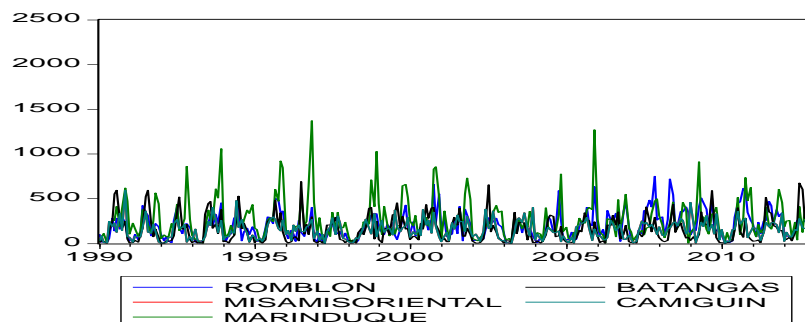
Figure 28. Time graph of rainfall (mm) in Marinduque and its nearest neighbors

For Marinduque and its nearest neighbors (Figure 28), all provinces follow similar pattern. It is unmistakable that Marinduque has higher spikes than the others specifically at 1996 and 2006 which is around 1200mm (Typhoon Toyang).
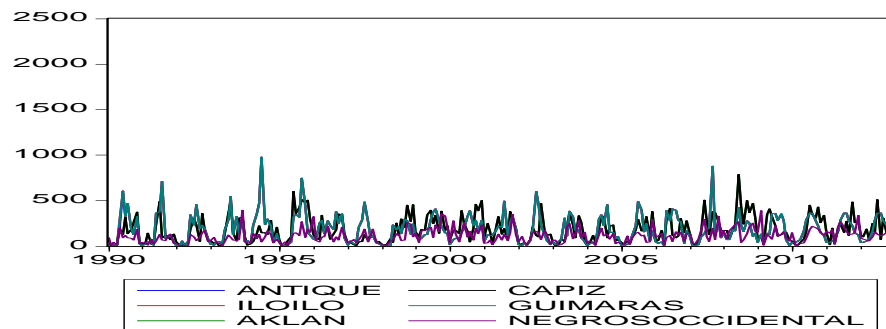
Figure 29. Time graph of rainfall (mm) in Iloilo and its nearest neighbors

For Iloilo and its nearest neighbors (Figure 29), Guimaras has evidently shown a higher amount of rainfall especially in the year 1994 with its maximum at about 1000mm (Tropical Storm Oyang and Tropical Depression Pasing). The remaining provinces has lower spikes than Guimaras but all of them displays seasonal pattern.
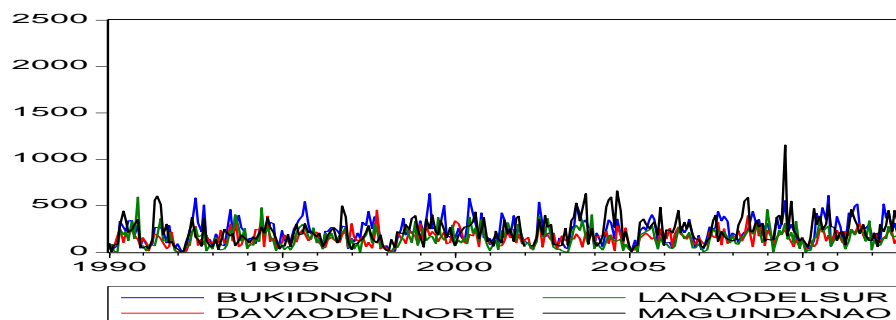
Figure 30. Time graph of rainfall (mm) in Bukidnon and its nearest neighbors

For Bukidnon and its nearest neighbors (Figure 30), the provinces shows a seasonal and similar pattern only that, Maguindanao has higher spike at 2009 which nearly reached 1200mm (Tropical Depression Jolina).
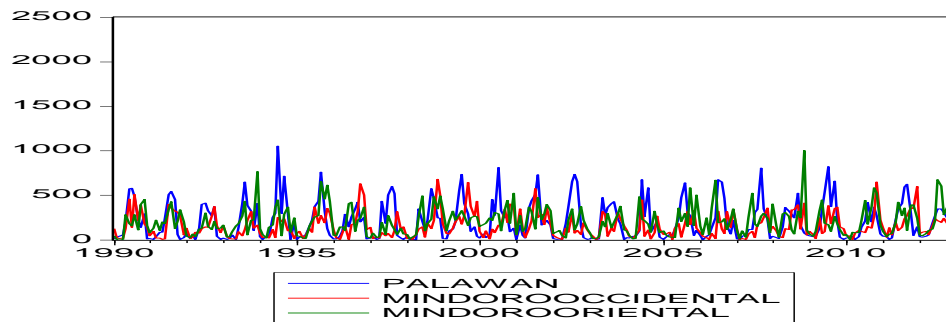
Figure 31. Time graph of rainfall (mm) in Palawan and its nearest neighbors

Palawan and its nearest neighbors (Figure 31) shows that the provinces display similar and seasonal pattern but it is obviously shown that Palawan has the highest peak among them occurred at 1994 which exceeds 800mm (Tropical Storm Oyang and Tropical Depression Pasing).
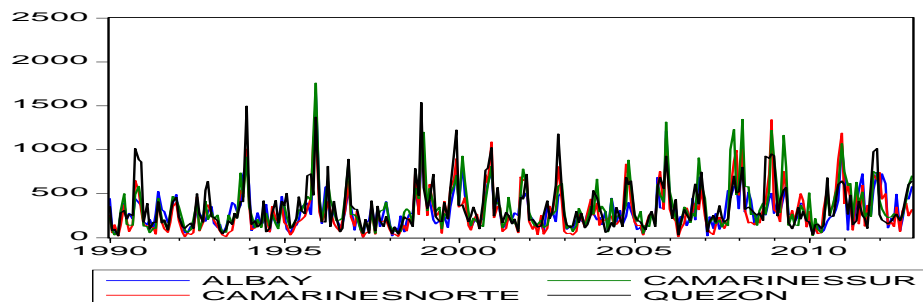
Figure 32. Time graph of rainfall (mm) in Albay and its nearest neighbors

Albay and its nearest neighbors (Figure 32) clearly illustrates a seasonal pattern. The provinces almost follow similar pattern and it can be observed that the province of Camarines Sur has received highest peak among them which occurred at 1995 at more than 1500mm (Tropical Storm Mameng).
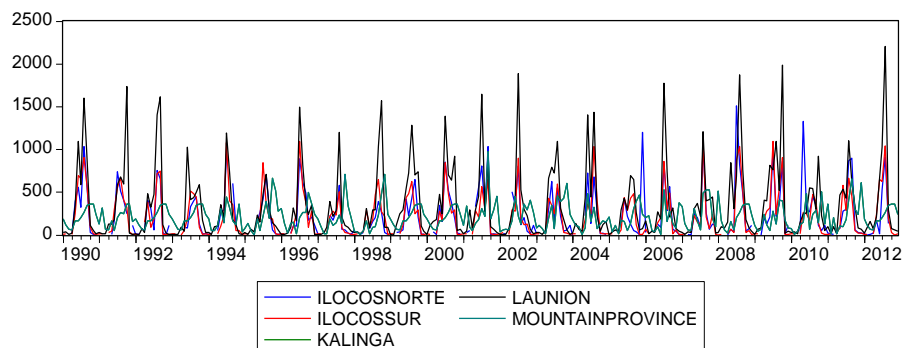
Figure 33. Time graph of rainfall (mm) in Ilocos Norte and its nearest neighbors

For Ilocos Norte and its nearest neighbors (Figure 33),it is evident that La Union has higher spikes than the other provinces which has a very great amount of rainfall especially in 2012 at more than 2000mm (Typhoon Pablo).

