Risk Assessment and Evaluation of Probability of Extreme Hydrological Events and Recommendation on Subsequent Disaster Management for Noakhali Sadar and Subarno char thanas

Draft Report

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Chapter 1:

1. Executive Summary

1.1 General

Bangladesh is generally known for its natural vulnerability to floods, cyclones, droughts etc. In recent years the country experienced floods in 2004, 1998, 1988, devastating cyclones in 1991, 1970 and droughts in 1981, 1982, 1989, 1992, 1994 and 1995. Impact of Climate Change and Climate variability experienced all over the world has called for urgent promotion of adaptation to climate change in Bangladesh being one of the most vulnerable countries of the world.

In order to evaluate the type of impact the following hydro-climatic elements:

- Temperature
- Precipitation
- Tidal Water Level in Bangladesh Coast
- Cyclone and storm surge

for the areas in and around Noakhali Sadar and Subarnochar areas were collected and organised in a database.

Related information in the form of maps and charts were also collected so that the location of Noakhali in relation to the country and the Bay of Bengal may be physically visualised and assessed.

1.2 GIS Presentations

The location of Bangladesh in South Asia particularly in relation to the Himalayas the two major rivers originating in the Himalayas and flowing past Noakhali and discharging into the Bay of Bengal have been defined.

1.3 Temperature

Seasonal temperature regime at Majdee Court (Noakhali Sadar and Subarnochar) is defined in the following table:

Season	Data Series	Max	Avg	Min
Summer	Tmax	37.6	32.0	19.7
	Tmin	30.7	22.7	8.2
Monsoon	Tmax	38.0	30.5	22.4
	Tmin	31.5	25.4	14.8
Post-Monsoon	Tmax	37.5	29.8	18.2
	Tmin	28.2	22.0	10.1
Winter	Tmax	35.5	26.5	12.1
	Tmin	27.8	14.6	4.8

Here the data series Tmax is daily maximum temperature series and Tmin is daily minimum temperature series.

Temperature (maximum and minimum) data at Noakhali is available from January 1952 to December 2001. During this period the highest temperature of 38.0^{0}C was recorded on 7/6/1989 and the lowest temperature of 4.8^{0}C was recorded on 18/1/1962. Daily average temperature however ranged from 32.8^{0}C on 15/9/1996 to 12.1 on 6/1/1964 with an average of 25.6^{0}C

Evaluated on the basis of average summer temperature, the hottest place in Bangladesh is Chuadanga (35.1^{0}C) and at Maijdee Court the highest temperature is 32^{0}C. Thus Maijdee Court has a much milder summer than the hottest places in Bangladesh. In fact, Maijdee Court stands as 26th hottest place out of 34 stations.

In comparison to 10 coldest places in Bangladesh, Maijdee Court has a much warmer winter. The average daily minimum temperature during winter is 10.4 ^{0}C at Sreemangal the coldest place whereas the average daily minimum winter temperature at Maijdee Court is 14.6 ^{0}C.

1.3.1 Temperature trend

Temperature trend has been established for each of the Daily maximum and minimum series for the seasons summer, monsoon, post monsoon and winter and also for the entire year a total of 30 trends have been established for the station Maijdee court.

Of the 30 trends, 24 trends are increasing trend and 6 trends are decreasing trend. It is therefore generally concluded that temperature has an increasing trend at Maijdee just like the entire country.

R^2 the co-efficient of determination was also evaluated. Coefficient of determination ranged from .0004 to .4126 with an average of .1101. Obviously R^2 is very low but since 80% of the trends have shown increasing values, increasing trend is established.

The highest value of R^2 = .4126 corresponds to Post-monsoon average temperature of daily maximum series. This is followed by Post-monsoon average temperature of daily minimum series with R^2 = 0.34580. Thus rising trend of Post-monsoon daily maximum and minimum are 3.28^{0}C and 4.23^{0}C per 100 years respectively.

The highest rising trend 6.67^{0}C is shown by Post-monsoon minimum of daily minimum series followed by Winter minimum of daily minimum series 6.46^{0}C per 100 year.

1.3.2 Temperature forecast

From the various combinations of 30 temperature trends, 50 forecasts of temperature for the years 2030, 2050 and 2100 have been formulated and is summarised below:

	Rise in Temp ^{0}C : Base Year:1990			
Season	Data Series	2030	2050	2100
Summer	Tmax	0.38	0.56	1.03
	Tmin	0.06	0.08	0.15
Monsoon	Tmax	0.81	1.22	2.23
	Tmin	0.58	0.88	1.61
Post-Monsoon	Tmax	1.31	1.97	3.61
	Tmin	1.69	2.54	4.65
Winter	Tmax	-0.17	-0.26	-0.47
	Tmin	1.53	2.29	4.20
Annual	Tmax	0.58	0.88	1.61
	Tmin	0.85	1.28	2.34

It is noticed, only Daily maximum series of Winter temperature has a decreasing trend while the Daily minimum series has a very significant rising trend and the sum total effect will be a much warmer winter.

1.4 Rainfall

Daily rainfall record of Maijdi (Noakhali Sadar upazila) has been collected from Bangladesh Meteorology Department (BMD) for the period 1951-2003. The following is a summary of annual rainfall statistics in mm.

max	4799
avg	3090
min	2036
stdev	514

Monthly rainfall distribution is the typical monsoon dominated rains as shown below:

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
11	21	63	122	318	594	711	620	378	214	53	8	3113

Seasonal rainfall and also expressed as percent of annual total is presented below:

Season	Rainfall	% of Total
Summer	504	16
Monsoon	2303	74
Post-Monsoon	266	9
Winter	40	1
Total	3113	100

1.4.1 Rainfall trend

SAARC Meteorological Research Centre in their study of "Recent Climatic Changes in Bangladesh" showed that trends of actual seasonal total country averaged rainfall over Bangladesh have a slight increasing trend. At Noakhali however neither the Annual Rainfall nor the 1 day maximum rainfall show any discernible trend for the rainfall. The data series broken down into two periods, an earlier period and a recent period however show a slight increase in the variability as shown below:

Noakhali rainfall station

Period	1952-79	1979-03
annual rain mm	2979	3171
stdev mm	422	595
%	14	19

Similar evaluation was also made for 1 day maximum rainfall and is presented below:

1 day maximum rainfall at Noakhali

Period	1952-79	1979-03
Avg 1 day max rain mm	183	194
stdev mm	37	92
% deviation	20	48

Slight increase in variability in both annual and 1 day maximum rainfall is observed.

1.5 Cyclones

An attempt has been made to study the long term trends in the annual frequencies of cyclonic disturbances (i.e. sum of depressions, cyclonic storms and severe cyclonic storms), depressions, cyclonic storms and severe cyclonic storms forming in the Bay of Bengal utilizing 110 years data during the period 1891-2000. There has been significant increasing trend in annual the frequency of cyclonic disturbances (CD) during the period 1900 through 1948 and it has a sharp decreasing trend during 1949-2000. The rates of increase and decrease in frequency are 0.1426 per year and -0.1048 per year respectively. The overall trend in the frequency of cyclonic disturbances for the period 1891-2000 gives a slight decreasing tendency, the rate of decrease is -0.017 per year. Similar trends have been found in the case of depressions. The rates of increase and decrease in the frequency of depressions are 0.1322 per year and -0.1049 per year during the periods 1900-1948 and 1949-2000 respectively. A slight increasing trend has also been found in the annual frequency of depressions during period of 1891-2000 and the rate of increase is insignificant.

The annual frequency of cyclonic storms has a slight increasing trend during the period 1900-1945, the rate of increase being 0.0213 per year, whereas there is a slight decreasing trend in the frequency of cyclonic storms during the period 1946-2000, the rate of decrease is -0.0188 per year. But for the overall period of 1891-2000, the frequency shows a decreasing trend, the rate of decrease being –0.0193 per year. The annual frequency of severe cyclonic storms for the periods 1900-1045 and 1949-2000 respectively shows increasing trends, which are not statistically significant. The rates of increase in the annual frequency of severe cyclonic storms are 0.0176 per year and 0.0247 per year during the periods 1900-45 and 1946-2000 respectively. For the overall period of 1891-2000, the annual frequency of severe cyclonic storms shows a slight increasing trend. The rate of increase in the annual frequency of severe cyclonic storms during the period 1891-2000 is 0.0023 per year. The study reveals that the annual frequency of depressions and cyclonic storms has the decreasing trends from mid 1950, whereas the annual frequency of severe cyclonic storms has the increasing trend. It means that most of the depressions and cyclonic storms have a tendency to be intensified into severe cyclonic storms after 1945.

Attempt has also been made to study the polynomial trends and it has been found that the polynomial curves are fitted better than the linear ones. There are long term oscillations in the annual frequency of cyclonic disturbances and storms for a period of about 50-60 years.

Trend analysis of monthly frequency of depressions in the Bay of Bengal were also done by grouping the frequencies into seasons (Annual, Pre-Monsoon, Monsoon, Post-Monsoon and Winter). Types of depressions considered are Depressions-Deep Depression (D-DD), Cyclonic Storms (CS), Severe Cyclonic Storms (SCS) and Cyclonic Disturbance (CD) by taking the three types together.

Summary of the trend analysis is shown in Table 3: Summary of Trends of Cyclonic Disturbance in Chapter 7. It is observed that out of 20 trends 14 has positive trends i.e. frequency of disturbance is increasing while 6 trends are decreasing. Grouping the trends into depression types results the following table:

DepressionType	Increasing	Decreasing
D-DD	5	0
CS	1	4
SCS	3	2
CD	5	0
Total	14	6

The lowest category of depression D-DD having the highest frequency has the increasing tendency in all the seasons. This is likely to reduce the fisherman's working days in the sea and navigation by smaller boats thereby affecting livelihood of these people.

1.6 Wind Speed Trend

Wind speed data from 12 coastal stations were available for analysis. Maximum and average wind speed were evaluated for each year of available record. Trend of maximum wind speed shows an increasing trend while the trend of annual average wind speed shows a decreasing trend.

1.7 Trend of Storm Surge Heights

From the Storm Surge data of Cyclone Landfall database trend of Storm Surge heights in the Bangladesh Coast has been established. Inspite of the inherent scattering of the plotting points, Storm Surge heights show a decreasing trend in Bangladesh. This also complements falling trends of Wind Speed in the Bangladesh Coast and thus the two trends strengthens each other. But this is in contradiction to the rising temperature and rainfall trend. These calls for additional quality control of Cyclone and Wind Speed data collected by BMD.

Chapter 2 :

Background information:

This is a sub-component of a bigger project – *Promotion of adaptation to climate change and climate variability in Bangladesh* financed by Netherlands Climate Change Assistance Program Phase II (NCAP). The project will be implemented in Noakhali coastal district and detailed studies will be undertaken in thanas – Noakhali Sadar and Subarno char thanas[1]. A Work Plan had been prepared in March 2005 and the project is under implementation. In the Work Plan (under article *1.2 Thematic areas of focus* page 2) it has been stated that "*Under the project, the study will also focus on the probability of extreme hydrological events to make specific predictions in order to combat with future climatic scenarios.*"

In response to a request, a draft Methodology for the study was submitted on 25/5/2005 and a report on Field Testing of Methodology was also submitted on 15/8/2005.

Timeframe:

- Submission of methodology by May 25, 2005
- Submission of a report on field testing the methodology and its applicability/effectiveness by August 15, 2005
- Submission of draft final report by October 25, 2005
- Submission of GIS module along with the draft report by October 25, 2005
- Submission of final report by November 10, 2005
- Submission of GIS map and report by November 10, 2005

Objective of this Report:

The first two items of the time frame has already been met and the objective of the present report is to submit a draft final report also covering GIS.

Noakhali District:

Noakhali District[2] (Chittagong Division) with an area of 3601 sq km, is bounded by Comilla district on the north, the Meghna Estuary and the Bay of Bengal on the south, Feni and Chittagong districts on the east, Lakshmipur and Bhola districts on the west. Annual average temperature: maximum 34.3 ^{0}C, minimum 14.4 ^{0}C; annual rainfall 3302 mm. Main rivers are Bamni, Noakhali khal and Meghna.

[1] Exhibit 1 shows location of the 2 upazila in CDSP-II areas.
[2] BANGLAPEDIA National Encyclopedia of Bangladesh (March 2003)

Noakhali (Town), Noakhali Sadar[3] Upazila[4] Town (Maijdee) consists of 9 wards and 36 mahallas. It has an area of 12.61 sq km. The town has a population of 74,585; male 51.50%, female 48.50%; population density per sq km 5915. Literacy rate among the town people is 60.7%. The ancient name of Noakhali was Sudharam. In 1948 when the Upazila headquarters were extinct by the erosion of the Meghna River, it was shifted 8 km to the north to its present place Maijdi. In addition to serious river erosion the district was seriously affected many times by natural disasters like high tidal bore, tornado, flood, cyclone etc since 1790. In November 1970 devastating Cyclone and storm surge took lives of about 10,00,000 people.

Population: The district has a population of 25,33,394; male 49.58%, female 50.42%.

Main occupations are: Agriculture 30.27%, agricultural labour 16.99%, wage labourer 2.86%, commerce 12.23%,service 19.39%, transport 2.46%, fishing 1.4%, and others 14.4%.

Land use: Total cultivable land 229385 ha, fallow land 17136 ha.

Land control: Among the peasants 21% landless, 41% marginal, 21% small, 14% intermediate and others 14.4%.

> Noakhali district was established in 1821. Its original name was Bhulua. Once the agricultural activities of the north-eastern region of Bhulua was seriously affected by the flood water of Dakatia flowing from the Tripura hills. To save the situation a canal was excavated in 1860 running from Dakatia through Ramganj, Sonaimuri, and Chaumuhuni to divert water flow

Main crops: Paddy, peanuts, pulses, chilli, sugarcane, potato

Main fruits: Mango, jackfruit, papaya, coconut, banana, litchi, betel nut, palm

Fisheries, dairies and poultries: Dairy 62, poultry 129, fishery 60, hatchery 32, artificial breeding centre 1, government breeding centre 1.

Communication facilities: Roads- Metalled road 804 km, semi-metalled 485 km, earthen road 2274 km; water ways 30 nautical miles, ferry ghat 1, railways 28 km, rail station 7.

Noakhali Sadar and Subarnochar Upazila

With an area of 1071.66 sq km, is bounded by Begumganj and Senbagh upazilas on the north, Hatiya upazila on the south, Companiganj and Sandwip upazila on the east and Ramgati and Lakshmipur sadar upazila on the west. Lower Meghna, Hatiya channel and Sandwip channel flowing near by and a forestry of 103.71 sq km may be noted.

Noakhali (Town) Noakhali Sadar Upazila Town (Maijdi) has an area of 12.61 sq km. Noakhali sadar thana was established in the year 1861 and was turned into upazila in 1983.

Population: 651171, male 50.22%, female 49.78%, density 608 person pr sq km.

Main Occupations: Agriculture 37.02%, agricultural labourer 18.08%, wage labourer 3.21%, commerce 10.53%, service 14.81%, transport 2.32%, fishing 1.04%, and others 12.99%

Land use: Cultivable land 674497.37 ha?, fallow land 13066.3 ha?.

