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Precipitation Modeling of Gwadar Port Baluchistan for Environmental Sustainability using Multilinear Regression Analysis Technique

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Abstract

Precipitation is the main source of fresh water in the water cycle. Climate change, because of global warming and the consequent change in the water cycle, is a global security issue. It would significantly influence water and food security. Disasters such as floods and droughts would lead to an adverse effect on the economy, peace, and geo-political situation around the world. In the present study, the change in precipitation patterns at Gwadar port is quantified in the context of climate change since it is the crown jewel in the China-Pakistan Economic Corridor (CPEC), as well as a vital part of One Belt One Road (OBOR) project. A data set of 40 years (1979-2018) is analyzed utilizing Mann-Kendall (MK) technique for precipitation trend detection, and Multi-Linear Regression Analysis (MLR) to develop a model of the study area. The model presents the potential determinants causing the variability in the precipitation patterns of the selected region. The model developed accounts for 80.47% (51.16%) of precipitation variability. The model successfully passed all estimation tests. This research will help the policymakers in legislation. The research also addresses United Nations Sustainable Development Goals (SDG): SDG# 13 (Climate Action).

Key Words: Precipitation, Mann-Kendal, Multiple Linear Regression, Statistical Modeling, Trend, Variables, Sustainable Development Goals (SDGs*)*

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1. INTRODUCTION

Today's world focus is on climate change and global warming keenly as climate change has its impact on economy, security, and the environment. Climate change is a reality and has a direct impact on global security and world politics. Since the end of the cold war, the concept of security has evolved and incorporates everything that revolves around the development and prosperity of a state (Ball, 2019). McNamara's concept of security best explains why preserving the environment becomes essential for the prosperity and development of the world at large and states in particular (Ball, 2019). The Copenhagen School of thought has projected the theoretical understanding of sustaining an environment essential for the overall security and development of a state. Without sustaining the environment, security cannot be achieved (Buzan,2007). According to UN Secretary-General António Guterres, the outcome of COP26 is a compromise, though it reflects the interests, contradictions, and state of political will in the world today (UN, 2021).

One cannot ignore the fact that the states are not doing enough to meet the requirements of climate change reality today, considering the rapidly changing requirements. Drastic measures at the global level are required to control climate change damage and preserve humankind from extinction. The Glasgow Climate Pact 2021, attended by around 200 countries, expresses an alarming environmental situation (UNEP, 2021). The conference shows utmost concern that human activities have caused around 1.1°C of global warming to date and that impacts are already being felt in every region. Parties also recognize that the impacts of climate change will be much lower at a 1.5°C rise compared with 2°C, and resolve to pursue efforts to keep to 1.5°C.

Climate study has become inevitable for Pakistan because of the high risk and vulnerability of the country's climates. Pakistan is ranked as the 8th most impacted country due to climate change, by Global Climate Risk Index 2020 (Eckstein, Hutfils, Winges, & Index, 2019). Managing with the death toll of 510 persons, Pakistan has borne the damage of US $ 3.8 Billion. Pakistan had experienced 145 climate-related incidents that smacked Pakistan in from 1998 to 2017 (Eckstein et al., 2019). Pakistan stands as 3rd highly impacted country in 2012 rating, by the influence of climate change (Kreft, Eckstein, & Melchior, 2013). According to the United Nations Development Programme (UNDP) 2020 report and Pakistan Council of Research in Water Resources (PCRWR) report, Pakistan will be a water-scarce country from the water-stressed country in 2025 (Ashraf, 2021) if it fails to take concrete measures and mitigation now as the condition continues to get worse in Baluchistan. Precipitation, the most important source of water in Baluchistan, is decreasing also. Baluchistan undergoes destructive, disastrous flash floods due to unprecedented precipitation in its rugged terrain, hills, and mountain. Although Baluchistan has a thriving economy, the present importance of the region is unprecedented due to the China-Pakistan Economic Corridor (CPEC) d the international warm deep-sea Gwadar port. The Port holds a slight edge due to its natural hammerhead location and utility. A strategic cargo route from Gwadar port can directly reach Western China through Pakistan than moving across China as shown in Figure1. This trade route is also a part of One Road One Belt (OROB).