Percentile
- ■ < 1% (0) [0 : 0]
- ■ 1% - 10% (8) [0 : 105]
- □ 10% - 50% (32) [105 : 186]
- □ 50% - 90% (34) [186 : 304]
- ■ 90% - 99% (8) [304 : 468]
- ■ > 99% (0) [468 : 468]

(a) 1990

Percentile
- ■ < 1% (0) [0 : 0]
- ■ 1% - 10% (8) [0 : 76.3]
- □ 10% - 50% (31) [76.3 : 159]
- □ 50% - 90% (35) [159 : 309]
- ■ 90% - 99% (8) [309 : 369]
- ■ > 99% (0) [369 : 369]

(b) 1991

Percentile
- ■ < 1% (0) [0 : 0]
- ■ 1% - 10% (8) [0 : 61.1]
- □ 10% - 50% (33) [61.1 : 151]
- □ 50% - 90% (33) [151 : 283]
- ■ 90% - 99% (7) [283 : 382]
- ■ > 99% (1) [382 : 384]

(c) 1992

Percentile
- ■ < 1% (0) [0 : 0]
- ■ 1% - 10% (5) [0 : 78]
- □ 10% - 50% (36) [78 : 171]
- □ 50% - 90% (33) [171 : 299]
- ■ 90% - 99% (7) [299 : 350]
- ■ > 99% (1) [350 : 363]
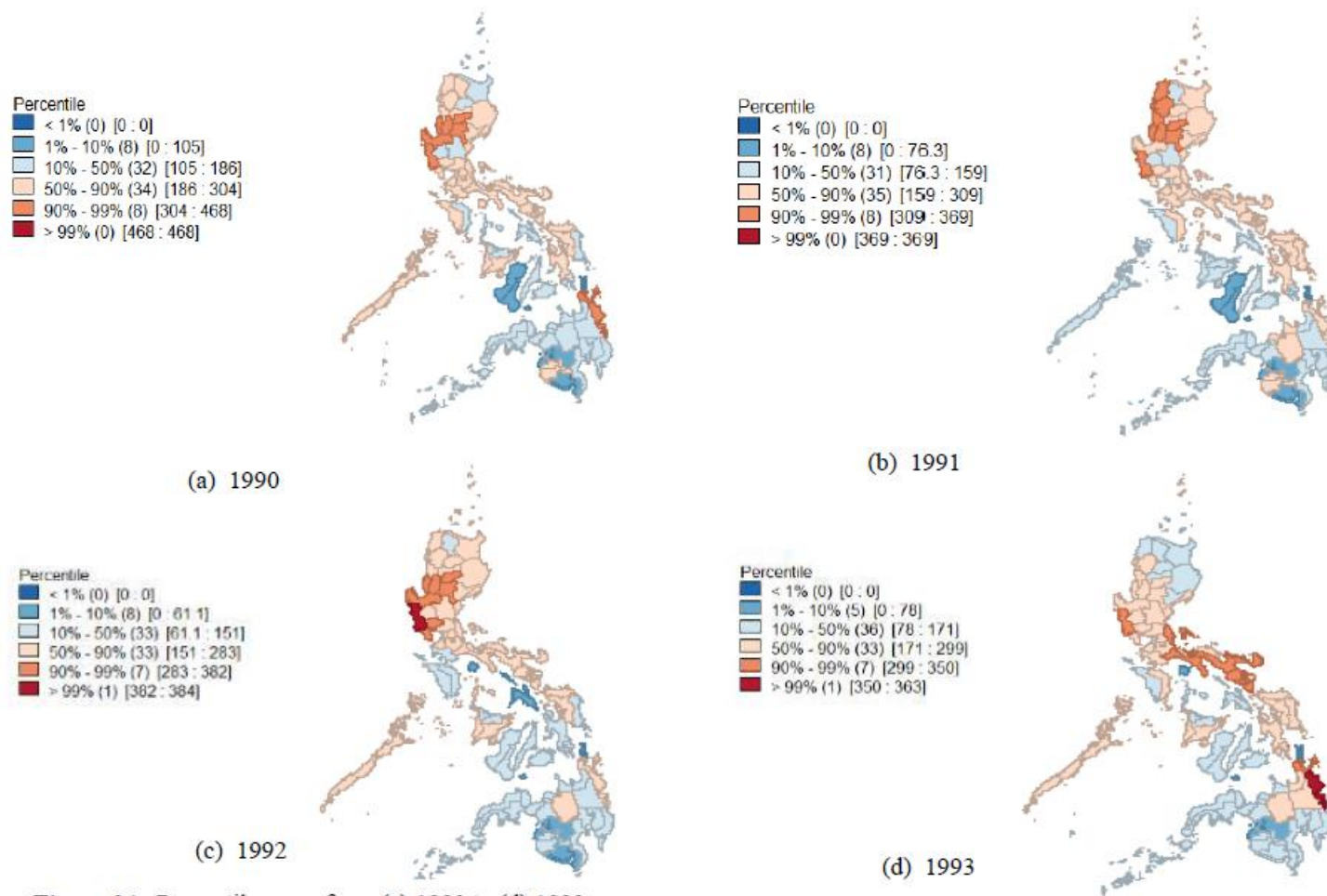
(d) 1993

Figure 34. Percentile maps from (a) 1990 to (d) 1993

Figure 34 shows the percentile map from year 1990 to 1993. Figure 34 (a) shows that for year 1990, the greatest amount of rainfall on the said year occurred at eight provinces: Zambales, Pangasinan, Benguet, La Union, Ifugao, Nueva Vizcaya, Surigao del Sur, and Surigao del Norte which is between 304mm and 468mm.

For the year 1991 (Figure 34 (b), it shows that the highest amount of rainfall occurred at Abra, Benguet, Ifugao, Ilocos Norte, Ilocos Sur, La Union, Nueva Vizcaya, and Zambales which is between 309mm and 369mm.

In year 1992 (Figure 34 (c)), the greatest amount of rainfall occurred at Zambales and the other provinces of the northern part of the country which is between 283mm and 384mm.

Figure 34 (d) is for the year 1993 and the highest amount of rainfall happened at Surigao del Sur and the eastern part of the country which is between 299mm and 363mm.

Percentile
- < 1% (0) [0 : 0]
- 1% - 10% (8) [0 : 93.9]
- 10% - 50% (33) [93.9 : 174]
- 50% - 90% (34) [174 : 250]
- 90% - 99% (6) [250 : 347]
- > 99% (1) [347 : 349]

(a) 1994

Percentile
- < 1% (0) [0 : 0]
- 1% - 10% (7) [0 : 103]
- 10% - 50% (34) [103 : 209]
- 50% - 90% (33) [209 : 350]
- 90% - 99% (8) [350 : 489]
- > 99% (0) [489 : 489]

(b) 1995

Percentile
- < 1% (0) [0 : 0]
- 1% - 10% (8) [0 : 123]
- 10% - 50% (32) [123 : 204]
- 50% - 90% (35) [204 : 342]
- 90% - 99% (6) [342 : 416]
- > 99% (1) [416 : 425]