[3] Sadar Upazila District Head quarter Upazila

[4] Upazila – sub-division of District

Land control: Among the peasants 22% are landless, 25% marginal, 32% small, 16% intermediate, and 5% rich peasants.

Some facts about Noakhali Sadar and Subarnochar upazila supplied by Directorate Agriculture Extension (DAE) and collected by Executive Director, Socio-economic Devolopment Programme (SDP) an NGO working in the area.

Area:	1,04,000 ha
Forest area:	10,375 ha
Water bodies:	5600 ha
Population:	754482#

Recently by taking out 7 unions from Noakhali Sadar a new Upazila has been formed with the name Subarnochar upazila.These 7 unions are: 1)Char Clark, 2)Char Bata, 3)Char Wapda, 4) Char Amanullah 5) Char Jubilee 6) Char Jabbar and 7) ??.

Offshore Island[5] an island (locally known as char) located near a coast or an offshore area. A large number of such islands have developed in between the channels across the funnel shaped and shallow northern Bay of Bengal. The combined Padma-Jamuna-Meghna river system through the Meghna estuaries brings enormous load of sediment to the offshore territory, there by forming a series of Islands. The distribution pattern of the islands is such that a majority of them have developed in the central part of the coast, running east of Tentulia river to the Feni river estuary. The region is most dynamic and intense erosion and sedimentation take place here regularly. As a result, the coastline is irregular and broken.

The major offshore islands of this region are Hatiya, Bhola, and Monpura. All these islands are densely populated. In the western region, the coastline is transverse to the structure of the continental margin. This front is stable and is covered by the dense mangrove forest known as the Sundarban. The very active tidal channel networks of this region have divided the region into several small islands, including the Sundarban. The islands under the Sundarban are treated as protected areas and cover the districts of Satkhira, Khulna and Bagerhat. Between Haringhata and Tentulia rivers there are quite a large number of densely populated offshore islands under the districts of Barguna and Patuakhali. Some of these islands are Patharghata, Amtali, Kalapara, Rangabali, and Bauphal. The coast of eastern region has a small number of islands. The most important of them are Sandwip, Urir char, Kutubdia, Moheshkhali and St. Martin’s island. Unlike Sandwip and Urir char, Kutubdia, Moheshkhali and St. Martin’s island are of tectonic origin.

[5] BANGLAPEDIA National Encyclopedia of Bangladesh March 2003

Data base:

As a first step towards preparation of the report a database has been developed that now contain available data on:

I Temperature
II Precipitation
III Tidal Water Level in Bangladesh Coast
IV Cyclone and Storm surge data

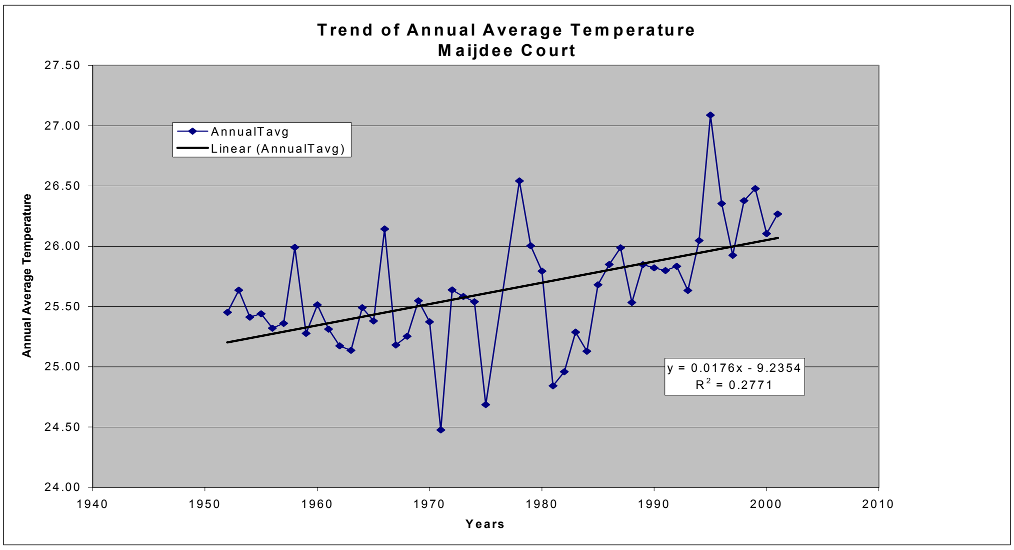
At this point of time data in the database is not complete, but the various organisation responsible to collect these data have been contacted and the process of getting these data is continuing.

Temperature:

Bangladesh Meteorology Department (BMD) maintains a meteorological station at Maijdee

Court which is the District HQ town of Noakhali district and also the thana HQ town of Noakhali Sadar. Feni is also a near by meteorological station at the District HQ town of Feni district. In order to test any trend in temperature annual average temperature was derived and time trend of annual average temperature was established at these two stations.

The following is the regression analysis of annual average temperature at Maijdee Court



station.

The regression equation shows that annual average temperature has an increasing tendency and has increased by 0.86 ^{0}C from 1952 to 2001. Annual average temperature at Feni is also showing increasing trend and if extrapolated for the same period of 1952 to 2001 shows a rise of temperature by 0.50 ^{0}C.
The methodology is thus tested and further analysis will be done to cover extreme meteorological events.

Rainfall:
BMD has a rainfall station at the District and Upazila HQ of Noakhali district.

Daily rainfall record of Maijdi (Noakhali Sadar upazila) has been collected from Bangladesh Meteorology Department (BMD) for the period 1951-2003. The following is a summary of annual rainfall statistics in mm.

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Seasonal rainfall and also expressed as percent of annual total is presented below:

Season	Rainfall	% of Total
Summer	504	16
Monsoon	2303	74
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Winter	40	1
Total	3113	100

Tidal Water Level in Bangladesh Coast:

The following is an extract from a recent study of MSL variation by the BWDB gauges in the Bangladesh coast by the writer. BWDB Hydrology operates 129 water level stations in 60 rivers in tidal area. But most of these tidal water level stations are far inland. In this brief study only 13 down most stations in 13 rivers were considered.

The period of available record was divided into two equal parts; an earlier part and the recent part. MSL was calculated for each part separately. The change in MSL in cm is shown in Column (5). It will be observed that each of the half period for which MSLs were calculated ranged from 16 to 27 years with an average of 21 years. During this period MSL changed within a range of –24 cm to 110 cm with an average of 22 cm.

Annual MSL were calculated for each year of record for each station, plotted and a linear time trend was fitted in each case. From the slope of the time trend line annual rate of rise/fall were calculated in mm/yr. for the entire period of record and shown in Column (7). The annual rate of rise ranged from –8.2 mm/yr. to 49.8 mm/yr. with an average of 10.9 mm/yr. It may be noticed that there were four cases of falling trend and all of these were in the East Coast of the bay.

Table-1

River	Station ID	Station	Change of MSL mm/yr
Ichamati (Western Border)	SW130	Kaikhali	10.50
Rupsa-Pasur	SW244	Mongla	10.90
Alaipur Khal Daratona	SW1	Bagerhat	6.20
Gorai-Madhumati-Haringhata-Baleswar	SW107.2	Rayenda	3.70
Bishkhali	SW39	Patharghata	15.70
Barisal-Buriswar	SW20	Amtali	4.50
Surma-Meghna	SW279	Tajumuddin	30.00
Hatiya	SW321	Hatiya	-1.80
Feni	SW87	Sonapur	49.80
Sangu	SW248	Dohazari	-2.10
Matamuhuri	SW204	Chiringa	20.70
Kutubdia Channel	SW176	Lemsikhali	-8.20
Moheshkhali Channel	SW200	Saflapur Moheshkhali	-6.20

Bangladesh coast has a length of over 700 km. Out of this from the point of out fall of Feni river down to Teknuf the southern tip of Bangladesh main land the coastline has a length of about 260 km. The remaining coast from the Meghna estuary to the border of West Bengal has a length of about 440 km (we will call it Gangetic delta in Bangladesh). These two parts of the coast are of very different characters. The east coast is very much unbroken and straight and is only intercepted by smaller rivers like Karnafuli, Sangu, Matamuhuri, Bogkhali etc. whereas remaining coast of Gangetic delta is very much broken and intercepted by large estuaries like arms of sea carrying sediment laden water. The east coast has a narrow coastal plain hardly a few km wide that quickly goes up into the hills while Gangetic delta in Bangladesh is very flat and tide travels far inland over 150 km into the country.

Exhibit 2 shows the distribution of SLR in Bangladesh coast in a GIS map.

If we now look back to the Table 1 we see that all the 7 tide stations in the Gangetic delta displays +ive changes in MSL while out of the 6 tide stations in east coast 4 stations displays –ive change and 2 stations show +ive change in MSL. The following table summarizes the result.

Summary of Changes in MSL

Coast	No. of +ive Changes	Av. +ive Change in cm	No. of -ive Changes	Av. -ive Change in cm	OverallTrend mm/yr
EntireCoast	9	37	4	-4.6	10.3
GangeticDelta	7	26	0	0	11.6
EastCoast	2	76	4	-4.6	8.7

According to IPCC estimates, the sea level along the Bangladesh coast is rising at about 3 millimeter a year and the rise in sea level would be in the range of 15 cm to 95 cm by 2100. On the high end, the rise could be 30 cm by 2030. Against this, rise in sea level has been recorded as 37 cm in about 21 years when only the +ive values are considered or 22 cm when all the +ive and –ive changes are considered.

Looking individually average +ive change of 76 cm in the East Coast is too high a value due to morphological changes at the out fall at Sonapur of Feni River. Predominant –ive values in the east coast calls for a more intensive study to determine **if the sea level in the east coast particularly in the southern part is falling.**

In the Gangetic Delta area the change in MSL is clearly +ive rising by about 26 cm in the last 21 years at an annual average trend of 11.6 mm/yr. It is well known that growth of extensive polderisation from 1960 in the Gangetic Delta, there has been morphological changes in the coastal rivers leading to rising trend of mean tide level. It is quite likely that a part of this rise (11.6 mm/yr) is due to sea level rise of 3 mm/yr due to Climate Change. It is therefore necessary that the study is continued by including BIWTA data from sea facing stations in the Gangetic Delta.

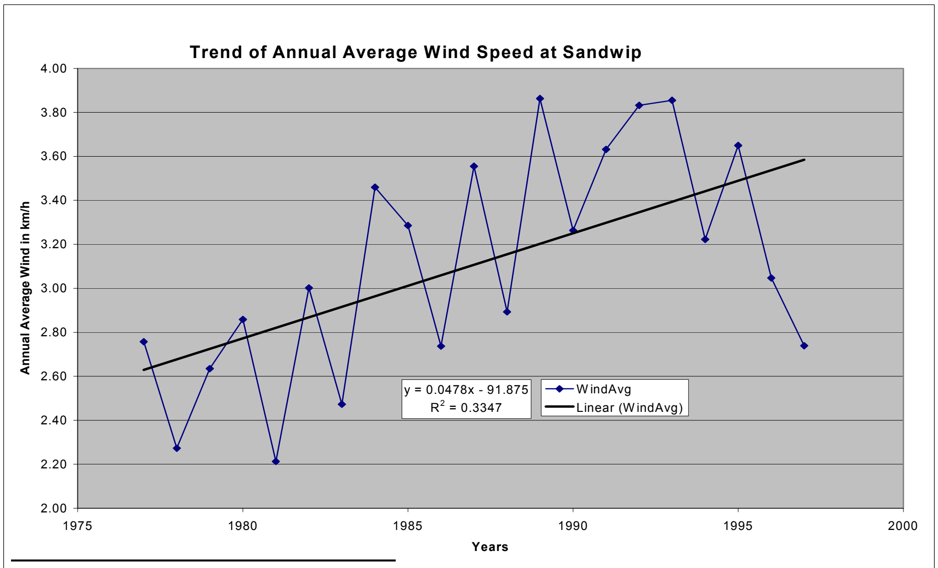
Cyclone and Storm surge:

Tropical Cyclones and the associated storm surges are responsible for the highest human casualties due to natural disasters in Bangladesh. There are two distinct seasons when frequency of cyclones hitting Bangladesh coast is highest. These seasons are Pre-monsoon and Post-monsoon. Thus in transition from the winter to the monsoon the instability of weather in the equatorial region initiates development of depression that steers into the Bay of Bengal. Similar mechanism works when the monsoon is in transition to the winter through the post-monsoon.

Annual frequency[6] of cyclonic storms has a slight increasing trend during the period 1900-1945, the rate of increase being 0.0213 per year, whereas there is a slight decreasing trend in the frequency of cyclonic storms during the period 1946-2000, the rate of decrease is -0.0188 per year. But for the overall period of 1891-2000, the frequency shows a decreasing trend, the rate of decrease being –0.0193 per year. The annual frequency of severe cyclonic storms for the periods 1900-1045 and 1949-2000 respectively shows increasing trends, which are not statistically significant. The rates of increase in the annual frequency of severe cyclonic storms are 0.0176 per year and 0.0247 per year during the periods 1900-45 and 1946-2000 respectively. For the overall period of 1891-2000, the annual frequency of severe cyclonic storms shows a slight increasing trend. The rate of increase in the annual frequency of severe cyclonic storms during the period 1891-2000 is 0.0023 per year. The study reveals that the annual frequency of depressions and cyclonic storms has the decreasing trends from mid 1950, whereas the annual frequency of severe cyclonic storms has the increasing trend. It means that most of the depressions and cyclonic storms have a tendency to be intensified into severe cyclonic storms after 1945.

Trend of wind in the Bangladesh Coast:

Wind data at Sandwip an offshore island (not very far from Noakhali) were readily available. A rapid analysis of annual average wind data demonstrated the following trend. Wind data will also be available at Maijdee Court BMD Class I station. After obtaining the data analysis will be made.



[6] Bangladesh National dialogue on Water and Climate: Climate Variability Induced Extreme Events IUCN, July 2004

Site visit at Noakhali Sadar and Subarno char.

In order to assess the field situation and the concept of people in the area regarding climate change and its impact on the life and property of the people a field visit was made from 12/8/2005 to 16/8/2005.

The field visit was co-ordinated by Lutfun Nahar Azad Executive Director of SDP. Mrs. Azad arranged meeting the following district level officers:

- Mr. Abu Taher Asstt. in charge Maijdee Court Meteorological centre
- Mr. Abdul Quader Executive Engineer LGED
- Abul Kalam Azad Executive Engineer BWDB
- Mr. Mafizul Islam Executive Engineer R & H Department
- Mr. Bellal Hossain UNO of Subarno char Upazila
- Mr. Khairul Anam Selim Principal Saikat Degree College and Chairman Charbata Union
- Mr. Sayed Ali Deputy Director, Agriculture
- Mr. Sk. Md. Abdus Sattar, Sr. Agricultural Adviser, CDSP-II
- Mr. M.A. Latif Sr. Socio-Economic Adviser, CDSP-II
- Mr. Md. Liaquat Ali Khan FCW CDSP-II

During the discussion the following points emerged:

Noakhali sadar and Subarno char areas have three water related major problems. These are:

- Serious drainage congestion during the monsoon
- No water during the dry season and
- Arsenic contamination in the drinking water from the ground water

Dynamic Morphology of the Meghna along the foreshore of Subarno char and natural levee

Inundation level marked red in the UNO office Noakhali Sadar

formation by the new alluvial deposits have made the Maijdi town and the area around a saucer shaped basin. Last year (Year:2004) Maijdee town experienced the highest one day maximum rainfall of 316.7 mm on 15/09/2004 and the previous highest record was 276.4 mm on 08/06/1969 when possibly it was not a saucer shaped basin. This high rainfall caused inundation of the town including roads and offices for over two weeks. From this several questions arises.