Figure 1. Strategic cargo route from Gwadar port to Western China.

Additionally, this research would be beneficial for policymakers to grasp the most recent scenario in the light of climate change and make policies, guidelines, strategies and programmes accordingly (IPCC, 2013).

Gwadar Port, the crown jewel of CPEC, is located in Baluchistan; the biggest province of Pakistan in terms of land with an area of 347,190 Km^2 which is about 44 % of Pakistan's total landmass. Baluchistan province is located in the southwestern part of Pakistan as indicated in Figure-1 (Naz, Dars, Ansari, Jamro, & Krakauer, 2020); Ashraf, 2017; Muhammad Ashraf & Routray, 2015). Baluchistan is dry, hilly, and rocky with both flat and rugged regions. The climate is a hot and desert type with low and high temperatures (Butt & Iqbal, 2009). Baluchistan's economic, and commercial source of growth depends on its upwelling shoreline, all along the Arabian Sea, on renewable resources such as coal, natural gas, gemstones, zinc, lead, copper, and marble, etc. Hence, Baluchistan is of outstanding significance because all three routes, i.e., western, eastern, and central CPEC routes meander through it.

Monsoon and the western disturbance are two important seasonal prevailing winds that impact the weather in Pakistan. During the winter season, western disturbance brings light to modest rainfall in southern parts, and modest to strong rainfall along with strong snowfall in the northern parts of Pakistan. In the summer season, the Monsoon rainfall occurs from June till September throughout Pakistan except for regions like Western Baluchistan, Chitral, and Gilgit–Baltistan. The Monsoon rainfalls are relatively strong by nature and are able to produce major flooding if they act together with western disturbances in the northern parts of Pakistan. Tropical storms usually occur in pre-monsoon months commencing from late April to June and then from September to November, affecting the coastline areas. Continental air predominates during the period causing very little to no precipitation (Hussain & Lee, 2014; Zahid & Rasul, 2011).

The western disturbances have a great influence on the weather of Baluchistan during the winter and spring months. The effect of the monsoon on the summer of this region is very mild. The effect of tropical storms in coastal areas is in autumn (Aamir et al., 2018; Ahmed, Shahid, & Nawaz, 2018; Gadiwala, Burke, & Geology, 2019; Sheikh et al., 2015; Aamir and Hassan 2020; Ahmed et al. 2015; Ashraf et al. 2015).

The non-parametric statistical technique Mann Kendall (MK) is the most extensively used technique in climate studies for detecting trends. It is a well-proven statistical test to find the precipitation trends on monthly, seasonal, and annual levels in climatology (Latif & Syed, 2016). (Ahmad, Tang, Wang, Wang, & Wagan, 2015) conducted a climate study using the MK test and Spearman’s Rho test. His area of study was the basin of Swat River, Pakistan. Another study conducted by Iqbal and Athar (2018) also selected MK statistical technique for trend analysis and most recently Naz et al. (2020) selected the MK technique to identify the trends and severity of drought in Baluchistan. Most of the researchers have used the Mann-Kendall test to find the trend analysis of Baluchistan for drought analysis but no study has focused on the prediction and modeling of precipitation patterns. To the best of the knowledge of the authors, this paper will be the first precipitation prediction model of Gwadar port using the Multiple Linear Regression technique.

The Multiple Linear Regression technique is one of the most common and extensively used technique. It is recently used by Faidah et al. (2022) for improving the rainfall prediction in Surabaya City, Indonesia. The MLR model developed is powerful and addresses 80.47% and 51.16% of precipitation variability for July. The model developed is good, as indicated by the performance indices. The study also focuses on two of the Sustainable

Development Goals (SDGs) intended to transform our world i.e., Goal 13: Climate Action and Goal 11: Sustainable Cities and Communities by reducing the negative impact of natural disasters, such as flooding or drought. The study also aims to educate people and create awareness about climate-related hazards, global warming, rise in sea level etc.