(c) 1996

Percentile
- < 1% (0) [0 : 0]
- 1% - 10% (7) [0 : 57]
- 10% - 50% (34) [57 : 150]
- 50% - 90% (36) [150 : 238]
- 90% - 99% (4) [238 : 396]
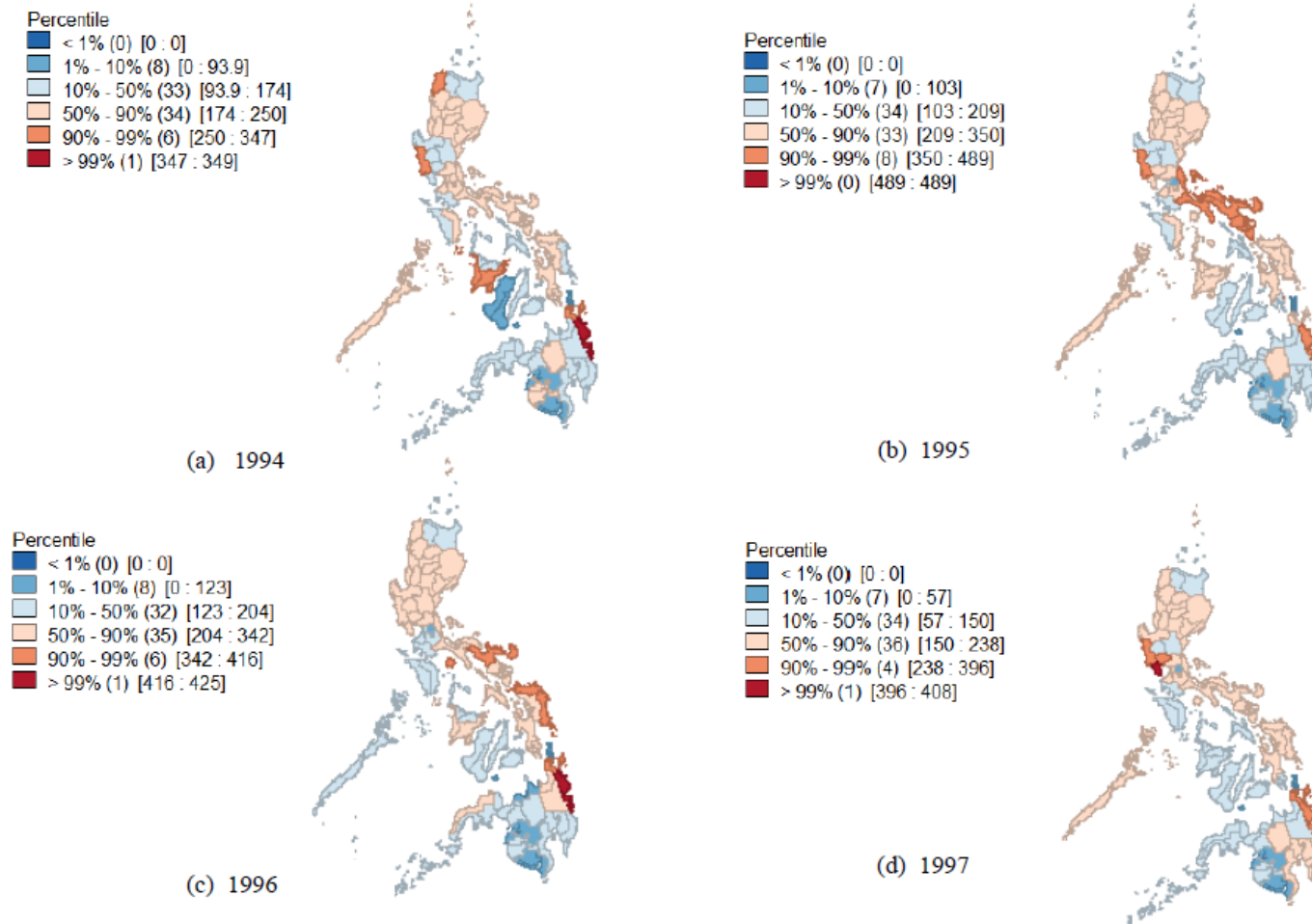- > 99% (1) [396 : 408]

(d) 1997

Figure 35. Percentile maps from (a) 1994 to (d) 1997

Figure 35 shows the percentile maps from 1994 to 1997. Figure 35 (a) displays that great rainfall occurred at Surigao del Sur which reached 349mm. The northern and eastern parts of the country also received a high amount of rainfall which is between 174mm and 347mm.

For the year 1995 (Figure 35 (b)), Albay, Camarines Norte, Camarines Sur, Catanduanes, Quezon, Sorsogon, Surigao del Sur, and Zambales have experienced great amount of rainfall which falls between 350mm and 489mm.

For the year 1996 (Figure 35 (c)), Surigao del Sur had received a very high amount of rainfall which is 425mm. The eastern part of the country has also high amount of rainfall which is between 342mm and 416mm.

Figure 35 (d) shows the percentile map for the year 1997. Bataan has the highest amount of rainfall in the said year which is 408mm. The northern, eastern and some province of the southern part of the Philippines has also experienced high amount of rainfall that is between 150mm and 396mm.
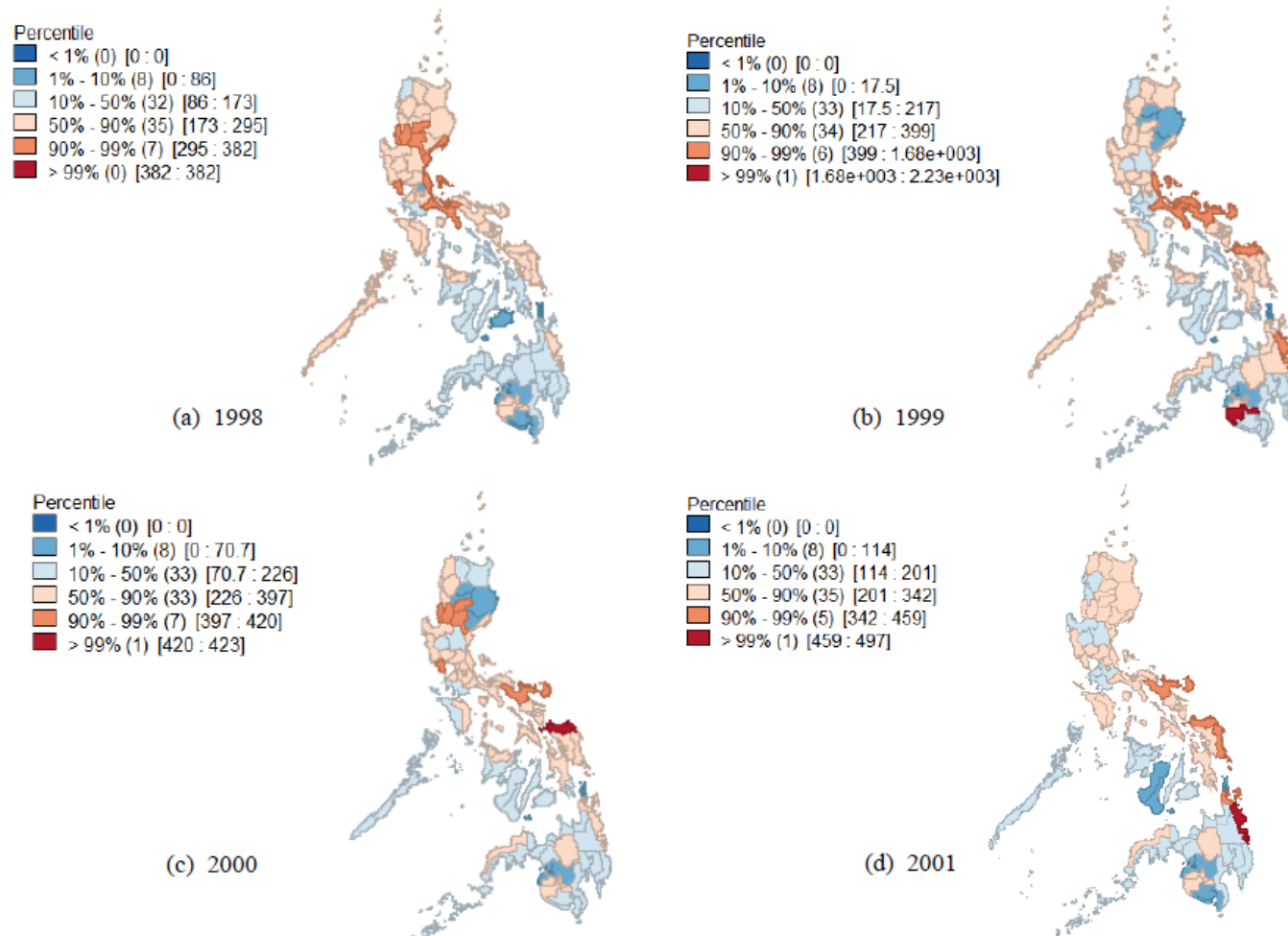
Figure 36. Percentile maps from (a) 1998 to (d) 2001

Figure 36 shows the percentile maps for the year 1998 to 2001. In Figure 36 (a), Aurora, Bataan, Benguet, Ifugao, La Union, Nueva Vizcaya, and Quezon has the highest amount of rainfall for the said year which is between 285mm and 382mm. These provinces were followed by the other provinces located in the northern part of the country between 173mm and 295mm.

The percentile map for year 1999 (Figure 36 (b)) shows that Sultan Kudarat has received a high amount of rainfall which is 1600mm. The eastern part of the country also experienced high amount of rainfall which is between 399mm and 1600mm.

For the year 2000 (Figure 36 (c)), Northern Samar experienced great amount of rainfall over the year which is 423mm.The western part of Luzon and other parts of Visayas Island has received rainfall between 226mm and 420mm.