- Is the rainfall intensity is increasing?
- Is the sea level rise at the outfall is making the drainage system less efficient?
- How the poorer sections of the people are being affected?

Another aspect of climate change that surfaced during discussion by Mr. Khairul Anam Selim Principal Saikat Degree College who said:

- Monsoon rainfall has shifted and as a result land preparation and plantation of second kharif has also shifted causing increased idle period for farm labourers
- Because of reduced growing period the yield is also decreasing

Mr. Sayed Ali Deputy Director is of the opinion that:

- Severity of cold and its duration is decreasing
- Because of reduced winter period insect population damaging crops is increasing

All the points that surfaced during testing of methodology will be addressed in the course of the study. The preliminary analysis has thus effectively proved the adequacy of the methodology.

Chapter 3:

3.1 Temperature in Noakhali

Maijdee Court at Noakhali is one of the 34 stations in Bangladesh where daily temperature (Daily maximum and Daily minimum temperature and dry bulb and wet bulb temperatures) is recorded by BMD (Bangladesh Meteorology Department). Database established under this project show that Daily Temperature (maximum and minimum) data at Noakhali is available from January 1952 to December 2001. During this period the highest temperature of 38.0^{0}C was recorded on 7/6/1989 and the lowest temperature of 4.8^{0}C was recorded on 18/1/1962. Daily average temperature however ranged from 32.8^{0}C on 15/9/1996 to 12.1 on 6/1/1964 with an average of 25.6^{0}C

Seasons: In Bangladesh although six seasons[7] are recognised according to Bangla Calendar, but in most of the technical literature the following four seasons are used:

Summer (Pre-monsoon)	March to May
Monsoon	June to September
Post-monsoon	October to November
Winter (Dry season)	December to February

Evaluated on the basis of average summer temperature, the hottest place in Bangladesh is Chuadanga (35.1^{0}C) and at Maijdee Court the highest temperature is 32^{0}C.

Table 1:Comparision of Maijdee Court with 10 top hottest stations in Bangladesh

Station	max	avg	min
Chuadanga	43.5	35.1	21.5
Ishurdi	44.0	34.5	19.8
Jessore	42.7	34.4	16.7
Satkhira	41.0	34.3	18.4
Rajshahi	43.8	34.3	21.4
Khulna	40.1	34.1	20.2
Mongla	40.0	33.7	21.6
Bogra	44.0	33.4	15.8
Madaripur	40.0	33.4	20.1
Faridpur	40.7	33.3	16.2
Maijdee Court	37.6	32.0	19.7

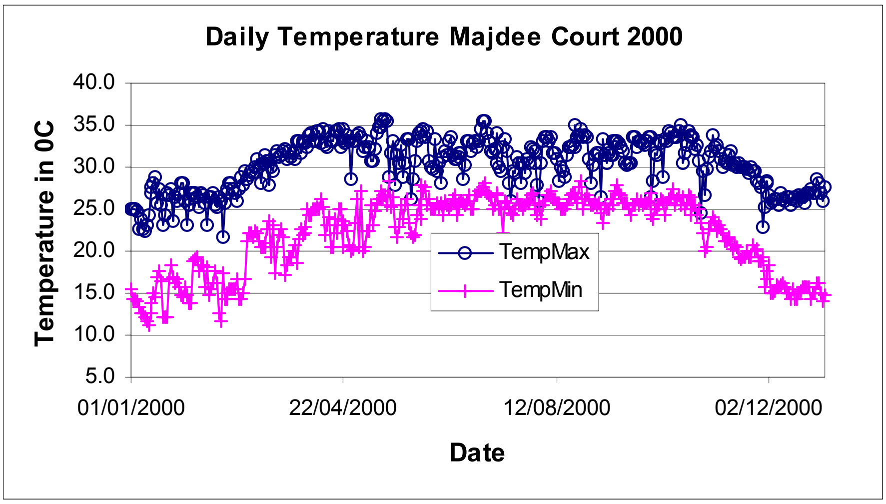
[7] Bangla Calendar (is a solar calendar and the first month Baishakh starts on 14th of June) has 12 months of Baishakh, Jaistha, Ashar, Sraban, Bhadra, Aswin, Kartik, Agrahaon, Paush, Magh, Falgoon and Chaitra. The six seasons are: Grishma (Summer)- Baishakh and Jaistha, Barsha (Rainy season)- Ashar and Sraban, Sarat (Autumn)-Bhadra and Aswin, Hemanta (Fall)- Kartik and Agrahaon, Sheet (Winter)-Paush and Magh, and Basanta (Spring)- Falgoon and Chaitra.

The comparison shows that Maijdee Court has a much milder summer than the hottest places in Bangladesh. In fact, Maijdee Court stands as 26th hottest place out of 34 stations.

In comparison to 10 coldest places in Bangladesh, Maijdee Court has a much warmer winter. The average daily minimum temperature during winter is 10.4 ^{0}C at Sreemangal the coldest place whereas the average daily minimum winter temperature at Maijdee Court is 14.6 ^{0}C.

Station	Seasonal T max	Seasonal T avg	Seasonal T min
Sreemangal	25.0	10.4	2.8
Ishurdi	25.5	11.5	3.5
Dinajpur	20.6	11.6	3.9
Rangpur	22.5	11.8	4.2
Sayedpur	21.4	12.0	5.0
Rajshahi	21.1	12.2	3.4
Chuadanga	21.7	12.4	5.2
Jessore	27.8	12.6	4.4
Bogra	24.3	12.8	4.9
Tangail	22.8	13.0	5.5
Maijdee Court	27.8	14.6	4.8

The following graph shows daily maximum and minimum temperature at Maijdee Court for they year 2000.



In the above figure the following characteristics of temperature regime may be observed:

- From January both the Tmax and Tmin temperature gradually rise and attains the maximum in April-May.
- After a slight fall in June, the temperature remains more or less steady particularly Tmin at around 27 ^{0}C.
- This condition prevails till the end of monsoon i.e. end of September or early October.
- Temperature then starts falling to repeat the cycle.

From the average of the daily minimum series during the winter the coldest place in Bangladesh seems to be Sreemangal with an annual winter average daily minimum temperature of 10.4 ^{0}C. This is followed by Ishurdi with an annual winter average daily minimum temperature of 11.5 ^{0}C and is the second coldest place in Bangladesh.

Station	Max	Avg	Min
Sreemangal	25.0	10.4	2.8
Ishurdi	25.5	11.5	3.5
Dinajpur	20.6	11.6	3.9
Rangpur	22.5	11.8	4.2
Sydpur	21.4	12.0	5.0
Rajshahi	21.1	12.2	4.6
Chuadanga	21.7	12.4	5.4
Jessore	27.8	12.6	4.4
Bogra	24.3	12.8	4.9
Tangail	22.8	13.0	5.5
Maijdee Court	27.8	14.6	4.8

The lowest temperature recorded in Bangladesh is 2.8^{0}C at Sreemangal on 4/2/1968 followed by 3.3^{0}C at the same place on 29 and 30/1/1964 and 3.5^{0}C at Ishurdi on 27/1/1964. In comparison to this the lowest recorded temperature at Maijdee Court is 4.8 ^{0}C and average winter temperature is 14.6^{0}C which is significantly higher than inland stations.

3.2 Availability of Temperature data

Bangladesh Meteorology Department records daily maximum and minimum temperature at 34 Stations - Exhibit 1: Location of Climatic Stations in Bangladesh. Data have been generally available from 1952. Number of stations for which data are available started with 12 stations in the year 1952 and gradually increased to 34 by 1991.

3.3 Seasonal Trends of Temperature

Temperature data were analyzed for two independent series, the daily maximum series and the daily minimum series.
Temperature trend for the country has been established separately for the Daily maximum series and the Daily minimum series over the Annual and the Seasonal basis. The seasons considered are:

- Pre-monsoon :from March to May
- Monsoon :from June to September
- Post-monsoon :from October to November
- Winter :from December to February

Trend for the annual series and also for each of the seasons were established for the means and extremes. Thus for the Daily maximum, Daily minimum series, for the Annual and four seasons and for the maximum, average and minimum a total of (2X5X3=30) thirty trends were established.

3.4 Summary of Temperature Trends

The graphs showing the trends are shown in Figures 1 to Figure 30. The results of the trends have been tabulated in Table 1. Of the 30 trends evaluated 25 cases show rising trend and 5 cases show falling trend. So it may be said that temperature regime in Bangladesh is showing a rising trend.

Table-1 Summary of Temperature Trend

AreaCod	DataT	Season	Statist	Period	RSqu	Slope	Formula
Maijdee	Daily	Annual	avg	1952-	0.17	0.014	y = 0.0146x +
Maijdee	Daily	Annual	max	1952-	0.03	0.008	y = 0.0089x +
Maijdee	Daily	Annual	min	1952-	0.01	0.018	y = 0.0182x -
Maijdee	Daily	Monsoon	avg	1952-	0.28	0.020	y = 0.0203x -
Maijdee	Daily	Monsoon	max	1952-	0.08	0.022	y = 0.0224x -
Maijdee	Daily	Monsoon	min	1952-	0.03	0.012	y = 0.0123x +
Maijdee	Daily	Post-	avg	1952-	0.41	0.032	y = 0.0328x -
Maijdee	Daily	Post-	max	1952-	0.19	0.034	y = 0.0342x -
Maijdee	Daily	Post-	min	1952-	0.01	0.014	y = 0.0141x -
Maijdee	Daily	Summer	avg	1952-	0.04	0.009	y = 0.0094x +
Maijdee	Daily	Summer	max	1952-	0.01	0.004	y = 0.0042x +
Maijdee	Daily	Summer	min	1952-	0.01	-	y = -0.0149x +
Maijdee	Daily	Winter	avg	1952-	0.01	-	y = -0.0043x +
Maijdee	Daily	Winter	max	1952-	0.14	-	y = -0.0342x +
Maijdee	Daily	Winter	min	1952-	0.01	0.018	y = 0.0181x -
Maijdee	Daily	Annual	avg	1952-	0.23	0.021	y = 0.0213x -
Maijdee	Daily	Annual	max	1952-	0.04	-	y = -0.0107x +
Maijdee	Daily	Annual	min	1952-	0.31	0.061	y = 0.0614x -
Maijdee	Daily	Monsoon	avg	1952-	0.21	0.014	y = 0.0146x -
Maijdee	Daily	Monsoon	max	1952-	0.00	-	y = -0.0014x +
Maijdee	Daily	Monsoon	min	1952-	0.11	0.043	y = 0.0437x -
Maijdee	Daily	Post-	avg	1952-	0.35	0.042	y = 0.0423x -
Maijdee	Daily	Post-	max	1952-	0.04	0.009	y = 0.0095x +
Maijdee	Daily	Post-	min	1952-	0.18	0.066	y = 0.0667x -
Maijdee	Daily	Summer	avg	1952-	0.00	0.001	y = 0.0014x +
Maijdee	Daily	Summer	max	1952-	0.07	-	y = -0.0186x +
Maijdee	Daily	Summer	min	1952-	0.02	0.022	y = 0.022x -
Maijdee	Daily	Winter	avg	1952-	0.12	0.038	y = 0.0382x -
Maijdee	Daily	Winter	max	1952-	0.01	0.015	y = 0.0152x -
Maijdee	Daily	Winter	min	1952-	0.19	0.064	y = 0.0646x -

The co-efficient of determination for the 27 cases showing rising trend of temperature ranged from 0.41520 to 0.00005 with an average of 0.11525. Because of large fluctuation of the annual series, the coefficient of correlation has been weak but because a large percentage of the analysis (83%) shows that temperature is showing rising trend in Bangladesh is established.

The slopes of the line of regression (rate of rise of temperature) ranged from 0.0008 ^{0}C per year to 0.1159 ^{0}C per year with an average of 0.0266 ^{0}C per year. The highest value 0.1159 ^{0}C per year corresponds to minimum of the Daily maximum Annual series while lowest value 0.0008 ^{0}C per year corresponds to maximum of the Daily maximum Pre-monsoon series.

A rate of rise of 0.1159 ^{0}C in the minimum of the Daily maximum Annual series is a very high rate within the present range of 7.2 to 18.8. But if we look to the average and maximum of the corresponding series, the rates of rise are: 0.0062 and 0.0041 which reassures us that the said rate will not be that high.

Pre-monsoon in Bangladesh is frequented by notorious nor'westers and twisters and also tropical cyclones. Rate of rise of 0.0008 ^{0}C, 0.003 ^{0}C and 0.0626 ^{0}C are all minimal and may not be a cause for very serious concern.

Post-monsoon trend of temperature shows a falling trend of 0.0231 ^{0}C for the maximum series and a rising trend of 0.0258 ^{0}C and 0.0416 ^{0}C corresponding to average and minimum series. Such changes are not very significant. The important meteorological event in this season are the tropical cyclones but these are originated in the tropics and temperature changes in Bangladesh may not affect frequency of occurrence of these cyclones. But changes in the weather regimes within Bangladesh though may however be responsible for the steering of these cyclones.

5.5 Summary of Temperature Forecast

Based on trend of temperature, forecast of temperature has been made for the years 1990, 2030,2050 and 2100. Also by using 1990 as base year, forecast of change in temperature (Rise/Fall) has been made for the years 2030, 2050 and 2100. Details of the forecast of temperature are given in Annex-A and the following table provides some salient features of the temperature rises in Noakhali Sadar.

	Rise in Temp ^{0}C : Base Year:1990			
Season	Data Series	2030	2050	2100
Summer	Tmax	0.38	0.56	1.03
	Tmin	0.06	0.08	0.15
Monsoon	Tmax	0.81	1.22	2.23
	Tmin	0.58	0.88	1.61
Post-Monsoon	Tmax	1.31	1.97	3.61
	Tmin	1.69	2.54	4.65
Winter	Tmax	-0.17	-0.26	-0.47
	Tmin	1.53	2.29	4.20
Annual	Tmax	0.58	0.88	1.61
	Tmin	0.85	1.28	2.34

On the basis of daily average temperature series, Annual average and Monsoon Average temperature will rise by 1 ^{0}C and 1.1 ^{0}C respectively by the year 2100 wrt the year 1990.

On the basis of daily maximum series, average Annual, Monsoon and Post-monsoon temperature will rise by 0.6 ^{0}C, 1.3 ^{0}C and 2.8 ^{0}C for the annual, Monsoon and Post-Monsoon season respectively. Pre-monsoon and Winter temperature will however fall by 0.9 and 0.5 ^{0}C respectively.