The study of variation of precipitation and predictability as to the outcome of this research also provides a very useful tool in the field of environmental engineering. It is useful for designing, functional operation of the facilities, and their periodical maintenance of structure related to irrigation, hydrology, hydraulic engineering, hydropower, water supply engineering and bridge design etc. In irrigation projects including barrages, dams' regulators, a reservoir for water storage and distribution of surface water through canal precipitation data is a must. Also, irrigation through deep tube well-utilizing groundwater without mining groundwater but maintaining a balance between recharge and discharge is maintained by monitoring precipitation. Flood protection bunds along the banks of the river are built in areas prone to heavy downpours and extreme precipitation. PMD, NDMA, local and provincial governments can use the model prediction to issue weather alerts, warnings against downpours and droughts. The study can help in providing precipitation updates, weather alerts along the CPEC route to improve and secure the international trade route, as the CPEC originates from Gwadar port. It is a well-established fact that the ultimate source of water is precipitation and precipitation is vital for maintaining a sustainable environment and the security of human life on earth.

2. METHODOLOGY

Pakistan's biggest province Baluchistan has the privilege to present the crown jewel of CECP, Gwadar port (Ebrahim, 2021). Gwadar Port is a warm-water, deep-sea port situated on the Arabian Sea at Gwadar city at 25.1105° N, 62.3396° E. The port is situated 533 km from Pakistan's largest city, Karachi, and is nearly 120 km from the Iranian border. It is the key strategic hub for trade and investment in South Asia.

According to the Koppen climate classification, Gwadar city has a hot desert type of climate. It is characterized by less rainfall with a high fluctuation of temperature between summer and winter. Out of the total 1050 Km long coastline of Pakistan nearly 800 km of coastline fall in Baluchistan province (IUCN 2016). The prevailing ocean current direction is clockwise during the southwest monsoon season and anti-clockwise during the northeast monsoon season. Continentality of Gwadar port, the oceanic effect from the current of the Arabian Sea subsides the temperatures in the summer season, resulting in notably cooler summer temperatures compared to other inlands and cities like Dubai located in the Persian Gulf (Forestypedia, 2021).

Figure 2. Gwadar Port and Its Strategic Location in Asia

Oceanic influence from the cool currents of the Arabian Sea moderates' temperatures, resulting in notably cooler summer temperatures compared to areas inland and cities in the Persian Gulf such as Dubai. The Arabian Sea also moderates winter temperatures, resulting in warmer winter nights as compared to inland areas.

Monthly precipitation data in millimeters, for this research paper, was obtained from Pakistan Meteorological Department (PMD). Authentic source, completeness, and accuracy of data were the top priorities while collecting data. The distribution of stations in different climatic regions within Baluchistan is shown in Figure-1. The study period constitutes forty (40) years from 1979-2018. Data collected from PMD was on the monthly basis in (mm/month). The monthly and average precipitation within the study period is tabulated and is attached as Annexure A.

Precipitation data is checked for its normality by applying four well-established tests namely i) Shapiro Wilk W test ii) Anderson Darling Test iii) Liliefors test iv) Jarque Bera test. The dataset was found to be not normally distributed. Since precipitation data is not normally distributed, therefore, nonparametric analysis technique Mann-Kendall is used for trend detection (Libiseller & Grimvall, 2002; Bastiaanssen & Ali, 2003; Bastiaanssen and Ali, 2003; Aamir & Hassan, 2020; Webster, Toma, & Kim, 2011). Trend analysis is the most extensively studied topic in climatology. The MK test is one of the commonly used, statistical technique to detect monotonic trends in data. Regression is a well-established, statistical approach that uses the connection between two or more quantitative variables so that the resultant variable can be predicted. Regression analysis focuses to predict the extent, the dependent variable (resultant) can be speculated from the independent variables. Regression analysis is greatly engaged in business, social, interactive, behavioural sciences analysis, and climate prediction.

3. RESULTS AND ANALYSIS

Precipitation data of the last 40 years (1979-2018) is obtained from Pakistan Meteorological Department (PMD) for analysis. Data was recorded on a daily basis (mm/day) was converted to monthly data to find out the trend on a monthly basis. Out of twelve months, only two months, i.e., July and October, have shown a significant increasing/positive trend when assessed through Mann-Kendall statistical trend detection technique. Mann Kendall statistics for July and October are 214 and 204 respectively, manifesting that both the months have an increasing/positive trend. The slope (change/unit) of July is 0.011 and October is 0.005 indicating that October has a very mild slope.