For the year 2001 (Figure 36 (d)), Surigao del Sur has the greatest amount of rainfall received over the said year which is 497mm. The northern and eastern parts of the country has also received high amount of rainfall which is between 201mm and 459mm.
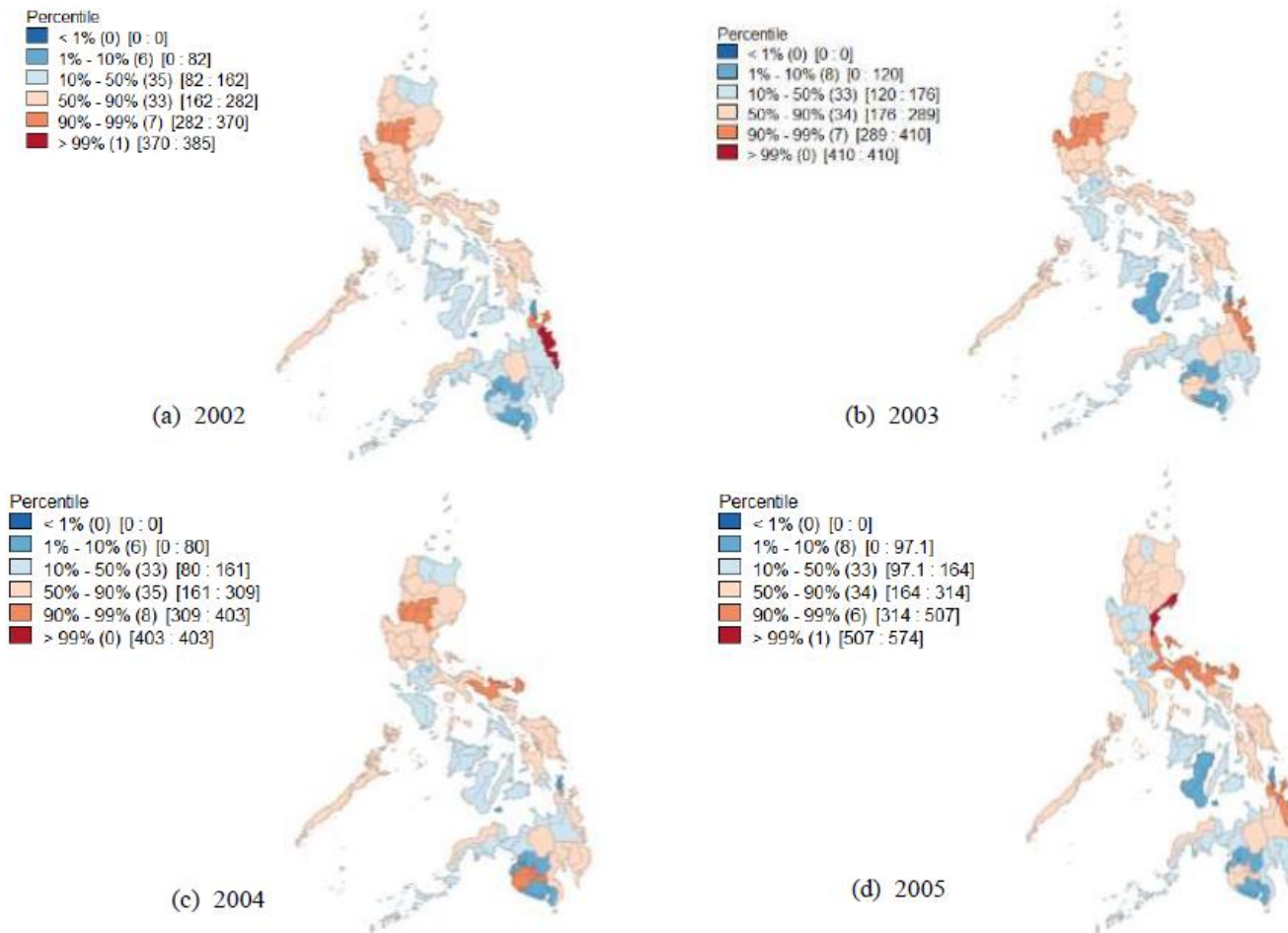
(a) 2002

(b) 2003

(c) 2004

(d) 2005

Figure 37. Percentile maps from (a) 2002 to (b) 2005

Figure 37 illustrates the percentile maps from 2002 to 2005. Figure 37 (a) shows that Surigao del Sur has the highest amount of rainfall on the year 2002 which is 385mm. The northern part of the country has also received high amount of rainfall which is between 162mm and 370mm.

For 2003 (Figure 37 (b)), the provinces which has the highest amount of rainfall are Benguet, Ifugao, La Union, Nueva Vizcaya, Pangasinan, Surigao del Norte, and Surigao del Sur which is between 289mm and 410mm while the southern parts of the country has rainfall that falls between 120mm and 176mm.

For 2004 (Figure 37 (c)),   the provinces of Benguet, Camarines Sur, Catanduanes, Ifugao, La Union, Maguindanao, Nueva Vizcaya, and Sultan Kudarat experienced great amount of rainfall which is between 309mm and 403mm. The other provinces of the northern and southern parts of the country has also experienced high amount of rainfall which is between 161mm and 309mm.

For the year 2005 (Figure 37 (d)), the province of Aurora received the highest amount of rainfall over the year which is 574mm. The eastern and northern parts of the state has also high amount of rainfall which is between 164mm and 507 mm.

(a) 2006

(b) 2007

(c) 2008

(d) 2009
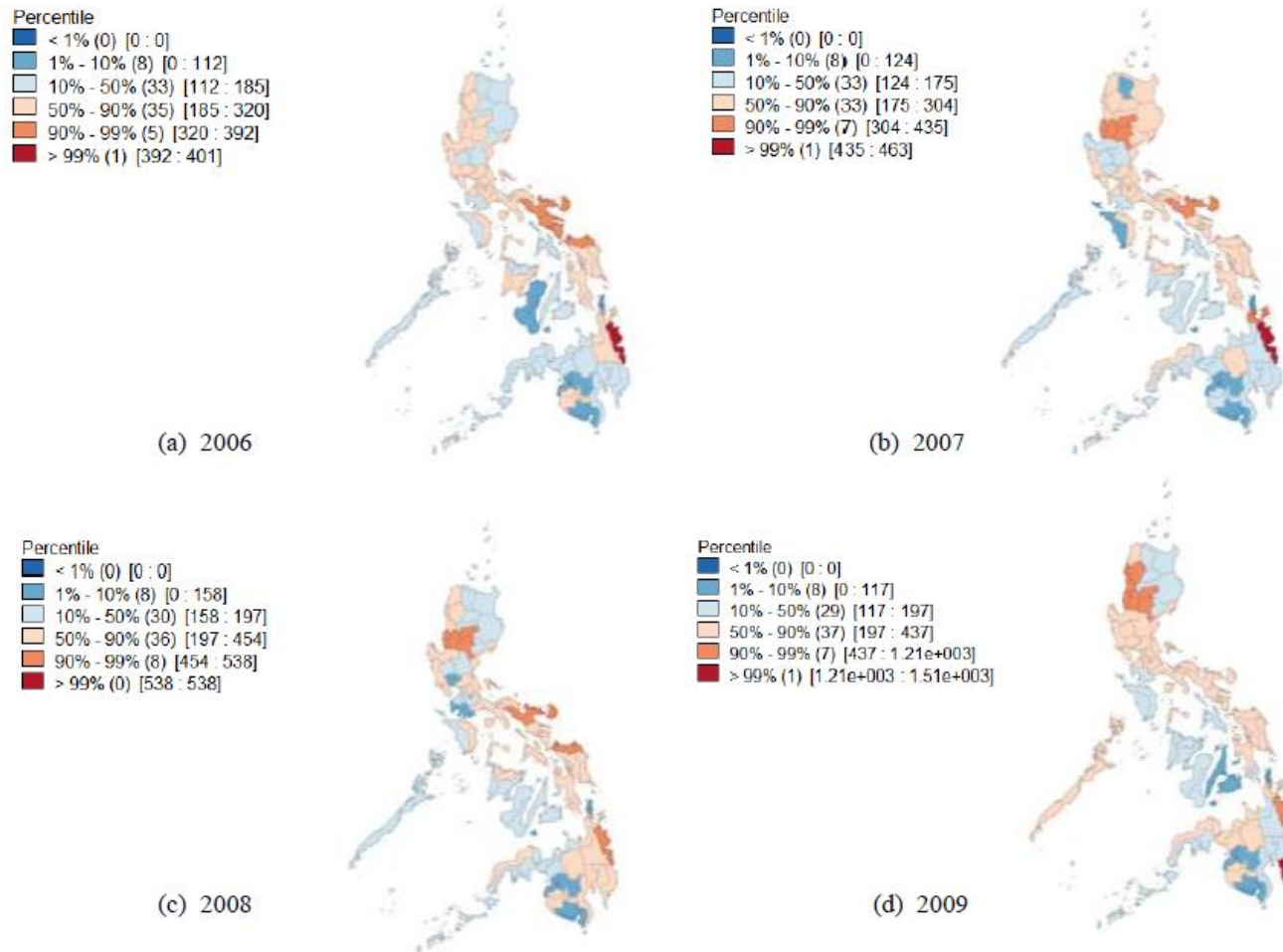
Figure 38. Percentile maps from (a) 2006 to (b) 2009

Figure 38 shows the percentile maps for 2006 to 2009. Figure 38 (a) is for the year 2006. Surigao del sur has the highest amount of rainfall for the said year which is 401mm. The western and eastern part of the Philippines has also high amount of rainfall which is between 185mm and 392mm.