On the basis of daily minimum series, Annual, Monsoon, Pre-Monsoon and Winter temperature will rise by 1.1, 0.8, 0.8 and 2.1 ^{0}C respectively while Post-Monsoon temperature will fall by 0.9 ^{0}C.

The overall effect of all these changes will be warming up by about 0.8 ^{0}C and if all combination of avg, max and min statistics are considered, the warming up may extend to 1.8 ^{0}C by the year 2100 with respect to base year 1990.

For all the trends established, a table of forecast temperature of rise or fall with respect to base year 1990 and forecast years 2030, 2050 and 2100 have been computed and placed in a database table and reproduced in Annex C. Figures 31 to 40 in Annex-D show the graphical presentation of the data.

The above results have been put together in two graphs A and B and placed in Annex-E and the following table is prepared:

Trend of Rise/Fall in the season

Data Series	Annual	Pre-Monsoon	Monsoon	Post-Monsoon	Winter
DailyMax	Rising	Falling	Rising	Rising	Falling
DailyMin	Rising	Rising	Rising	Rising	Rising

Actual rise or fall from the base year of 1990 to the forecast year 2100 is:

		Actual Rise/Fall in the season from 1990 to 2100			
Data Series	Annual	Pre-Monsoon	Monsoon	Post-Monsoon	Winter
DailyMax	0.6	-0.9	1.3	2.8	-0.5
DailyMin	1.1	0.8	0.8	2.7	3.7

Chapter 4: Rainfall Regime at Noakhali

4.1 Annual and Monthly Rainfall

Daily rainfall record of Maijdi (Noakhali Sadar upazila) has been collected from Bangladesh Meteorology Department (BMD) for the period 1951-2003. The following is a summary of annual rainfall statistics in mm.

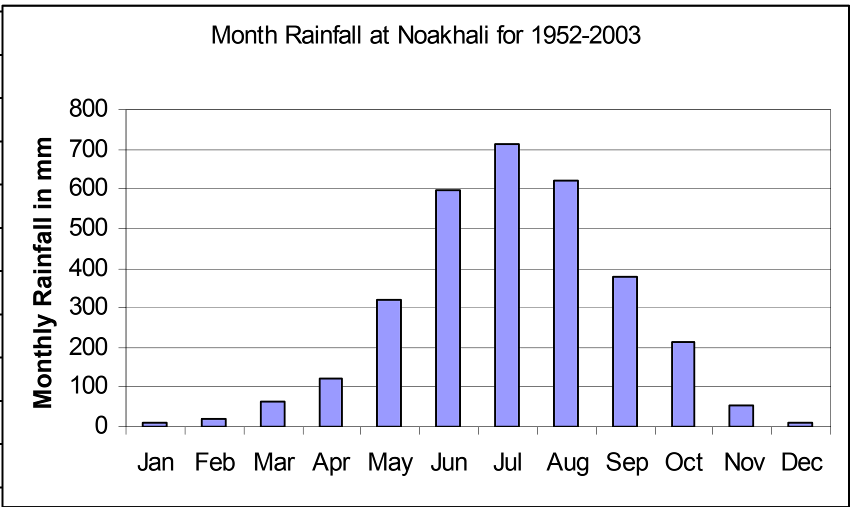
Table 4.1: Annual Rainfall Statistics

max	4799
avg	3090
min	2036
stdev	514

The following are the monthly rainfall and the bar chart:

Figure 1: Monthly rainfall bar chart

Months	1952-2003
Jan	11
Feb	21
Mar	63
Apr	122
May	318
Jun	594
Jul	711
Aug	620
Sep	378
Oct	214
Nov	53
Dec	8
Total	3113



It is noted that the monthly distribution of rainfall is typical monsoon rainfall of Bangladesh. The following is the seasonal distribution of rainfall in mm and also in percent of annual rainfall.

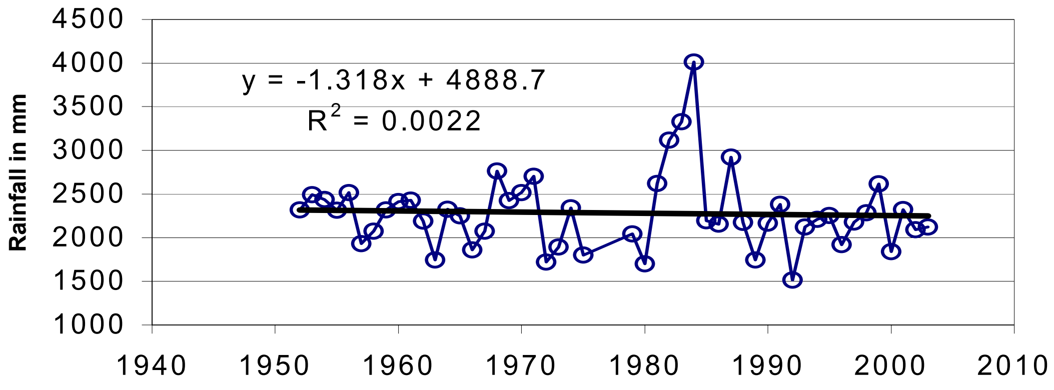
Table 4.2: Seasonal Rainfall Distribution

Period	1952-2003	
Season	Rainfall	% of Total
Summer	504	16
Monsoon	2303	74
Post-Monsoon	266	9
Winter	40	1
Total	3113	100

4.2 Change in the distribution of annual and monthly rainfall

Monsoon rainfall for the period of record was calculated for Noakhali Sadar and plotting of the same does not show any discernible trend (Figure 6.2). But SAARC Meteorological

Figure 4.2:Trend of Monsoon Rainfall at Noakhali



Research Centre in their study of "Recent Climatic Changes in Bangladesh" showed that trends of actual seasonal total country averaged rainfall over Bangladesh have a slight increasing trend.

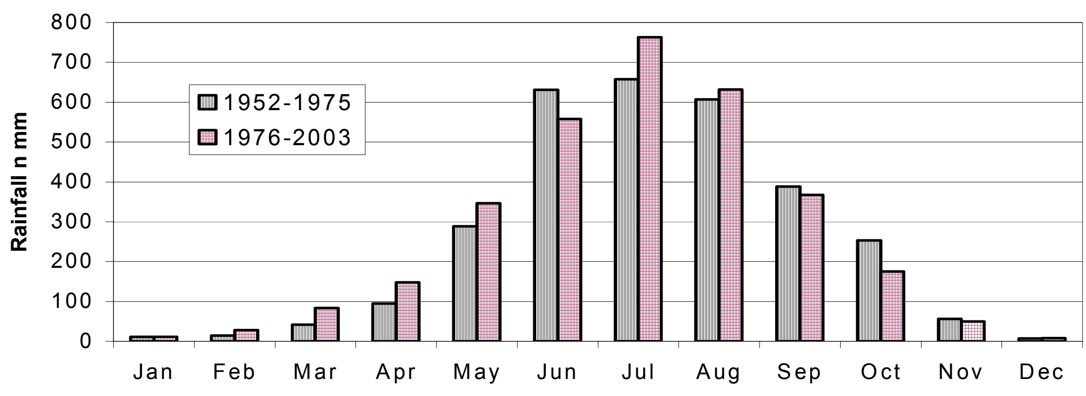
The period of record divided into two parts 1952-1975 and 1976-2003; monthly distribution of rainfall is shown in table 6.3 in mm and in % of annual Total. The data has also been presented in

Table 4.3 Comparison of distribution of monthly distribution

Months	1952-1975		1976-2003	
	Rain mm	% of Total	Rain mm	% of Total
Jan	11	0.4	12	0.4
Feb	15	0.5	28	0.9
Mar	42	1	83	3
Apr	95	3	148	5
May	289	9	347	11
Jun	631	21	558	18
Jul	657	22	763	24
Aug	607	20	632	20
Sep	388	13	368	12
Oct	253	8	176	6
Nov	56	2	50	2
Dec	7	0.2	8	0.3
Total	3052	100	3171	100

the form of bar chart in Figure 6.3 below. The difference in the two distributions is not very significantly although July and August rainfalls seem to have increased by 106 and 25 mm respectively. This does not support the view that rainfall in these two months have decreased causing delay in rice plantation with consequent reduction in yield.

Figure 4.3 Comparison of Rainfall at Noakhali for two periods



Ten wettest and driest monsoon rainfall was calculated and is shown below:

Table 4.4 Ten wettest monsoon rain

Year	Rain in mm
1984	4010
1983	3326
1982	3117
1987	2920
1968	2760
1971	2703
1981	2617
1999	2614
1956	2517
1970	2516

It is noticed that out 10 wettest monsoon, 6 occurred after 1975. This signifies some increase in monsoon activity in recent years for which average monsoon rainfall has increased but at the same time variability (stdev) of monsoon rainfall has also increased in recent years as seen in the following table:

Table 4.5 variability of monsoon rain

Period	mean	stdev
1952-75	2243	295
1976-03	2320	545

In the above table, it is seen that monsoon rain has increased by only 3% but the variability has increased by 85%. It is because of this increased variability a general feeling has developed that monsoon rainfall has not been sufficient in the recent years for timely plantation of rice.

The 10 driest monsoon rainfall was also calculated for Noakhali and is presented in the following table:

Table 4.6 Ten driest monsoon rain

Year	Monsoon
1996	1919
1973	1891
1966	1860
2000	1838
1975	1801
1989	1745
1963	1743
1972	1719
1980	1700
1992	1512

Like the wettest monsoon, in the driest monsoon series also 6 driest monsoon occurred in recent years that supports the concept of inadequate monsoon rain available for timely plantation of rice.

Chapter 5: Analysis of Cyclonic Trends[8]

5.1 Introduction

Tropical cyclones are the most talked weather events in countries namely Bangladesh, India, Pakistan and Sri Lanka. These cyclones originate in the North Indian Ocean (i.e. the Bay of Bengal and the Arabian Sea). The Bay of Bengal cyclones which cross Bangladesh and adjoining West Bengal coast of India move in the north or northeasterly direction; and the cyclones which cross the eastern coast of India move in westerly or northwesterly direction and sometimes recourse northeastwards. These disturbances cause considerable loss of life and property in the region with their ferocious wind and heavy rainfall.

During pre-monsoon and post-monsoon periods, disastrous tropical cyclones form in the Bay of Bengal. During the southwest monsoon season, a number of cyclone disturbances form in the Bay of Bengal and intensify into depression or deep depression. These systems can not intensify, usually, into cyclones due to the presence of strong vertical wind shear in the atmosphere over the North Indian Ocean during this season; however, a few of them intensify into cyclonic storms. Andhra Pradesh, Tamil Nadu and Orissa on the eastern coast of India and the coastal areas of Bangladesh are more vulnerable to cyclones in the Bay of Bengal region. The damages caused by tropical cyclones in Bangladesh are the greatest in the world. The is because of the high astronomical tide in the Bay of Bengal, shallow Bay configuration of the North Bay and the funneling shape of the northern tip of the Bay of Bengal for which the storm surge height is the highest in the coastal region of Bangladesh.

Meteorologists need a past climatic information on tropical cyclones, their trend, intensity, landfall and associated storm surges for the forecasting purposes along with the objective models for storm surges. The increasing use of the coastal areas for agricultural, industrial and recreational purposes needs vulnerability condition of an area to tropical cyclones and storm surges which are essential to coastal land use planners. Keeping in view of this fact, it has been felt that the trend of the frequency of cyclonic disturbances and storms in the Bay of Bengal is very important for long term planning of a country like Bangladesh.

There have been a few climatological and statistical studies on the depressions and storms in the Indian seas (Rai Sircar, 1958; Karmakar and Shrestha, 1998), but none of these are related to a long term trends in the frequencies of cyclonic disturbances of the north Indian Ocean. Some studies have also been made on the prediction of movement of cyclonic disturbances rather than prediction of their frequency (Sikka and Suryanarayana, 1968; Dutta and Gupta, 1975; Neumann and Mandal, 1978). Singh (2001) has made a long term trends in the frequency of monsoonal cyclonic disturbances over the north Indian Ocean utilizing 110 years data of 1890-1999. According to him, there have been significant decreasing trends in both the frequencies but the frequency of cyclonic disturbances has diminished at a faster rate

[8] Taken from Bangladesh National Dialogue on Water and Climate: Climate Variability Induced Extreme Events-M.A.Matin and S. Karmaker

(6 – 7 cyclonic disturbances/100 years) in the monsoon season. The frequency of cyclonic storms of the monsoon season has decreased at the rate of 1 – 2 cyclones/100 years.

The cyclonic disturbances during the monsoon season are mainly limited to the stages of depressions and a few turns into cyclones. They are associated with copious rainfall. But the cyclones cause a devastating damage and colossal loss of lives. Therefore, it is important to study the long term trends and variations of their frequencies.

5.2 Data used

The annual frequencies of cyclonic disturbances, depression/deep depressions, cyclonic storms and severe cyclonic storms of 110 years from 1891 through 2000 have been taken from the study of Karmakar and Shrestha (1998) and Bangladesh Meteorological Department.

5.3 Significance test of the coefficient of determination

The annual frequency of cyclonic disturbances, depression/deep depressions, cyclonic storms and severe cyclonic storms for the period 1891 through 2000 have been taken find the trends, both linear and polynomial of sixth degree and the corresponding regression equations and the coefficients of determination are obtained accordingly. The significance test of the coefficient of determination (R^2) has been carried out by using F-Test (Makridakis, *et al.*, 1983):

$$F = R^2 (n-k) / (1- R^2)(k-1)$$

Where n is the number of observations, (n-k) is the degree of freedom and k is the number of parameters. This coefficient of determination indicates how best the data are fitted to the trend line. If the calculated value of R^2 is greater than the theoretical value at certain significance level (0.05 or 0.01 i.e. 95% or 99% significance level) then R^2 is taken as significant at that level. The slopes of the linear regression equations give the increasing or decreasing trends of the frequency of the respective disturbances. The positive slope indicates increasing trend and the negative slope indicates decreasing trend of the climatic data.

5.4 Results and discussion

Analyses of the annual frequency of cyclonic disturbances (sum of the depressions/deep depressions, cyclonic storms and severe cyclonic storms), depressions and deep depressions combined together (here-in-after called depressions only), cyclonic storms and severe cyclonic storms formed in the Bay Bengal have been made by using the actual yearly frequency during the period 1891 through 2000. The trends of the annual frequency of cyclonic disturbances, depressions, cyclonic storms and severe cyclonic storms have been studied by fitting straight lines and polynomial curves and the results are given in Figs. 1-16. The salient features are presented below.

5.4.1 *Year to year variation in the frequency of cyclonic disturbances and storms in the Bay of Bengal*

i) The annual frequency of cyclonic disturbances over the Bay of Bengal shows a decreasing trend till around 1911 and increasing trend afterwards with maximum peak around 1946. It is to be noted that a minimum frequency period is found in1950's with again increasing trend having another peak around 1966 and a decreasing trend afterwards. The yearly frequency of cyclonic disturbances clearly shows a short period fluctuation of around 2-5 years (Figs.1-3).

ii) The yearly frequency of depressions over the Bay of Bengal (Figs. 4-6) shows the predominance of the short-term fluctuations. However, the general trend can be described as minimum around 1911 with slowly increasing trend with maximum around 1945 and then decreases.