Multiple Linear Regression (MLR) is adopted to develop the model for the potential determinants causing the variability in precipitation of the two significant months with a positive trend of precipitation based on the Mann Kendall trend detection technique. The objective of the present study is to find the potential determinants of precipitation variability in the international port city of Gwadar using Multi-Linear Regression analysis. The dependent variable in the regression analysis is the time series precipitation data of region 1 in Baluchistan whereas the independent variables (regressors) are the potential determinants including climatic indices and large-scale circulation.

The validity of the model is judged by its performance indices. Most reported statistics in regression are Multiple (R), Coefficient of determination R Square (R^2), Adjusted R Square (Adj R^2) and Sigma (σ). The statistics of these tests for the month of July and October is listed in Table 1 below.

Table 1. Regression Statistics for July and October

Regression Indices	July	October
Pearson correlation coefficient (R)	0.8970	0.7151
Coefficient of determination R^2	0.8047	0.5116
Adjusted R^2	0.7760	0.4558
Sigma	0.2975	0.1654
Observations	40	40

Table 1 shows the performance indices for July obtained using the MLR technique with precipitation as a response variable. The coefficient of determination R^2 came out to be 0.8047 which indicates that 80.47 % variation in precipitation can be estimated by explanatory variables in the regression equation of July. The explanatory variable includes Relative humidity at 500 hpa, Relative humidity at 850 hpa, Uwind at 1000 hap, and VWind at 850 hpa and 1000 hpa. The regression equation for the month of July is given by the following equation:

Precipitation July = 1.813 + 0.0295*RH500 + 0.04537*RH850 + 0.3088*UW1000 + 0.6368*VW850 -0.8911*VW1000

The graphs and histograms between the observed values and estimated/predicted values for the study period are shown in Figures 3 and 4 (for the month of July).

Figure 3. Graph Showing Observed versus Estimated Precipitation of Gwadar

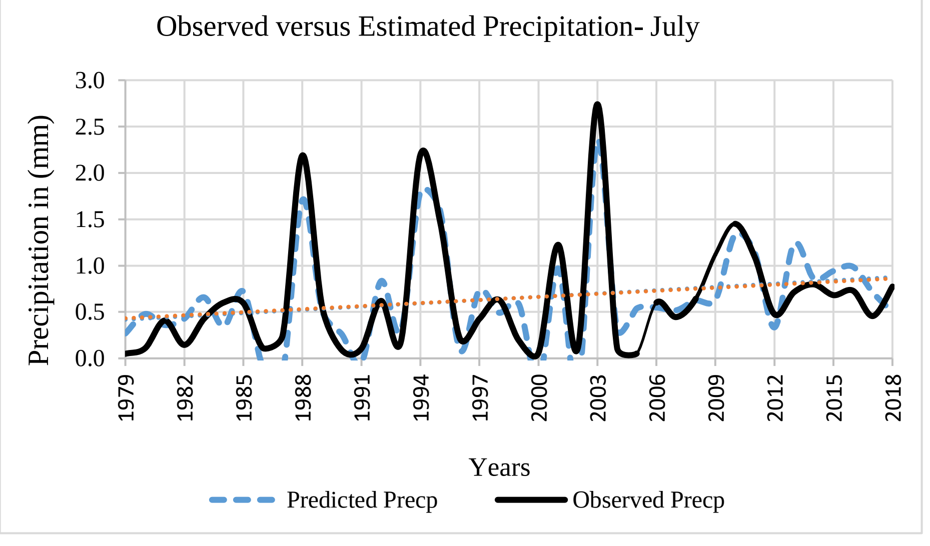


Figure 4. Histogram Showing the Comparison between Observed Versus Estimated Precipitation of Gwadar