For the year 2007 (Figure 38 (b)), Surigao del Sur has the greatest amount of rainfall over the year which is 464mm. The northern part of the country has also high amount of rainfall which is between 175mm and 435mm.

For the year 2008 (Figure 38 (c)), the provinces of Benguet, Camarines Sur, Catanduanes, Ifugao, La Union, Northern Samar, Nueva Vizcaya, and Surigao del Sur received the highest amount of rainfall over the year which is between 454mm and 538mm.

For 2009 (Figure 38 (d)), the province of Davao Oriental experienced the highest amount of rainfall in the year 2009 which is 1513mm.The northern and other provinces of southern part of the country has also received high amount of rainfall which is between 437mm and 1213mm.

Percentile
- ■ < 1% (0) [0 : 0]
- ■ 1% - 10% (8) [0 : 93.7]
- □ 10% - 50% (33) [93.7 : 176]
- □ 50% - 90% (33) [176 : 323]
- ■ 90% - 99% (7) [323 : 427]
- ■ > 99% (1) [427 : 443]

(a) 2010

Percentile
- ■ < 1% (0) [0 : 0]
- ■ 1% - 10% (0) [0 : 0]
- □ 10% - 50% (41) [0 : 219]
- □ 50% - 90% (34) [219 : 434]
- ■ 90% - 99% (6) [434 : 648]
- ■ > 99% (1) [648 : 675]

(b) 2011

Percentile
- ■ < 1% (0) [0 : 0]
- ■ 1% - 10% (0) [0 : 0]
- □ 10% - 50% (41) [0 : 163]
- □ 50% - 90% (33) [163 : 380]
- ■ 90% - 99% (7) [380 : 464]
- ■ > 99% (1) [464 : 476]
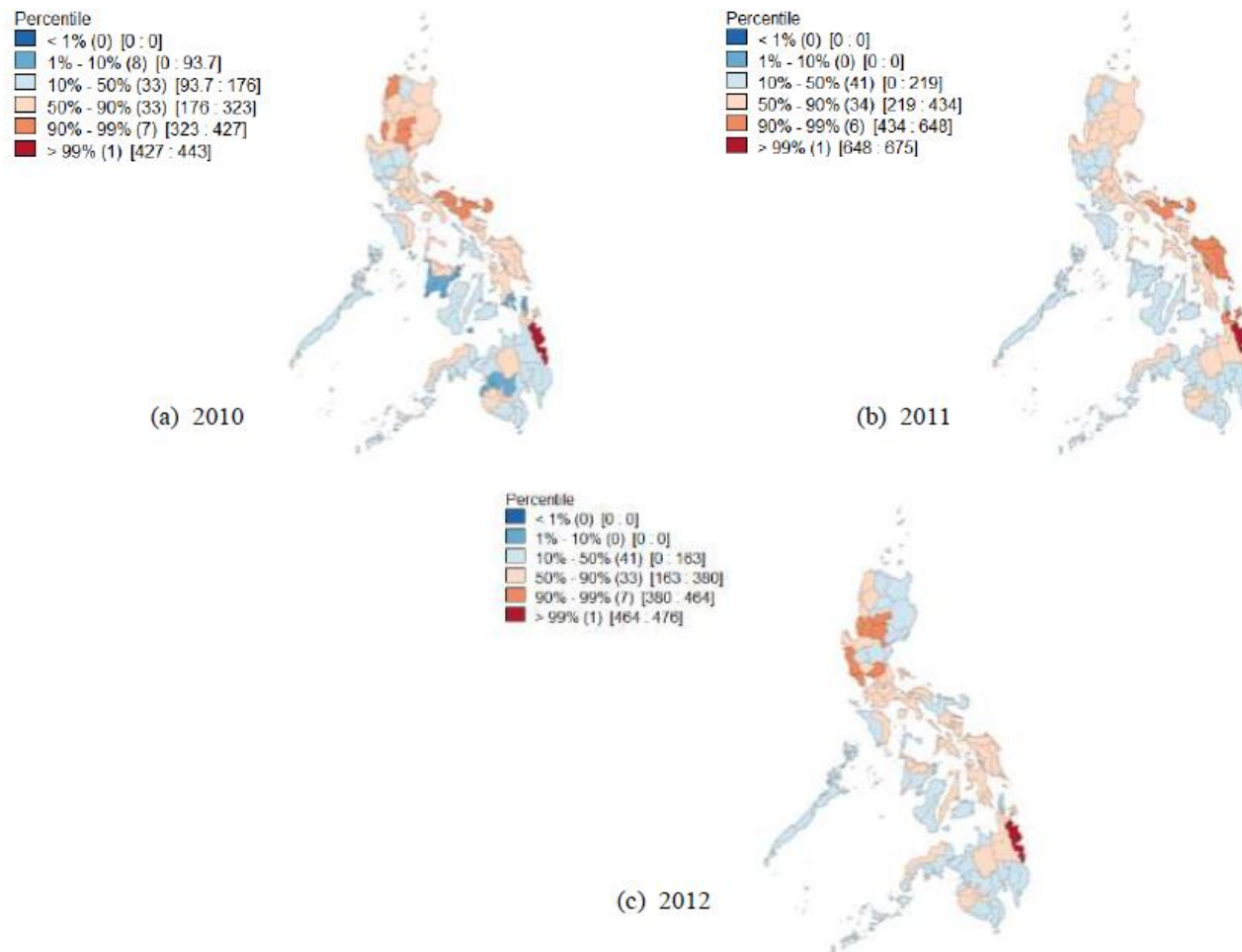
(c) 2012

Figure 39. Percentile maps from (a) 2010 to (c) 2012

Figure 39 shows percentile maps from 2010 to 2012. Figure 39 (a) shows that Surigao del Sur has experienced the highest amount of rainfall for the year 2010 which is 443mm. The northern part of the country has also high amount of rainfall which is between 176mm and 437mm.

For year 2011 (Figure 39 (b)), Surigao del Sur also has the greatest amount of rainfall over the year which is 675mm. The northern part of the country has also received high amount of rainfall which is between 219mm and 648mm.

For the year 2012 (Figure 39 (c)), Surigao del Sur also has the highest amount of rainfall receives for the said year which is 476mm. The western and middle parts of the country has also received high amount of rainfall which is between 163mm and 464mm.

Table 4 shows the spatial autocorrelation coefficients. All of the coefficients imply positive autocorrelation or dependence except for the year 1999 which is negative.

Table 4. Spatial autocorrelation coefficients.

The cluster maps shown below illustrates how the attribute rainfall clusters. The

YEAR	MORAN'S I	YEAR	MORAN'S I
1990	0.51	2002	0.48
1991	0.46	2003	0.31
1992	0.59	2004	0.44
1993	0.45	2005	0.31
1994	0.21	2006	0.42
1995	0.45	2007	0.39
1996	0.38	2008	0.36
1997	0.31	2009	0.11
1998	0.44	2010	0.31
1999	-0.09	2011	0.38
2000	0.35	2012	0.25
2001	0.33		

red color shows tracts where high rate cluster with high rates, and blue shows where low rates cluster with low rates.   There is even a mix of high-low, which is the pink color for the following graphs. So, there is a cluster of high rainfall and clusters of lower rainfall. The values enclosed in the parentheses refers to the number of units in each cluster.