-4-

iii) Figs. 7-9 depict the frequency of cyclonic storms with prominent short-term fluctuation of 2-5 years.

iv) The annual frequency of severe cyclonic storms over the Bay of Bengal does not show any definite trend of year to year fluctuations (Figs.10-12). However, it presents the short period fluctuation as shown in the cases of other disturbances as above. There are also the period during early 1950's which marks the minimum frequency followed by rapidly increasing trend with maximum peak around 1971-1972 and again it decreases. It is to be noted that though there is decreasing trend after 1972, the frequency remained at relatively higher values of more than 1 except in 1986.

5.4.2 *Trends in the frequency of cyclonic disturbances and storms in the Bay of Bengal*

5.4.2.1 *Linear trends*

The linear trends of the annual frequency of cyclonic disturbances (CD) in the Bay of Bengal are shown in Figs. 1-3. Fig. 1 shows the trend of the frequency of CD for the period 1900 through 1948 and indicates significantly increasing trend with R^2 = 0.548, which is statistically significant at 99% level. The rate of increase in frequency is 0.1426 per year. After 1948, the frequency of cyclonic disturbances has a sharp decreasing trend (Fig. 2) upto 2000 with R^2 = 0.2215, which is significant at 97.5% level. The rate of decrease in frequency is -0.1048 per year. When these two periods are combined, the overall trend in the frequency of cyclonic disturbances for the period 1891-2000 (Fig. 3) gives a slight decreasing tendency with R^2 = 0.0306, which is not statistically significant. The rate of decrease is -0.017 per year.

The linear trends in the annual frequency of depressions are shown in Figs. 4-5 for the periods 1900-1048 and 1949-2000 respectively. These figures show the same trends as those of cyclonic disturbances and both the trends are significant at 99% level with R^2 = 0.4313 and R^2 = 0.3615 respectively. The rate of increase in the frequency of depressions is 0.1322 per year during the period 1900-1948 and the rate of decrease is -0.1049 per year during the period 1949-2000. But for the overall period of 1891-2000, the Fig. 6 shows a slight increasing trend with $R^2 = 2 \times 10^{-8}$, which is not at all statistically significant. The rate of increase in the frequency during 1891-2000 is $1\text{x } 10^{-5}$ per year.

The linear trends in the annual frequency of cyclonic storms are shown in Figs. 7-8 for the periods 1900-1045 and 1946-2000 respectively. Fig. 7 shows that the frequency of cyclonic storms has a slight increasing trend during the period 1900-1945 with R^2 = 0.0258, which is not statistically significant. The rate of increase in the frequency of cyclonic storms is 0.0213 per year. Fig. 8 for the period 1946-2000 shows a slight decreasing trend in the frequency of cyclonic storms during the period

1946-2000 with R^2 = 0.0345, which is not significant and the rate of decrease is 0.0188 per year during the period 1946-2000. But for the overall period of 1891-2000, the Fig. 9 shows a decreasing trend with R^2 = 0.1166, which is significant at 95% level of significance. The rate of decrease in the frequency during 1891-2000 is –0.0193 per year.

The linear trends in the annual frequency of severe cyclonic storms are shown in Figs. 10-11 for the periods 1900-1045 and 1949-2000 respectively. Both the figures show an increasing trends in the frequency of severe cyclonic storms with R^2 = 0.0439 during the period 1900-1945 and R^2 = 0.1191 during the period 1946-2000. The values of R^2 are not statistically significant. The rates of increase in the frequency of severe cyclonic storms are 0.0176 per year and 0.0247 per year during the periods 1900-45 and 1946-2000 respectively. But for the overall period of 1891-2000, the Fig. 12 shows a slight increasing trend with R^2 = 0.0042, which is not significant. The rate of increase in the frequency of severe cyclonic storms during the period 1891-2000 is 0.0023 per year.

It is interesting to note that from mid 1950, the annual frequency of depressions and cyclonic storms has the decreasing trends whereas the annual frequency of severe cyclonic storms has the increasing trend. It means that most of the depressions and cyclonic storms have a tendency to be intensified into severe cyclonic storms after 1945. This may be related to the global warming.

5.4.2.2 *Polynomial trends*

The polynomial trends in the annual frequency of cyclonic disturbances, depressions, cyclonic storms and severe cyclonic storms are shown in Figs. 13-16 respectively. The figures show that the polynomial curves are fitted better than the linear ones, as indicated by the values of R^2. The values of R^2 are 0.4088, 0.4244, 0.1526 and 0.0871 respectively for cyclonic disturbances, depressions, cyclonic storms and severe cyclonic storms, and these values are statistically significant at 99%, 99% and 95% except for the latter which is not significant.

Fig. 13 for the polynomial trend in the annual frequency of cyclonic disturbances shows that the frequency decreases from 1891 to 1900 and then begins to increase having maximum frequency around 1945. The frequency is above the mean (here-in-after called normal) between 1915 and 1974 (about 60 years), and then it decreases significantly having a minimum in around 2000. The duration between two minimum values is about 100 years.

The polynomial curve for the depressions (Fig. 14) shows the same trend as that of the cyclonic disturbances, having the two minima in 1900 and 2000 with duration of 100 years and the maximum value in 1945. The annual frequency is above normal from 1922 to 1974 (about 53 years).

Fig. 15 for the cyclonic storms shows a clear and significant decreasing trend in the annual frequency of cyclonic storms with cycles of variations for different periods. The trend shows minimum peaks in 1900 and 1950 with duration of 50 years and in 1950 and 1996 with 46 years of duration. The trend also shows two maximum peaks in 1920 and 1970 with duration of 50 years

Fig. 16 shows a slight increasing trend in the annual frequency of severe cyclonic storms in the Bay of Bengal with fluctuations of different periods. This curve indicates the minimum peaks in 1900 and1945 with the duration of 45 years and in 1945 and 1995 with duration of 50 years. The curve shows two maximum peaks in 1922 and 1972 with duration of 50 years.

5.5. Projected increase/decrease in the annual frequency of cyclonic disturbances, depressions, cyclonic storms and severe cyclonic storms based on linear trends

Based on the linear trends the projected increase/decrease in the annual frequency of cyclonic disturbances, depressions, cyclonic storms and severe cyclonic storms are given in Table 1.

Table 1: Projected increase/decrease in the annual frequency of cyclonic disturbances and storms based on linear trends during the period 1891-2000

Type of disturbances	Rate of increase / decrease per year	Projected increase/decrease in the annual frequency of disturbances in					
		2010	2020	2030	2040	2050	2100
Cyclonic disturbances	-0.017	-0.17	-0.34	-0.51	-0.68	-0.85	-1.7
Depressions	$1x\ 10^{-5}$	$1x\ 10^{-4}$	$2x\ 10^{-4}$	$3x\ 10^{-4}$	$4x\ 10^{-4}$	$5x\ 10^{-4}$	$1x\ 10^{-2}$
Cyclonic storms	–0.0193	–0.193	–0.386	–0.579	–0.772	–0.965	–1.93
Severe cyclonic storms	0.0023	0.023	0.046	0.069	0.072	0.115	0.23

Table 1 shows very insignificant increase/decrease in the annual frequency of cyclonic disturbances and storms.

5.6 Conclusions

On the basis of the present study, the following conclusions can be drawn:

(a) The yearly frequency of cyclonic disturbances clearly shows a short period fluctuation of around 2-5 years. The yearly frequency of depressions over the Bay of Bengal shows the predominance of the short-term fluctuations. The frequency of cyclonic storms with prominent short-term fluctuation of 2-5 years. The annual frequency of severe cyclonic storms over the Bay of Bengal does not show any definite trend of year to year fluctuations. However, it presents the short period fluctuation as shown in the cases of other disturbances as above.

b) The annual frequency of cyclonic disturbances (CD) in the Bay of Bengal shows a significantly increasing trend (at 99% level) for the period 1900 through 1948, the rate of increase in frequency being 0.1426 per year. After 1948, the frequency of cyclonic disturbances has a sharp decreasing trend, which is significant at 97.5% level. The rate of decrease in frequency is -0.1048 per year. The overall trend in the frequency of cyclonic disturbances for the period 1891-2000 gives a slight decreasing tendency, which is not statistically significant. The rate of decrease is -0.017 per year.

c) The annual frequency of depressions shows the same trends as those of cyclonic disturbances for the periods 1990-1948 and 1949-2000 and both the trends are significant at 99% level. The rate of increase in the frequency of depressions is 0.1322 per year during the period 1900-1948 and the rate of decrease is -0.1049 per year during the period 1949-2000. But for the overall period of 1891-2000, a slight increasing trend is observed, which is not at all statistically significant. The rate of increase in the frequency during 1891-2000 is 1x 10^{-5} per year.

d) The annual frequency of cyclonic storms has a slight increasing trend during the period 1900-1945, which is not statistically significant; the rate of increase being 0.0213 per year. There is a slight decreasing trend in the frequency of cyclonic storms during the period 1946-2000, which is not also significant and the rate of decrease is -0.0188 per year. But for the overall period of 1891-2000, the frequency shows a decreasing trend (significant at 95% level). The rate of decrease in the frequency during 1891-2000 is –0.0193 per year.

e) The annual frequency of severe cyclonic storms for the periods 1900-1045 and 1949-2000 respectively shows increasing trends, which are not statistically significant. The rates of increase in the frequency of severe cyclonic storms are 0.0176 per year and 0.0247 per year during the periods 1900-45 and 1946-2000 respectively. But for the overall period of 1891-2000, the frequency of severe cyclonic storms shows a slight increasing trend, which is not significant. The rate of increase in the frequency of severe cyclonic storms during the period 1891-2000 is 0.0023 per year.

f) From mid 1950, the annual frequency of depressions and cyclonic storms has the decreasing trends whereas the frequency of severe cyclonic storms has the increasing trend. It means that most of the depressions and cyclonic storms have a tendency to be intensified into severe cyclonic storms after 1945. This may be related to the global warming.

g) The polynomial trends show that the polynomial curves are fitted better than the linear ones, as indicated by the values of R^2. The values of R^2 are 0.4088, 0.4244, 0.1526 and 0.0871 respectively for cyclonic disturbances, depressions, cyclonic storms and severe cyclonic storms, and these values are statistically significant at 99%, 99% and 95% except for the latter which is not significant.

h) There are long term oscillations in the annual frequency of cyclonic disturbances and storms for a period of about 50-60 years.

Acknowledgement

The author wishes thank to Mr. Md. Akram Hossain, Director of Bangladesh Meteorological Department for giving the opportunity to be involved in the present study. Thanks are also due to Mr. Sujit Kumar Debsarma, Assistant Director, Mr. M. A. Mannan, Assistant Meteorologist and S. M. Quamrul Hassan, Assistant Meteorologist for their help in the compilation of data.

7.6 Additional Analysis of Monthly frequency of Cyclonic Disturbance

Trend analysis of monthly frequency of depressions in the Bay of Bengal were also done by grouping the frequencies into seasons (Annual, Pre-Monsoon, Monsoon, Post-Monsoon and Winter). Types of depressions considered are Depressions-Deep Depression (D-DD), Cyclonic Storms (CS), Severe Cyclonic Storms (SCS) and Cyclonic Disturbance (CD) by taking the three types together.

Summary of the trend analysis is shown in Table 3: Summary of Trends of Cyclonic Disturbance in Chapter 7. It is observed that out of 20 trends 14 has positive trends i.e. frequency of disturbance is increasing while 6 trends are decreasing. Grouping the trends into depression types results the following table:

Depression Type	Increasing	Decreasing
D-DD	5	0
CS	1	4
SCS	3	2
CD	5	0
Total	14	6

The lowest category of depression D-DD having the highest frequency has the increasing tendency in all the seasons. This is likely to reduce the fisherman’s working days in the sea and navigation by smaller boats there by affecting livelihood of these people

Table 3: Summary of Trends of Cyclonic Disturbance

CyClone	Season	Period	Rsquar	Slope	Interce	Formuala
D-DD	Annual	1891-	0.0272	0.0153	-23.802	y = 0.0153x - 23.802
D-DD	Pre-	1891-	0.0034	0.0011	-1.906	y = 0.0011x - 1.906
D-DD	Monsoon	1891-	0.0054	0.0048	-5.3432	y = 0.0048x - 5.3432
D-DD	Post-	1891-	0.0253	0.0059	-10.225	y = 0.0059x - 10.225
D-DD	Winter	1891-	0.027	0.0034	-6.3275	y = 0.0034x - 6.3275
CS	Annual	1891-	0.0756	-	35.279	y = -0.0168x + 35.279
CS	Pre-	1891-	0.0026	-	1.9602	y = -0.0009x + 1.9602
CS	Monsoon	1891-	0.2208	-	35.133	y = -0.0175x + 35.133
CS	Post-	1891-	0.0054	0.0026	-4.0942	y = 0.0026x - 4.0942
CS	Winter	1891-	0.0033	-0.001	2.2795	y = -0.001x + 2.2795
SCS	Annual	1891-	0.0059	0.003	-4.4258	y = 0.003x - 4.4258
SCS	Pre-	1891-	0.00000	-	0.4186	y = -1E-05x + 0.4186
SCS	Monsoon	1891-	0.0322	-	6.2644	y = -0.0031x + 6.2644
SCS	Post-	1891-	0.0182	0.0038	-6.6818	y = 0.0038x - 6.6818
SCS	Winter	1891-	0.0263	0.0024	-4.427	y = 0.0024x - 4.427
CD	Annual	1891-	0.0002	0.0015	7.0509	y = 0.0015x + 7.0509
CD	Pre-	1891-	0.0011	0.0009	-0.7254	y = 0.0009x - 0.7254
CD	Monsoon	1891-	0.0485	0.0009	-0.015	y = -0.015x + 34.657
CD	Post-	1891-	0.0519	0.0116	-19.639	y = 0.0116x - 19.639
CD	Winter	1891-	0.0242	0.0041	-7.2413	y = 0.0041x - 7.2413

5.7 Analysis of Wind speed in coastal areas in Bangladesh

Wind speed data from 12 coastal stations were available for analysis. Maximum and average wind speed were investigated and evaluated for each year of available record. There could be large errors in the data and without appropriate quality control only limited inferences can be drawn.