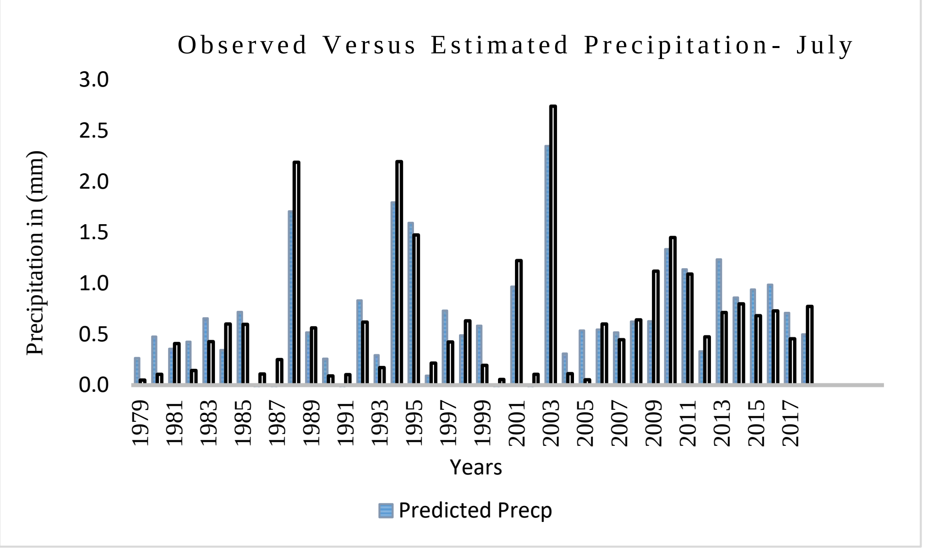


Table 1 shows the performance indices for the month of October with precipitation as the response variable. The coefficient of determination R^2 came out to be 0.5116 which indicates that 51.16 % variation in precipitation can be estimated by explanatory variables in the regression equation of October. The explanatory variable includes Relative humidity at 850 hpa, Relative humidity at 1000 hpa, U Wind at 500 hap, and U Wind at 1000 hpa. The regression equation for the month of October is given by the following equation:

Precipitation October = 1.794 -0.0212*RH850 + 0.04362*RH1000 + 0.04107*UW500 + 0.1002*UW1000

In Figure 3 and Figure 5, the dotted line shows the precipitation trend for the month of July and October. In Figure 3, the line is ascending; thus indicating that the precipitation trend is increasing in July and more precipitation is expected. In Figure 5, the line is descending; proving that the precipitation trend is decreasing in October and less precipitation is anticipated.

Figure. 5. Graph Showing Observed versus Estimated Precipitation of Gwadar

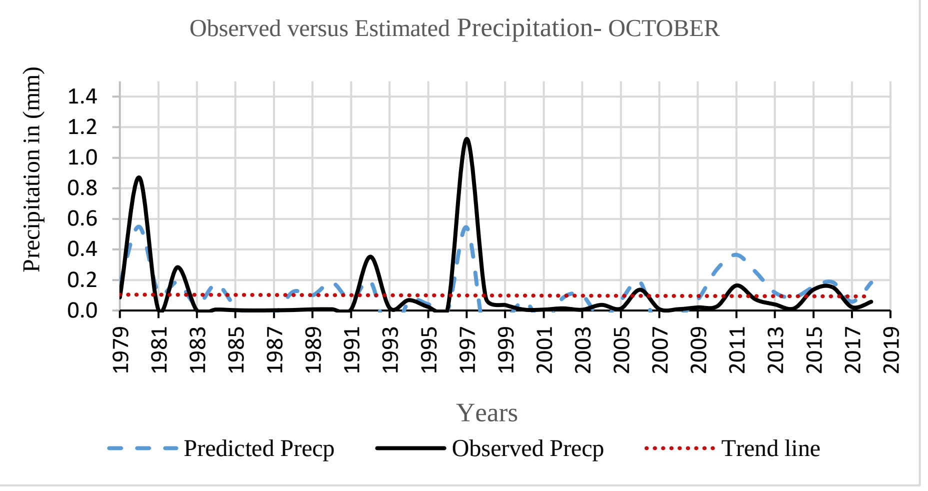
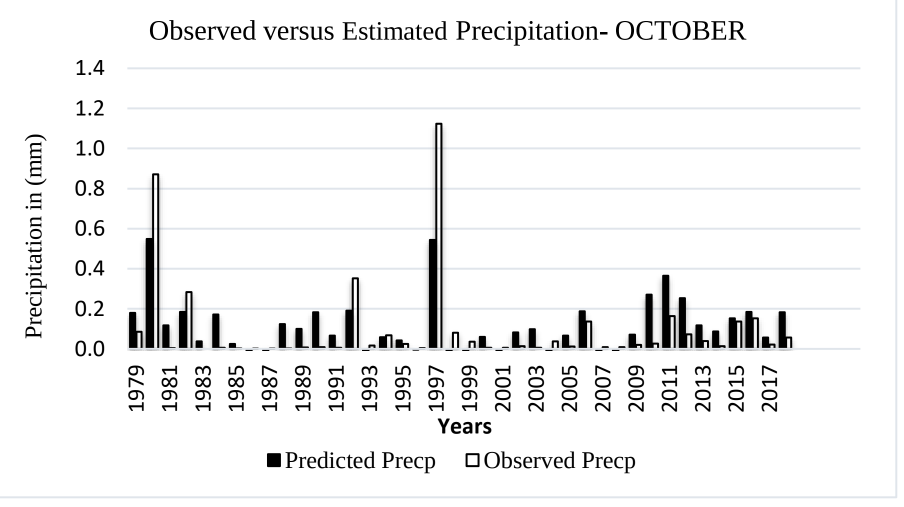