Since a significant spatial autocorrelation exists for the rainfall events in the Philippine provinces, spatial prediction can be conducted but in this case, spatio-temporal analysis was conducted to account for both time and space.
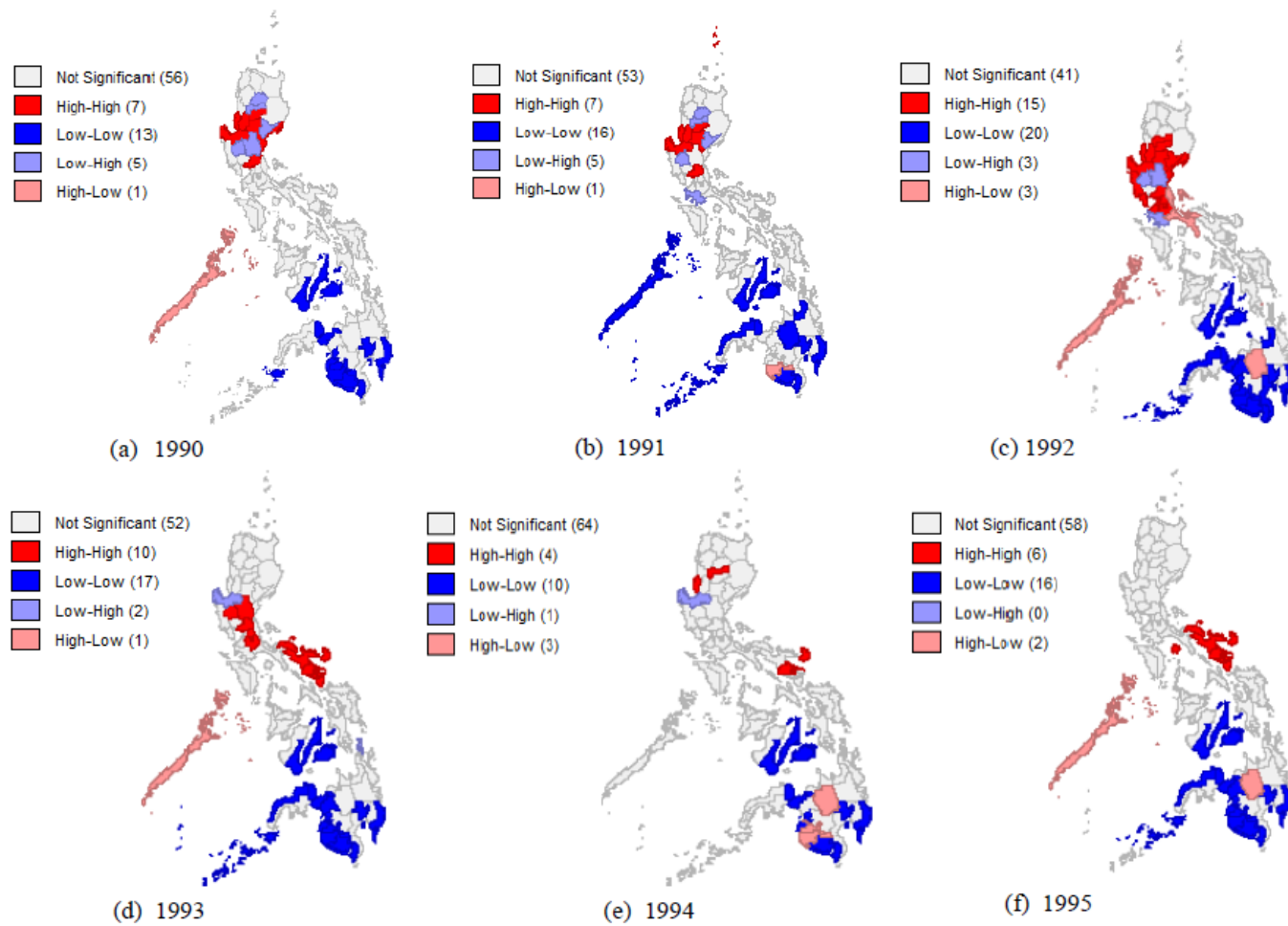
Figure 40. Cluster maps from (a) 1990 to (f) 1995

The test of effects in mean structure of the model was tested. Since the p-value is less than 0.05, the model is significant.

The quality of the model was assessed using mean squared error (MSE). In this case, the MSE (4.42E-20) is very small which means that the model fits.

Autoregressive orders specify which previous values are used to predict current values. This is to specify the number of previous records that are used to calculate a new value. This table shows the autoregressive coefficients. These are estimated based on the residuals from the mean structure model accounting for spatial dependence. The lag is up to five and the coefficients are as shown in the table above. Since the p-values are all less than 0.05, the coefficients are significant. This means that the model can be used to predict up to five months.

Table 5. Autoregressive coefficients.

LAG	COEFFICIENT	SIG.
1	0.30	0.00
2	0.17	0.00
3	0.07	0.00
4	0.03	0.00
5	-0.04	0.00

The test of spatial covariance is one of the criteria that are used to determine whether a variogram-based model is appropriate. A variogram is a description of the spatial continuity of the data. After testing the spatial covariance model, the p-value is less than 0.05, it means that the model is significant. The significance of this model is supported by the spatial correlations and covariances shown in Table 6.
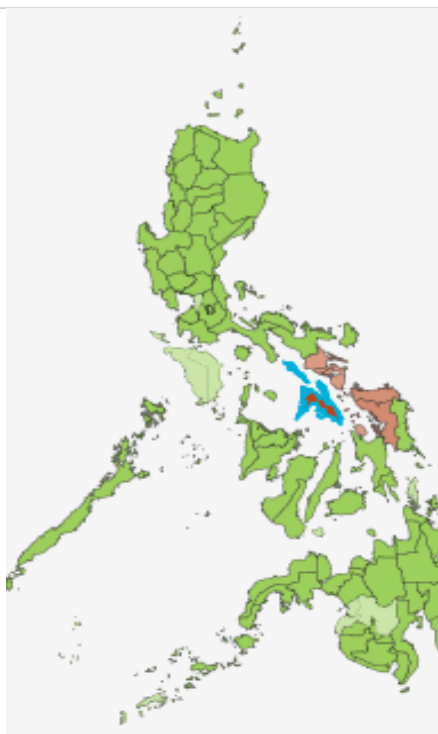
Figure 44. Correlations heat map

This figure shows the correlation heat map of the Philippines. Heat maps are well-suited for visualizing large amounts of multi-dimensional data and can be used to identify clusters with similar values, as these are displayed as areas of similar color. The selected province is Masbate and the other highlighted provinces are the top related regions with the said province that were discussed in the table 6.

Table 6 shows the spatial covariance and correlation of the provinces stated above. The top related provinces with Masbate are Samar, Northern Samar, Sorsogon, Albay, and Biliran with moderate spatial correlations and covariances listed in the table.

Table 6. Top five related regions.

REGION	SPATIAL COVARIANCE	SPATIAL CORRELATION
Samar	12 057.94	0.63
Northern Samar	15 879.43	0.60
Sorsogon	12 919.95	0.54
Albay	12 907.29	0.54
Biliran	9 327.78	0.53

Figure 45. Correlations map

This figure above shows the correlations map for the top two spatially correlated provinces in the country in terms of rainfall amount through the past years which was described in the table below.

Table 7 shows the correlation between the top two correlated provinces in the country. It significantly explains a strong positive correlation between the two.

Table 7. Spatial correlation matrix.

| REGION	Laguna	Cavite
Laguna	1.00	1.00
Cavite	1.00	1.00

Table 8 shows the spatial covariance matrix for the top two related provinces in the country. 39 312.08 is the spatial covariance between them which means that they are positively related with each other.

Table 8. Spatial covariance matrix.