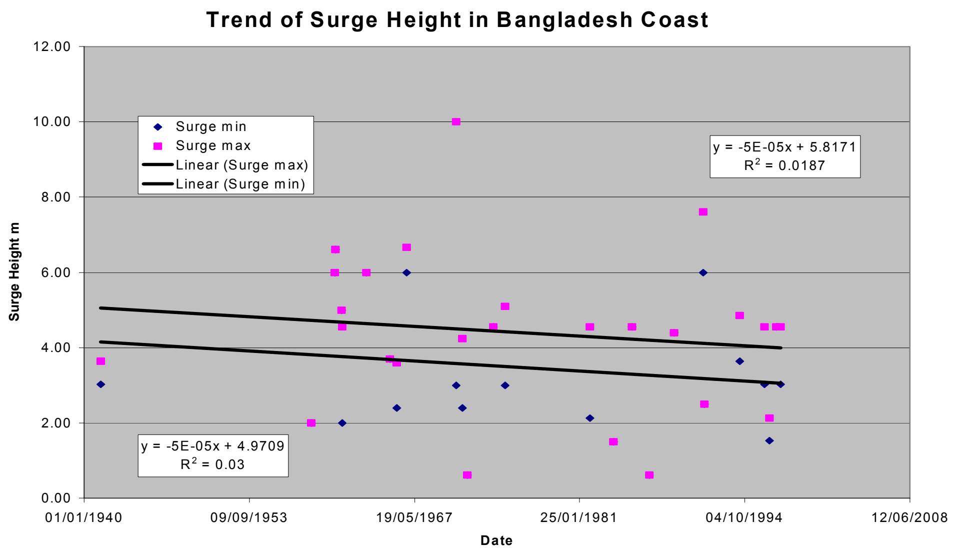
Annex-F shows the trends of average wind speed for annual and the four seasons, Pre-Monsoon, Monsoon, Post-Monsoon and Winter. Annual average and all the four seasonal series show falling trends.

Incase of annual maximum series the data for the years 1975 to 1979 seem doubtful (see Figure 48 in Annex-F). The trend of maximum series for the period 1980 to 1998 for both annual and monsoon show increasing trend. These trends for Pre-Monsoon, Post-Monsoon and Winter however show decreasing trend and are shown in Annex-F.

5.8 Trend of Storm Surges

Recorded storm surge data are not available in Bangladesh. Cyclone Landfall data available mainly from BMD and other sources have been computerized in a database for facility of computations. In the Cyclone Landfall data table a total of a total of 119 Cyclones from the year 1582 to 1997 have been recorded. Cyclone information in this table prior to 1940 is for historical interest only. Of these 119 Cyclones, Storm surge data for 30 Cyclones are available and plotting of these in the form a time series yield the figure shown overleaf.

It is noticed that just like the falling wind speed shown in Annex-F, the storm surge data from these 30 cyclones also show a decreasing trend. Storm Surge heights are dependent on a number of parameters such as Wind Speed, speed and direction of movement of cyclone, stage of tide, sea hydrographic bathymetry etc. But Wind Speed is one of the major factors. Thus decreasing trend in both Wind Speed and Cyclone surge heights from two independent sources strengthens the two trends. Never the less, in view of trends of temperature and rainfall it is difficult comprehend the falling trend of Surge heights and Wind Speed. This also indicates importance and necessity of stricter quality control of Cyclone and Wind data of BMD.



Chapter 6: Analysis of Wind Trends[9]

6.1 Analysis of Wind speed in coastal areas in Bangladesh

Wind speed data from 12 coastal stations were available for analysis. Maximum and average wind speed were investigated and evaluated for each year of available record. There could be large errors in the data and without appropriate quality control only limited inferences can be drawn.

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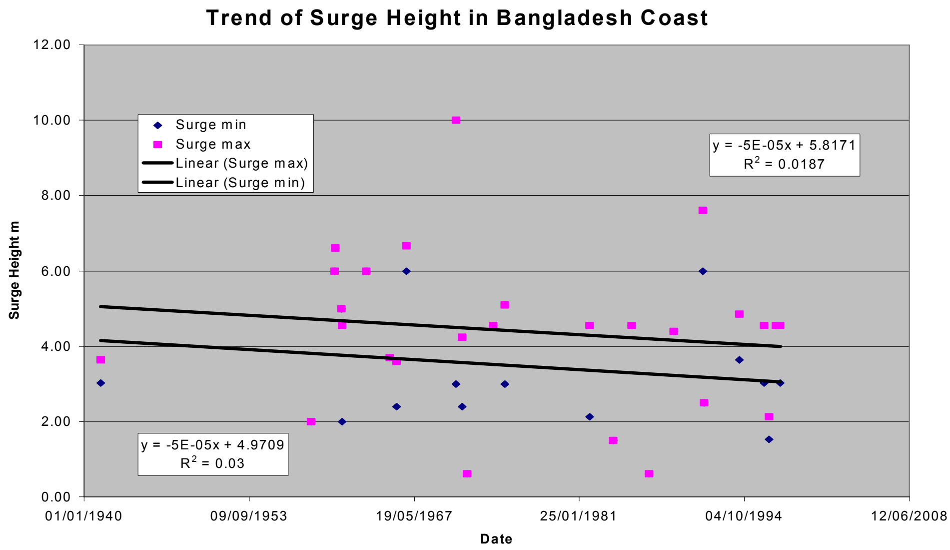
It is noticed that just like the falling wind speed shown in Annex-F, the storm surge data from these 30 cyclones also show a decreasing trend. Storm Surge heights are dependent on a number of parameters such as Wind Speed, speed and direction of movement of cyclone, stage of tide, sea hydrographic bathymetry etc. But Wind Speed is one of the major factors. Thus decreasing trend in both Wind Speed and Cyclone surge heights from two independent sources strengthens the two trends. Never the less, in view of trends of temperature and rainfall it is difficult comprehend the falling trend of Surge heights and Wind Speed. This also indicates importance and necessity of stricter quality control of Cyclone and Wind data of BMD.

[9] Taken from Bangladesh National Dialogue on Water and Climate: Climate Variability Induced Extreme Events-M.A.Matin and S. Karmaker


Trend of Surge Height in Bangladesh Coast
Surge Height m
Date
12.00
10.00
8.00
6.00
4.00
2.00
0.00
01/01/1940
09/09/1953
19/05/1967
25/01/1981
04/10/1994
12/06/2008
Surge min
Surge max
Linear (Surge max)
Linear (Surge min)
y = -5E-05x + 5.8171
R^2 = 0.0187
y = -5E-05x + 4.9709
R^2 = 0.03

Chapter 7 :

Recommendation

Noakhali Sadar and Subarnochar upazila are newly accreted area after erosion in mid-forties. The area is protected by Coastal Embankment Project Polder P59/3B. The embankment has been designed as Sea-dyke with crest level 7.00 m-PWD. Agriculture although has a great scope is not developed like other parts of the country.

The area is already suffering from water shortage and lack of assurance of water during the crop season. Inadequate drainage during heavy shower is also a problem. There is a good number of natural and man made canals in the area and presently these are not in a very good shape. These canals could be re-excavated in order to provide efficient drainage when needed.

Traditionally this area has good number ponds and tanks. Sweet water fish culture is being practised in these ponds. Low water demand crops and vegetables could be developed from these ponds and re-excavated canal system.

Important Khals of Noakhali Sadar and Subarnochar Upazila

1. Noakhali khal	Kadir Hanif, Niazpur, Aswadia, Char Clark unions	70 km
2. Gobadia khal	Naruttampur, Niazpur unions	12 km
3. Datter Khal	Binodpur, Noannai unions	20 km
4. Islamia khal	Kadir Hanif, Noannai unions	12 km
5. Malek khal	Ewazbalia, Kaladaraf unions	15 km
6. Karambaksh kalamukh khal	Naruttampur-Mundalpur unions	22 km
7. Gopalkhal	Char Jabbar-Char Jubili	20 km
8. Bhulua khal	Char Motua-Moani	10 km
9. Char Jabbar khal	Char Jabbar	8 km
10.Baten khali khal	Char Bata	10 km

According to the temperature forecast, post-monsoon and winter temperature could rise by about 2^0C by the middle of the current century. This on the one hand is likely to increase pest attacks on the crops, and on the other will increase evaporation loss. Without an assured supply of water and ground water being polluted by arsenic contamination, canalisation and development of pond for irrigation can bring about immediate solution to the problem. Growing winter vegetables is labour intensive job and thus can help the agricultural labours.

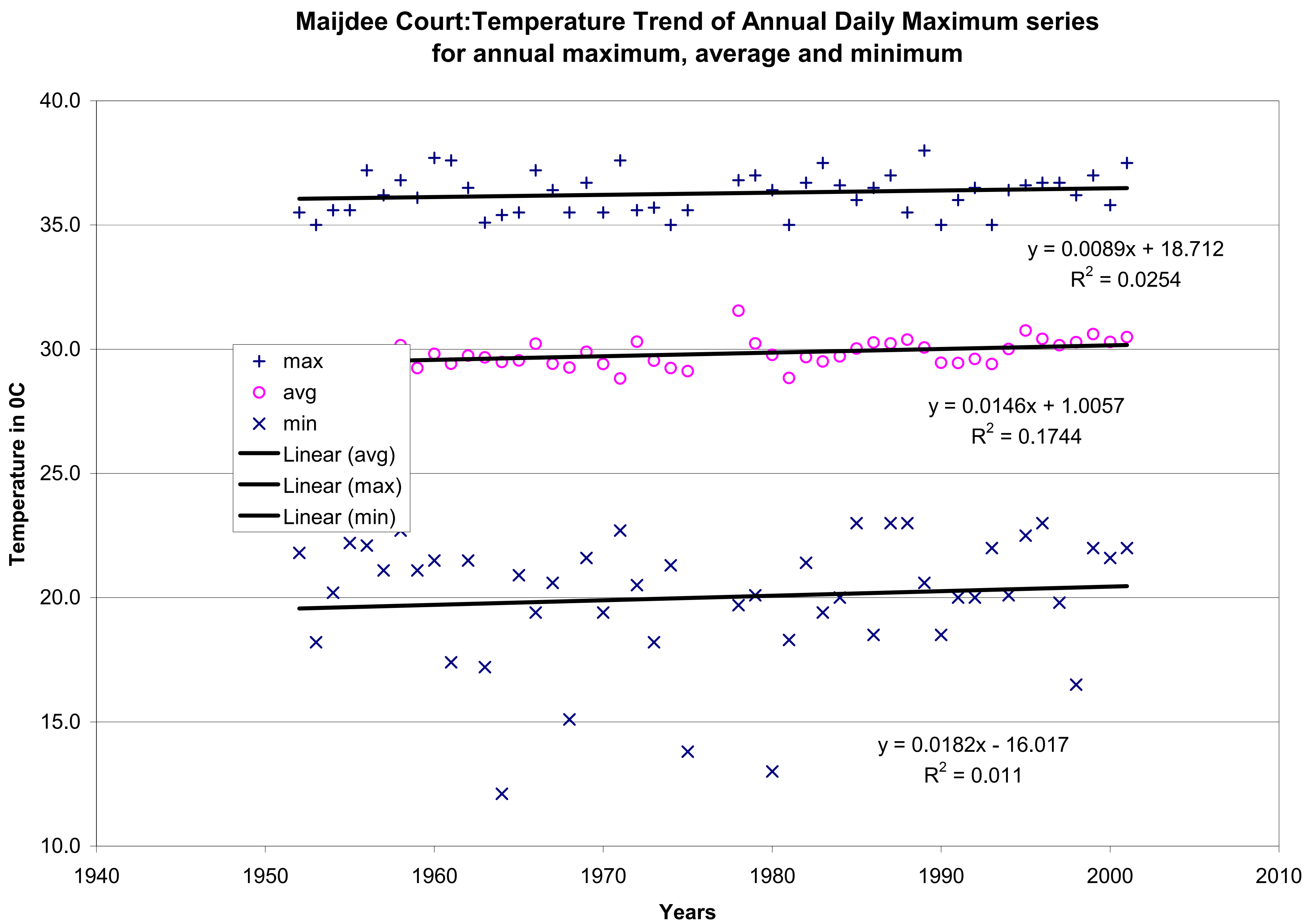
Subarnochar area is protected by Coastal Embankment Project Polder P59/3B. Crest level of dike is set at 7.00 m-PWD. Present estimate of sea level rise in Bangladesh coast is about 3-10 mm/year. Even with the highest rate of 1 cm/yr, the level may go up by only 0.5 m which can be comfortably absorbed by annual/periodic maintenance of dike.

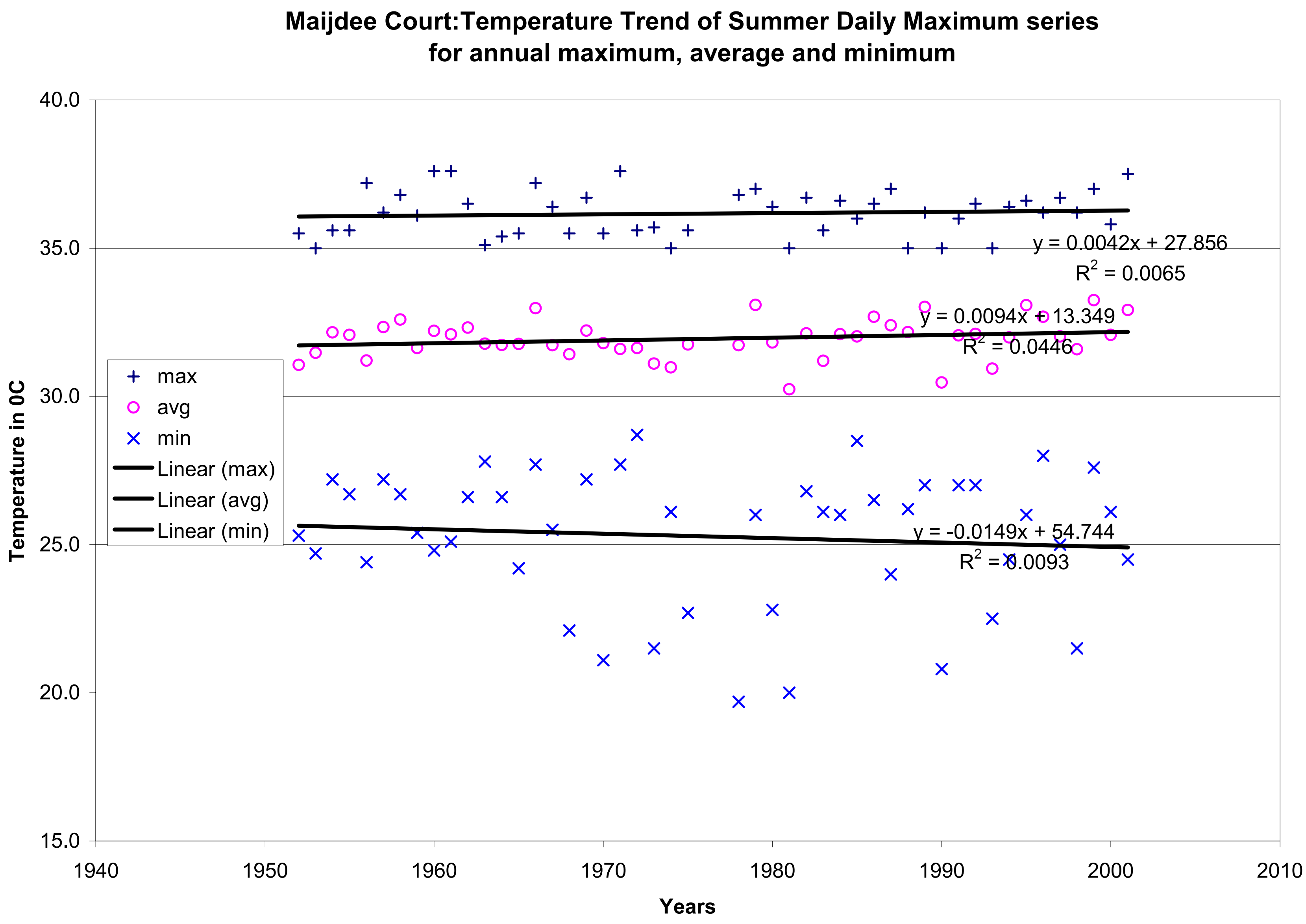
No significant change in rainfall pattern has been identified. But a tendency of slight increase in variability has been located. The area is already suffering from drainage congestion. Improvement in existing canal system has been proposed. If in the near future requirement of additional vents is demanded, additional drainage sluices may be constructed at locations demanding drainage relief.