Figure. 6. Histogram Showing Comparison between Observed Versus Estimated Precipitation of Gwadar



4. CONCLUSION

The regression Equation of precipitation for the month of July was formulated using MLR addresses about 80.47 % variation in precipitation. RH 850, RH 500, Uwind 1000, V Wind 850, and V Wind 1000 are identified as potential determinants for the month of July. The model is reasonably good as indicated by the $R^2 = 0.8047$ that indicates that 80.47 % variation in precipitation can be estimated by explanatory variables. The regressors in the regression model show that RH500, RH850, Uwind1000, VWind 850 and V

Wind1000 influence the precipitation and explain the maximum variability of the precipitation in July. The direction and strength of the association (influence) are provided by the coefficient of regressors. Similarly, the Regression Equation of precipitation for the month of October using MLR addresses about 51.16% variation in precipitation. Relative humidity at 850 hpa, Relative humidity at 1000 hpa, Uwind at 500 haps, and UWind at 1000 hpa. are identified as the potential determinants of the precipitation variability for the month of October. The coefficient of determination R^2 came out to be 0.5116, suggesting 51.16 % variation in precipitation can be estimated by explanatory variables.

Based on the above concluding remarks, the policymakers must frame policies in such a fashion that can help people to adapt to the new changing precipitation trends in Baluchistan. Indeed, it is highly important for the region in terms of the successful implementation of the CPEC project. The Government should cater to the institutional grievances to minimize any emerging conflict of interest that can affect not only the successful completion of the CPEC project but also control the environmental damage at large. Policies should be designed that take into consideration the 2021 Glasgow Pact Climate Change concerns. Overall environmental security should be considered vital for the overall security, prosperity, and development of the State.