REGION	Laguna	Cavite
Laguna	39 307.94	39 312.08
Cavite	39 312.08	39 076.89
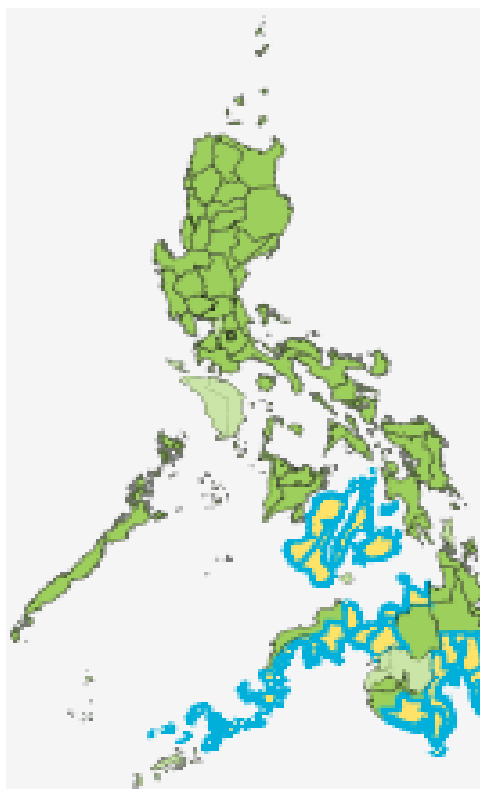
Figure 46. First clustering locations

The yellow highlighted provinces are the first clustering locations with 0.60 correlation. They are located in the southern part of the country. These (18) provinces are Negros Occidental, Negros Oriental, Cebu, Bohol, Basilan, Zamboanga del Sur, Zamboanga Sibugay, Misamis Occidental, Misamis Oriental, Lanao del Norte, Lanao del Sur, South Cotabato, Sarangani, Davao del Norte, Davao del Sur, Davao Oriental, Compostela Valley, and Sulu.
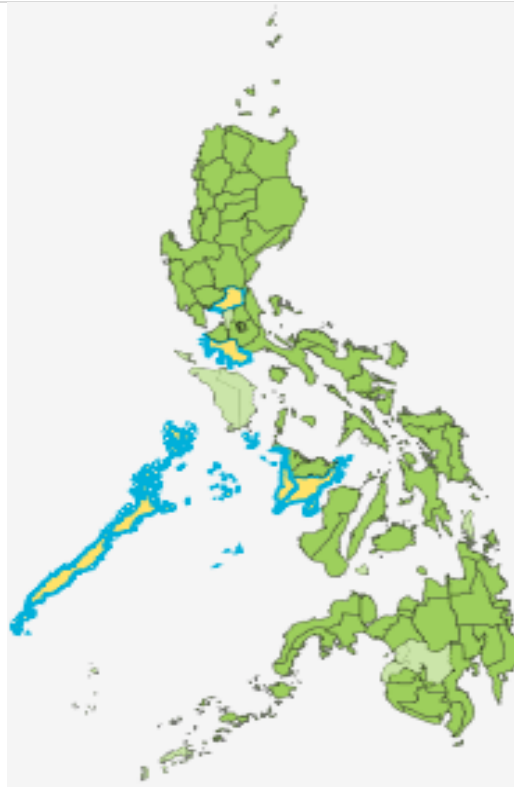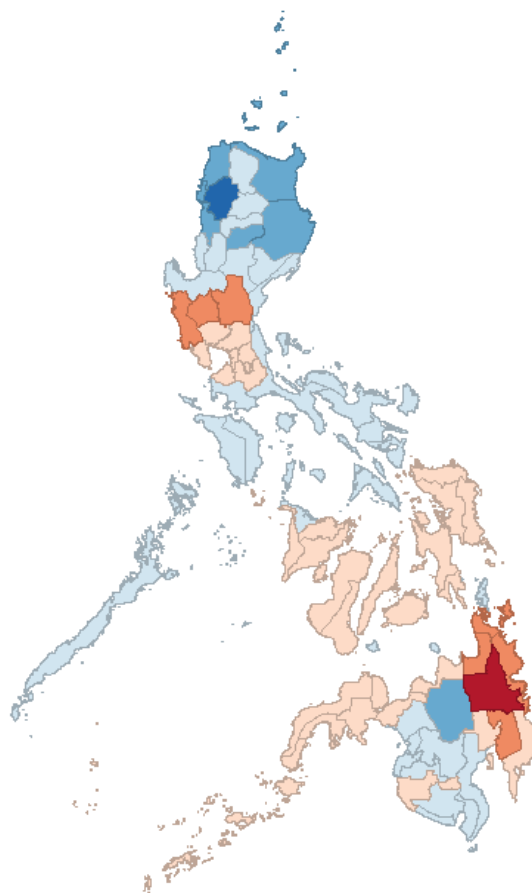
Figure 47. Second clustering locations

The yellow highlighted provinces are the second clustering locations with also 0.60 correlation. They are located in the western part of the country. These (5) provinces are Palawan, Batangas, Bulacan, Antique, and Ilo-ilo.

Prediction

Figure 48. Predicted pattern of rainfall for
January 2013

This figure shows the predicted pattern of rainfall for January 2013 accounting for both spatial and temporal property. It can be observed that the central and southern parts of the Philippines has darker shade which means that this part received great amount of rainfall during the said date.

Based on Japan Meteorological Agency (JMA), (2013), early on January 1, a tropical depression had developed about 1,090 km (675 mi) southwest of Guam. The center passed over the Philippine island of Mindanao. During the next day, PAGASA named the depression Auring. During the 6th day of the same month, a tropical depression had developed, about 480 km (300 mi) to the southeast of Melekeok, Palau. Over the next few days the JMA continued to monitor the system as a tropical depression, before PAGASA named it Bising during January 11. It was last noted during January 13, as it weakened into an area of low pressure. Bising caused moderate to

heavy rains across Bicol Region, Eastern Visayas, Central Visayas and Mindanao. The other parts of Luzon also experience light rains (Padua, 2013).
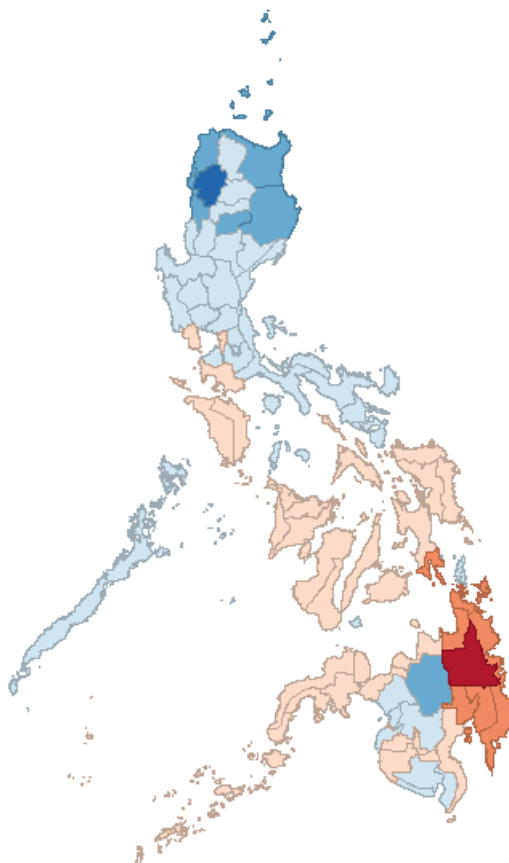
Figure 49. Predicted pattern of rainfall
for February 2013

The predicted pattern of rainfall for February 2013 was shown in the figure above. The southern part was still expected to receive the highest amount of rainfall on February of 2013.

JMA (2013) stated that on February 18, a tropical depression formed about 650 km (405 mi) east of southern Mindanao, with PAGASA naming it Crising with the center located at 750 km Southeast of General Santos City. Typhoon Signal No. 1 was immediately declared over Davao del Norte, Davao del Sur, Davao Oriental and Compostela Valley, Samal Island, the southern part of Surigao del Sur, Agusan del Sur, Bukidnon, Lanao del Norte, Lanao del Sur, North Cotabato, Maguindanao, Sultan Kudarat, South Cotabato, Sarangani, Misamis Occidental, Zamboanga del Norte, Zamboanga del Sur, Zamboanga Sibugay, Basilan, Sulu and Tawi-Tawi. With low to moderate wind shear, the depression developed further. The JMA reported that the depression intensified into Tropical Storm Shanshan on February 21.
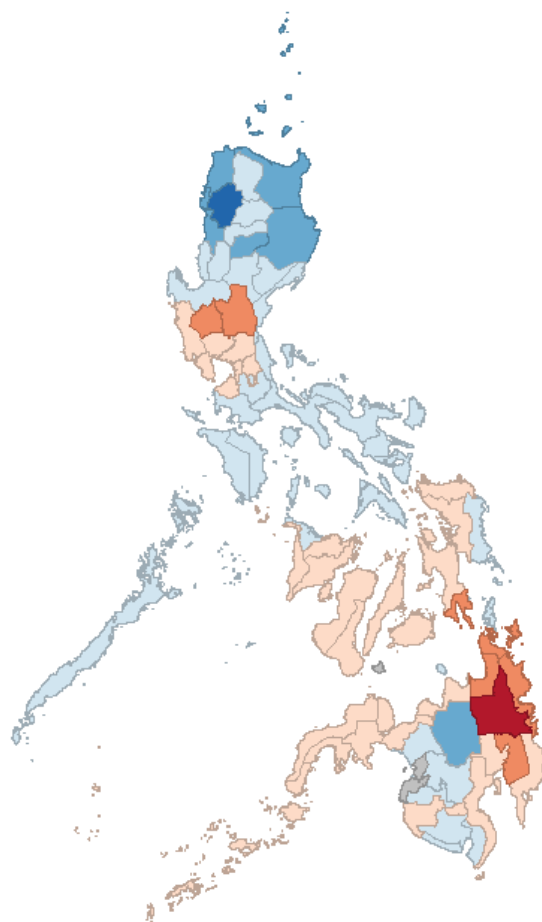
Figure 50. Predicted pattern of rainfall for
March 2013