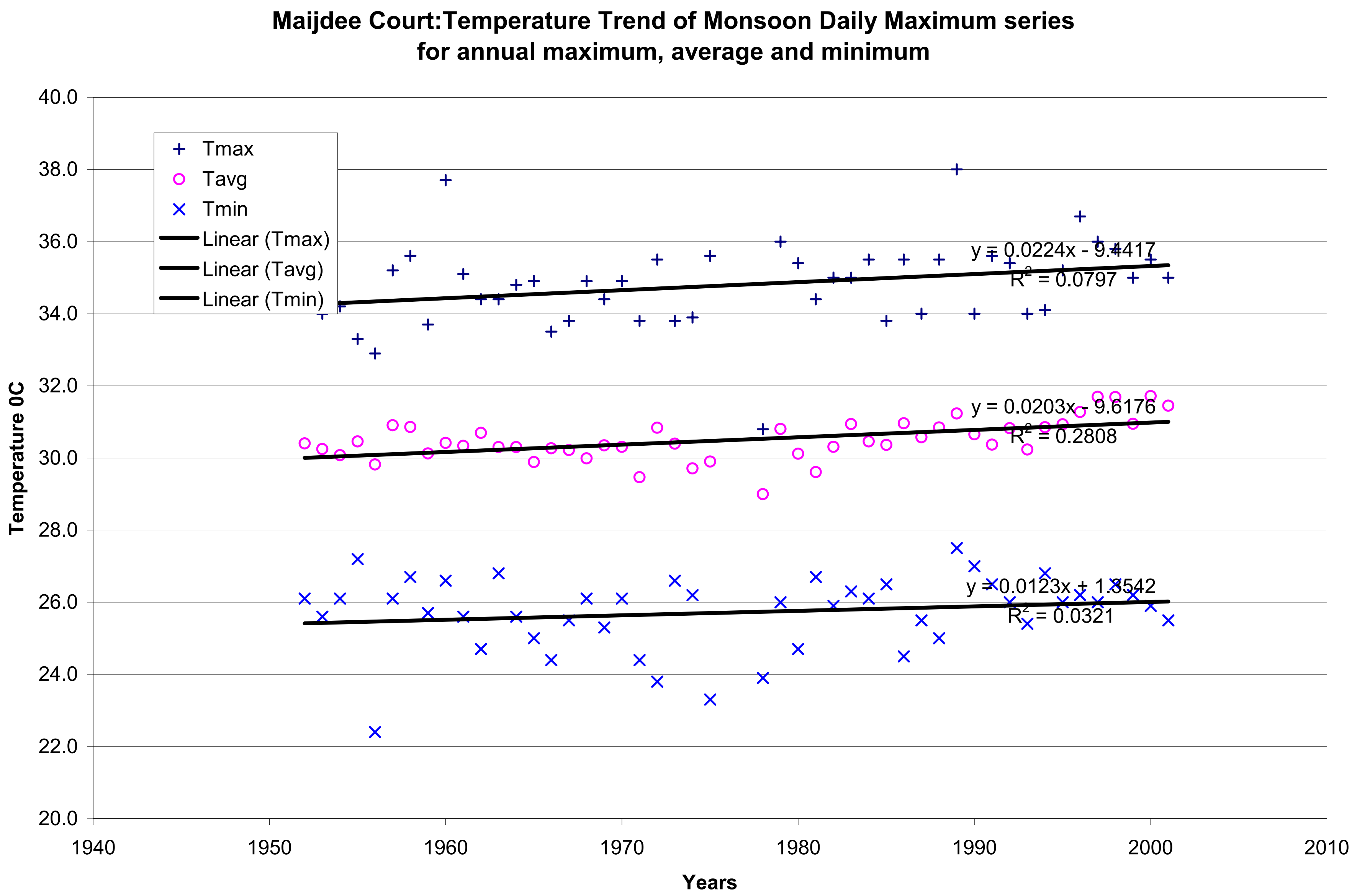
Inspection of dike system in and around steamer ghat (opposite Boyerchar) in Subarnochar upazila have shown the dike in a very good section and condition. Thr fore shore area seem to be well protected by growth of forests. Thus storm surges if hits the are will be dampened before hitting the dike proper.

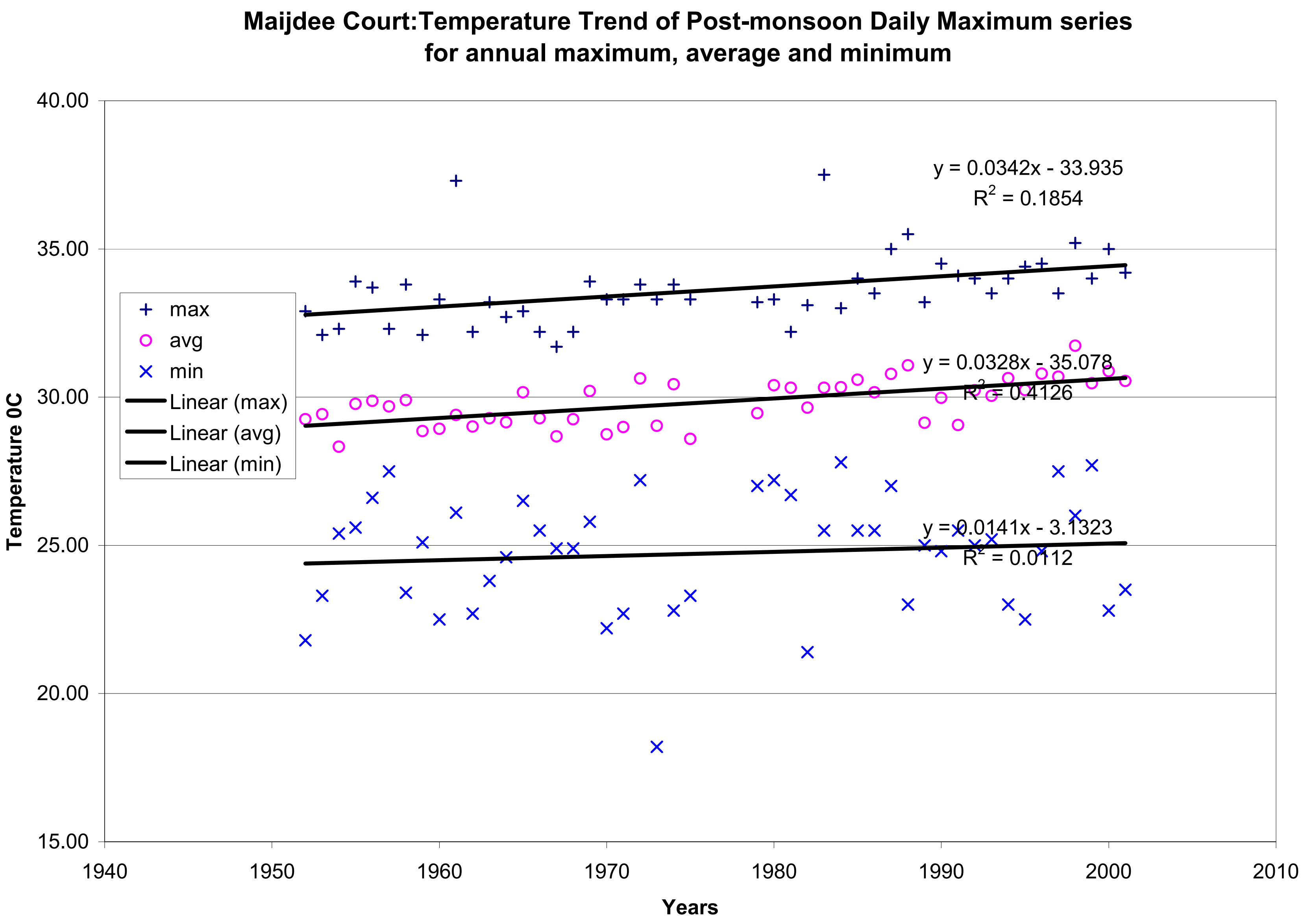
Most habitations are comfortably away from dike to the countryside. These inhabitants are confident that they will not be affected by storm surges. But new habitation are developing close to dike and they may remain vulnerable to storm surges. It may therefore be useful to prepare a vulnerability map of likely areas that may be affected by storm surges or due to drainage congestion, in case of overtopping dike system.

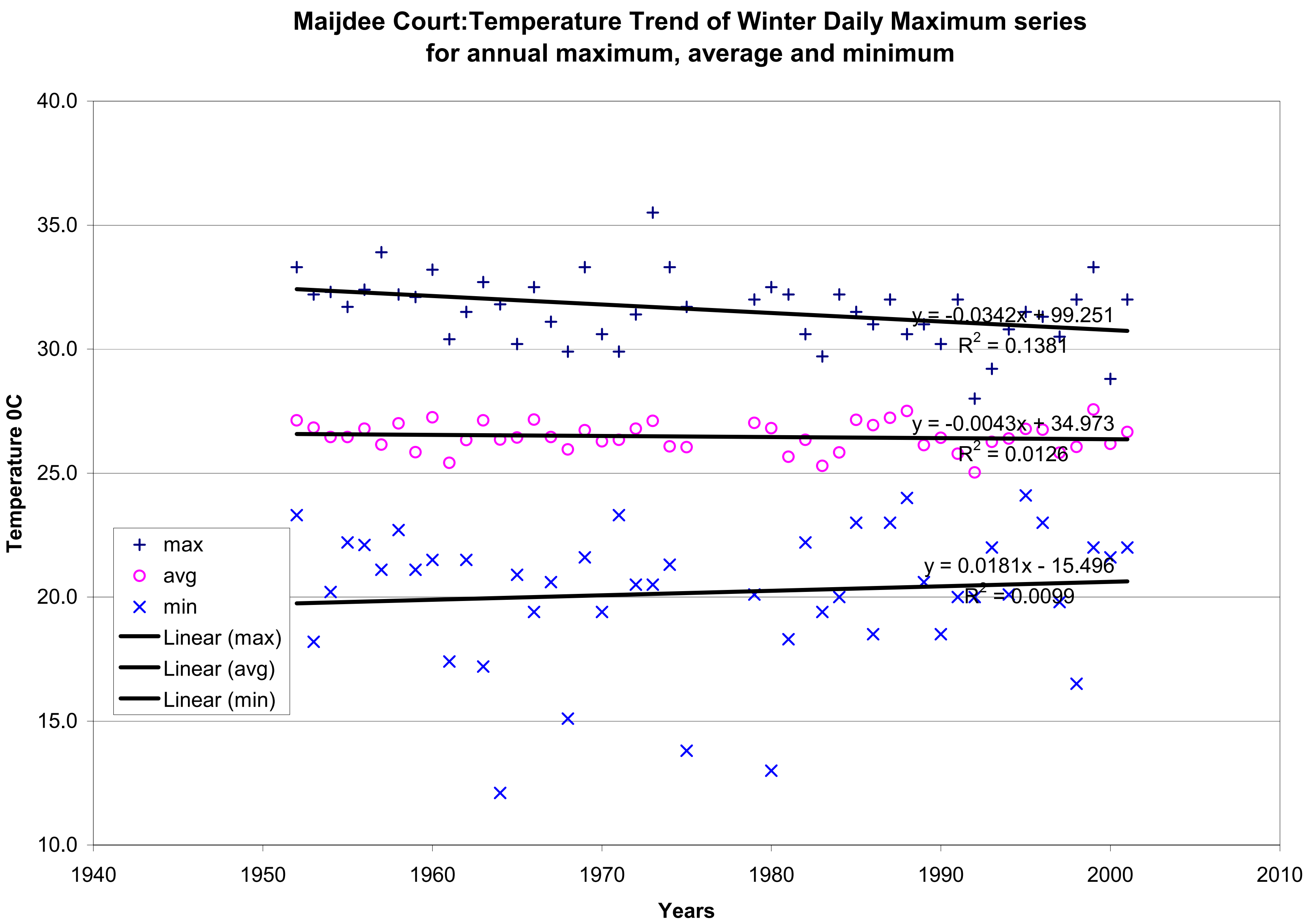
Annex A: Time trend of seasonal temperature means and extremes

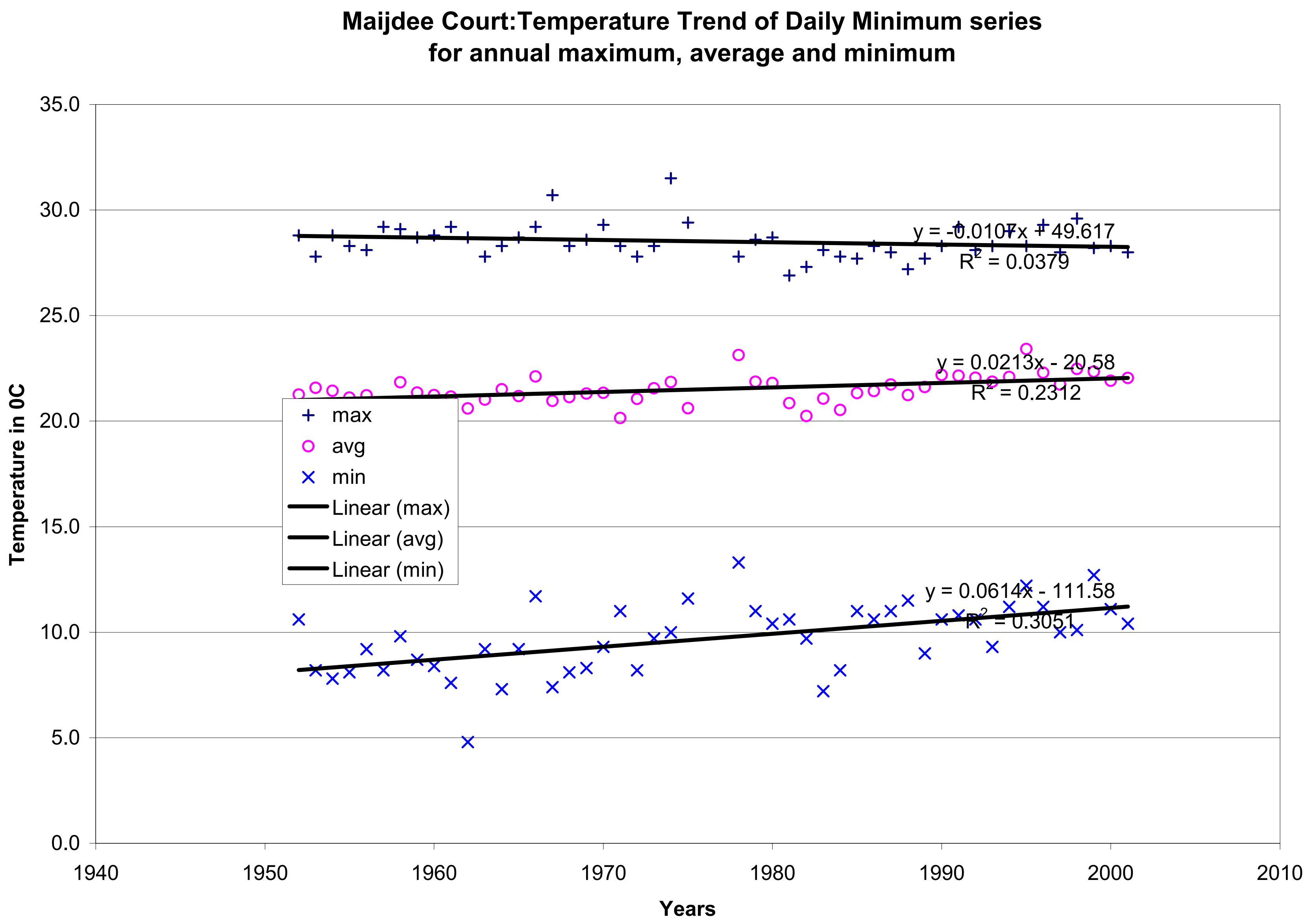

Maijdee Court:Temperature Trend of Annual Daily Maximum series
for annual maximum, average and minimum
40.0
35.0
30.0
25.0
20.0
15.0
10.0
Temperature in 0C
1940
1950
1960
1970
1980
1990
2000
2010
Years
max
avg
min
Linear (avg)
Linear (max)
Linear (min)
y = 0.0089x + 18.712
R^2 = 0.0254
y = 0.0146x + 1.0057
R^2 = 0.1744
y = 0.0182x - 16.017
R^2 = 0.011