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Annexure- A												
GWADAR-Precipitation Data for the study period (1979-2018) by the courtesy of PMD												
Years	**JAN**	**FEB**	**MAR**	**APR**	**MAY**	**JUN**	**JLY**	**AUG**	**SEP**	**OCT**	**NOV**	**DEC**
1979	0.660	0.723	0.716	0.277	0.072	0.083	0.049	0.115	0.013	0.086	0.052	1.560
1980	0.502	0.106	0.836	0.109	0.110	0.250	0.108	0.032	0.013	0.871	0.049	0.707
1981	0.146	0.419	1.432	0.172	0.140	0.053	0.408	0.077	0.000	0.005	0.093	0.030
1982	0.976	2.753	1.107	1.377	0.436	0.029	0.145	0.144	0.160	0.283	0.226	2.089
1983	0.266	1.056	0.258	0.675	0.211	0.209	0.427	1.276	0.047	0.000	0.029	0.226
1984	0.119	0.020	2.145	0.038	0.098	0.031	0.602	0.291	0.397	0.006	0.036	0.337
1985	0.308	0.054	0.386	0.174	0.056	0.076	0.596	0.008	0.001	0.002	0.022	0.419
1986	0.140	1.549	0.380	0.073	0.034	0.421	0.110	1.039	0.005	0.000	0.126	0.025
1987	0.173	0.404	1.120	0.272	0.941	0.087	0.251	0.126	0.004	0.001	0.024	0.016
1988	0.700	0.280	0.180	0.105	0.053	0.064	2.189	0.182	0.018	0.003	0.027	0.019
1989	0.009	0.040	0.676	0.103	0.103	0.126	0.562	0.197	0.025	0.008	0.100	0.546
1990	0.415	1.553	0.194	0.202	0.168	0.032	0.090	0.259	0.108	0.008	0.062	0.262
1991	1.734	1.002	1.325	0.134	0.070	0.016	0.105	0.038	0.049	0.006	0.087	0.098
1992	1.276	0.804	0.713	0.488	0.106	0.031	0.620	0.771	0.064	0.352	0.023	0.415
1993	0.622	0.054	0.117	0.312	0.064	0.020	0.173	0.012	0.237	0.017	0.030	0.003
1994	0.416	0.344	0.220	0.607	0.078	0.053	2.196	0.818	0.491	0.068	0.028	0.613
1995	0.031	0.682	0.478	0.557	0.046	0.046	1.475	0.163	0.042	0.024	0.003	1.711
1996	1.497	0.342	0.676	0.019	0.138	0.273	0.218	0.019	0.009	0.004	0.007	0.042
1997	1.102	0.013	2.269	0.863	0.575	0.567	0.426	0.300	0.103	1.123	0.733	0.376
1998	0.543	0.434	1.325	0.039	0.032	0.115	0.631	0.027	0.334	0.081	0.004	0.001
1999	0.319	1.111	0.800	0.008	0.046	0.096	0.194	0.033	0.053	0.036	0.004	0.002
2000	0.077	0.024	0.048	0.008	0.151	0.040	0.057	0.099	0.022	0.005	0.008	0.225
2001	0.008	0.077	0.059	0.036	0.015	0.099	1.225	0.116	0.010	0.006	0.004	0.012
2002	0.018	0.092	0.146	0.025	0.128	0.108	0.107	0.281	0.025	0.014	0.195	0.389
2003	0.404	0.252	0.189	0.256	0.202	0.030	2.741	0.019	0.017	0.005	0.009	0.014
2004	0.714	0.012	0.008	0.012	0.045	0.008	0.113	0.135	0.018	0.037	0.008	1.504
2005	0.638	3.239	1.586	0.065	0.303	0.151	0.052	0.036	0.029	0.012	0.005	0.028
2006	0.143	0.118	0.283	0.013	0.083	0.151	0.601	0.931	0.084	0.136	0.100	2.966
2007	0.115	0.588	1.447	0.049	0.121	5.435	0.445	0.820	0.039	0.009	0.009	0.049
2008	1.622	0.170	0.034	0.118	0.089	0.650	0.643	0.775	0.068	0.009	0.026	0.492
2009	1.138	0.192	0.418	0.230	0.075	0.200	1.121	0.259	0.079	0.020	0.032	0.615
2010	0.179	1.534	0.108	0.071	0.136	1.962	1.451	0.463	0.247	0.027	0.068	0.075
2011	0.070	0.950	0.833	0.661	0.269	0.082	1.093	1.402	0.481	0.164	0.735	0.028
2012	0.602	0.121	0.081	0.513	0.658	0.055	0.476	0.126	0.292	0.073	0.043	0.840
2013	0.081	0.817	0.456	1.147	0.118	0.546	0.714	1.993	0.511	0.040	0.677	0.005
2014	0.587	0.386	0.820	0.464	0.343	0.072	0.798	0.426	0.135	0.014	0.078	0.015
2015	0.290	0.533	0.812	0.211	0.277	0.401	0.682	0.106	0.119	0.136	0.034	0.028
2016	0.088	0.012	1.063	0.193	0.166	0.372	0.729	0.270	0.201	0.152	0.017	0.011
2017	1.111	0.275	0.145	0.067	0.281	0.152	0.456	0.480	0.096	0.022	0.020	0.017
2018	0.036	0.130	0.126	0.125	1.762	0.092	0.774	0.263	0.088	0.057	0.041	0.008
Average	0.497	0.582	0.650	0.272	0.220	0.332	0.646	0.373	0.118	0.098	0.097	0.420