This figure shows the predicted pattern of rainfall for March 2013. The central and southern parts of the Philippines experienced great amount of rainfall during the said month. There has been no heavy rain reported during this month but according to Servando (2012) from PAGASA, there has been consistent rainfall pattern for January and February that can occur during March because based on PAGASA, 2-3 tropical cyclones always visits Philippines in the periods January to March.

Only tropical depression visited the country. Early on March 20, the JMA reported that a tropical depression had developed about 1,470 km (915 mi) to the southeast of Manila influencing other parts of Luzon, in an area of moderate vertical wind shear. Over the next two days the system moved towards the west-northwest, before it was last noted by the JMA during March 22, as it dissipated over Southern Mindanao. (Young, 2013) This statement supports the pattern above in which the central and Southern Mindanao has darker shades than the others.
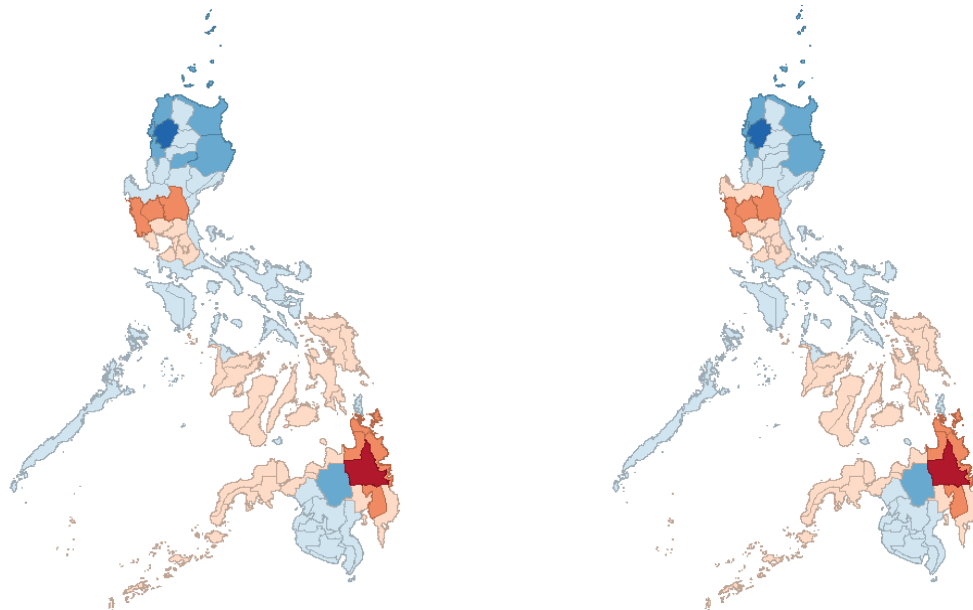
Figure 50. Predicted pattern of rainfall for April and May 2013

Figure 51 shows the predicted pattern of rainfall in the Philippines for April 2013. Still, the central and southern parts of the country had great amount of rainfall during that particular date. This pattern did not happen during the said date but there was just that possibility that it might have happened because according to Young (2013), PAGASA predicted that two to four tropical cyclones were predicted for the April to June period that may happen in the Philippines.

SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

Summary

Considering the vulnerability of the country to extreme rainfall events, this study aims to study the patterns and forecast rainfall given data from different weather stations for the benefit of the citizens residing in the Philippines. Through the use of spatio-temporal analysis, the researcher was able to study the patterns given space and time.

Spatial maps and time graphs that describe the rainfall amounts were made thoroughly. Through spatial maps, it was found out that every year, the northern part of the country had been receiving great amount of rainfall. However, there were some adjustments and differences in the provinces receiving great amount of rainfall year on year. At some points, the southern part of the country that used to be less vulnerable to rainfall also experienced heavy rains specially the province of Surigao del Sur. The time graphs show that all of the locations had seasonal patterns.

Moran's I test was used to test for the spatial dependence for every year. Except for 1999, the remaining years showed positive spatial autocorrelations which was visually shown via cluster maps.

At 5% level of significance, it was found out that the model was significant. The autoregressive coefficients up to 5 lags were also significant. Correlation heat map and map of the clustering locations were also conducted. Correlation heat map shows the top five related regions with Masbate (selected region) namely: Samar, Northern Samar, Sorsogon, Albay, and Biliran with high spatial correlations. The map of clustering locations were discussed as: the first cluster are the (18) provinces which are Negros Occidental, Negros Oriental, Cebu, Bohol, Basilan, Zamboanga del Sur, Zamboanga Sibugay, Misamis Occidental, Misamis Oriental, Lanao del Norte, Lanao del Sur, South Cotabato, Sarangani, Davao del Norte, Davao del Sur, Davao Oriental, Compostela Valley, and Sulu. They are located in the southern part of the country. The second clustering locations were: Palawan, Batangas, Bulacan, Antique, and Ilo-ilo. These two clusters have 0.60 spatial correlations.

The spatio-temporal predicted pattern was also made and extracted from the output of SPSS. Five months was forecasted specifically from January to May and was compared to real-life data on weather patterns during this period to verify the prediction validity.

Conclusion

Based on the results and discussions, the following conclusions were made:

1. Every year, the northern part of the country receives great amount of rainfall but as years go by, the southern part of the country which used to be less susceptible to rainfall events experiences great amount of rain specifically the Surigao del Sur province. The time graphs of rainfall on each province was found to have seasonal pattern.

2. Before defining the spatio-temporal structure, on each year, spatial autocorrelation test was conducted using Moran's I test and also, cluster maps were made. Spatial autocorrelation tests showed that except 1999, the remaining years have positive spatial dependence and was significant. There is a cluster of high-high and low-low and also, there is a cluster of high-low rainfall.

3. The increment or interval is by one month starting from January 1990 to December 2012 with 276 unique points (shown in appendix 2). The corrected model was also found to be significant at 5% level of significance. In evaluating this model, mean squared error (MSE) was computed. Since the MSE (4.42E-20) is very small, the model fits.

Based on the result of autoregressive coefficients, the lag is up to five and the coefficients are all significant. The test for spatial covariance model was also found to be significant as it is very important to account for spatial continuity.

The top related and most spatially correlated provinces with Masbate are Samar, Northern Samar, Sorsogon, Albay, and Biliran with moderate spatial correlations.

The clustering locations are also made and described as: the first cluster are the provinces of Negros Occidental, Negros Oriental, Cebu, Bohol, Basilan, Zamboanga del Sur, Zamboanga Sibugay, Misamis Occidental, Misamis Oriental, Lanao del Norte, Lanao del Sur, South Cotabato, Sarangani, Davao del Norte, Davao del Sur, Davao Oriental, Compostela Valley, and Sulu. They are located in the southern part of the country. The second clustering locations were: Palawan, Batangas, Bulacan, Antique, and Ilo-ilo. These two clusters have 0.60 spatial correlations.

Rainfall pattern was predicted and was verified the pattern by comparing the predicted and the actual rainfall during January to May of 2013.

Recommendation

The researcher would like to recommend that predictors should be included in the model such as land area, population, and other factors that can affect rainfall. It was also recommended that the use of ArcGIS software is better in conducting a spatio-temporal analysis as it can visually show the changes through time. Reading more about this analysis and digging deeper through related literatures can also be a great help in understanding the said analysis more.

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