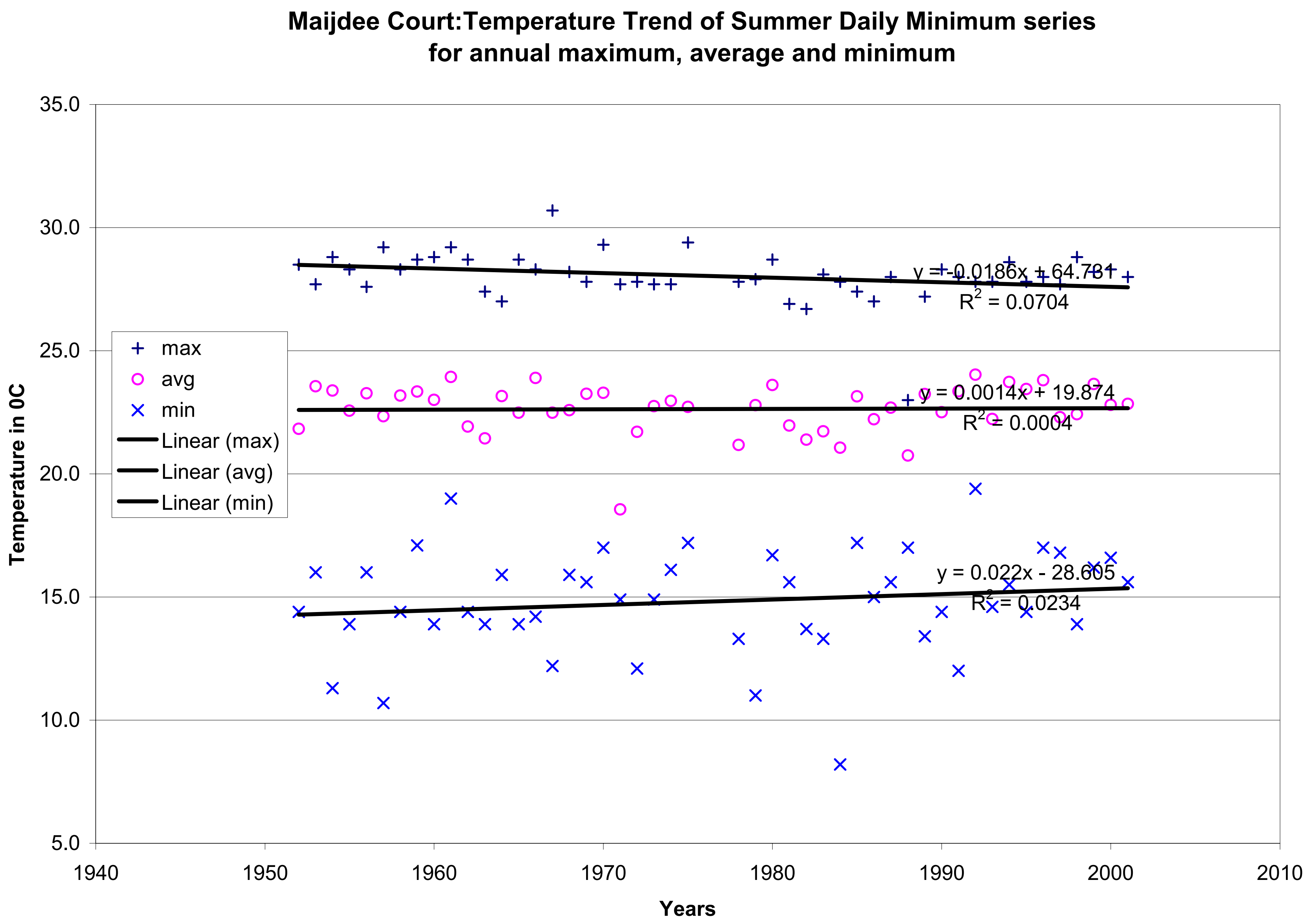

Maijdee Court:Temperature Trend of Summer Daily Maximum series for annual maximum, average and minimum
Temperature in 0C
Years
40.0
35.0
30.0
25.0
20.0
15.0
1940
1950
1960
1970
1980
1990
2000
2010
max
avg
min
Linear (max)
Linear (avg)
Linear (min)
y = 0.0042x + 27.856
R2 = 0.0065
y = 0.0094x + 13.349
R2 = 0.0446
y = -0.0149x + 54.744
R2 = 0.0093

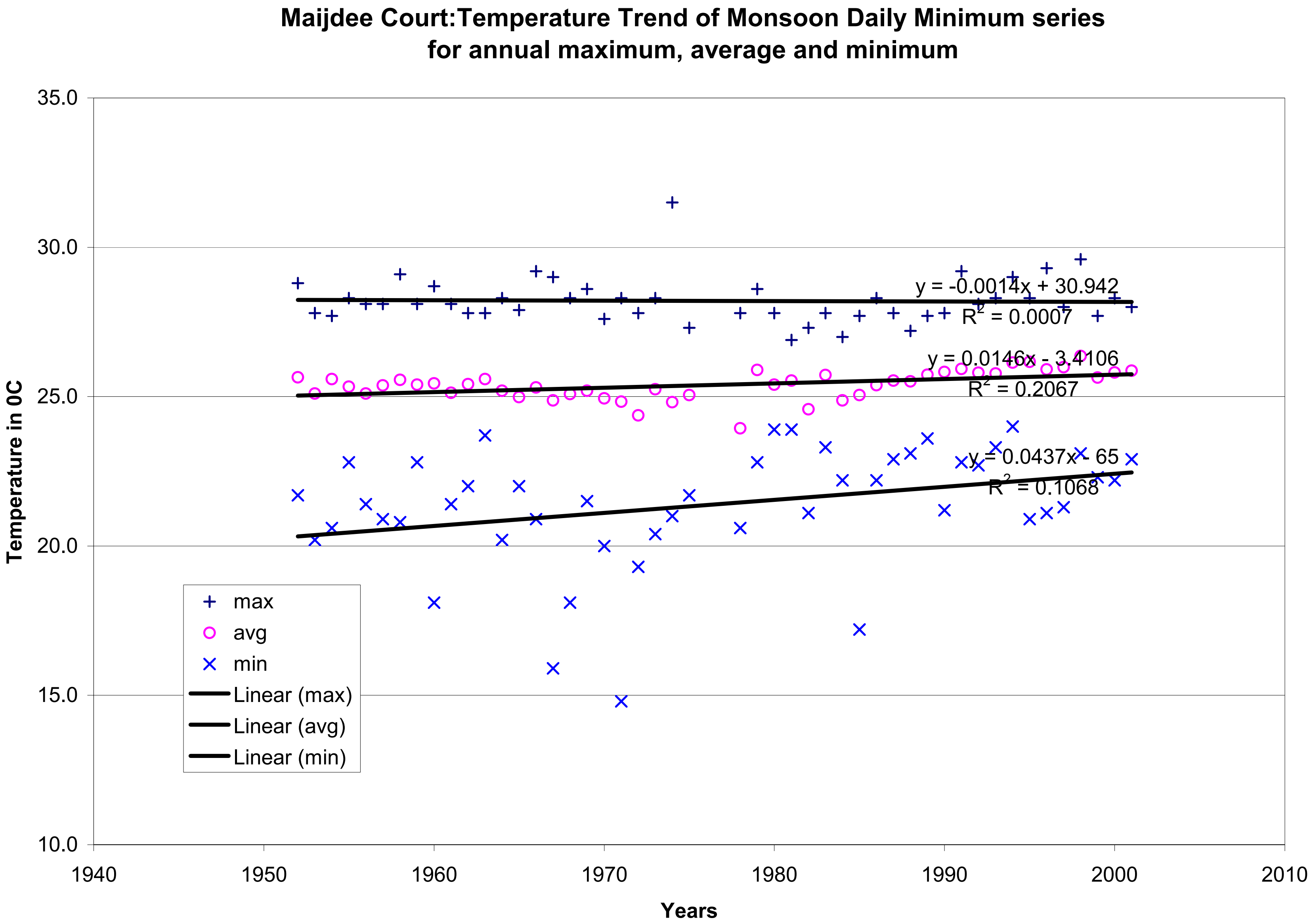

Maijdee Court:Temperature Trend of Monsoon Daily Maximum series
for annual maximum, average and minimum
Tmax
Tavg
Tmin
Linear (Tmax)
Linear (Tavg)
Linear (Tmin)
y = 0.0224x - 9.4417
R² = 0.0797
y = 0.0203x - 9.6176
R² = 0.2808
y = 0.0123x + 1.3542
R² = 0.0321
Temperature 0C
Years
40.0
38.0
36.0
34.0
32.0
30.0
28.0
26.0
24.0
22.0
20.0
1940
1950
1960
1970
1980
1990
2000
2010

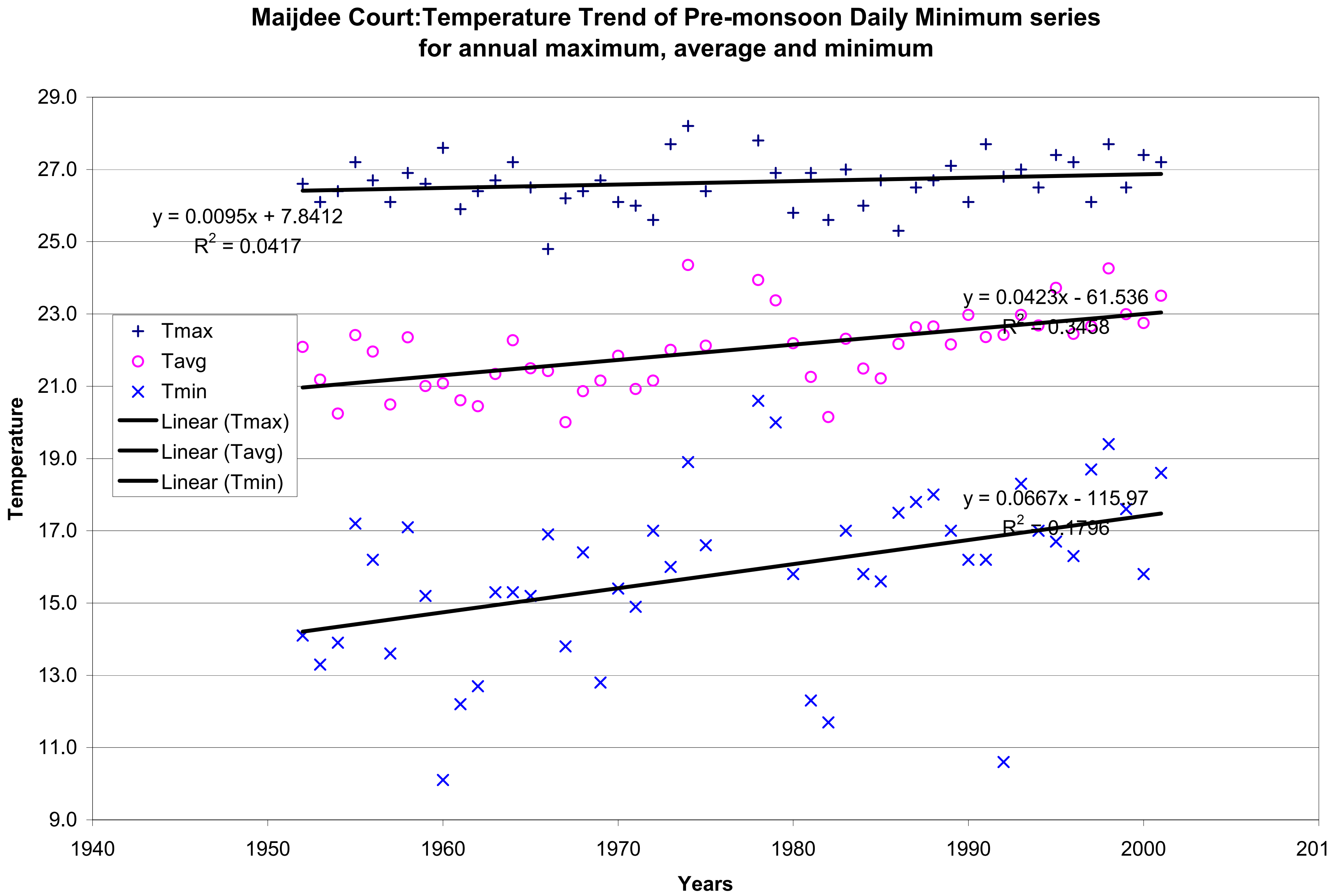

Maijdee Court:Temperature Trend of Post-monsoon Daily Maximum series
for annual maximum, average and minimum
Temperature 0C
Years
40.00
35.00
30.00
25.00
20.00
15.00
1940
1950
1960
1970
1980
1990
2000
2010
max
avg
min
Linear (max)
Linear (avg)
Linear (min)
y = 0.0342x - 33.935
R2 = 0.1854
y = 0.0328x - 35.078
R2 = 0.4126
y = 0.0141x - 3.1323
R2 = 0.0112

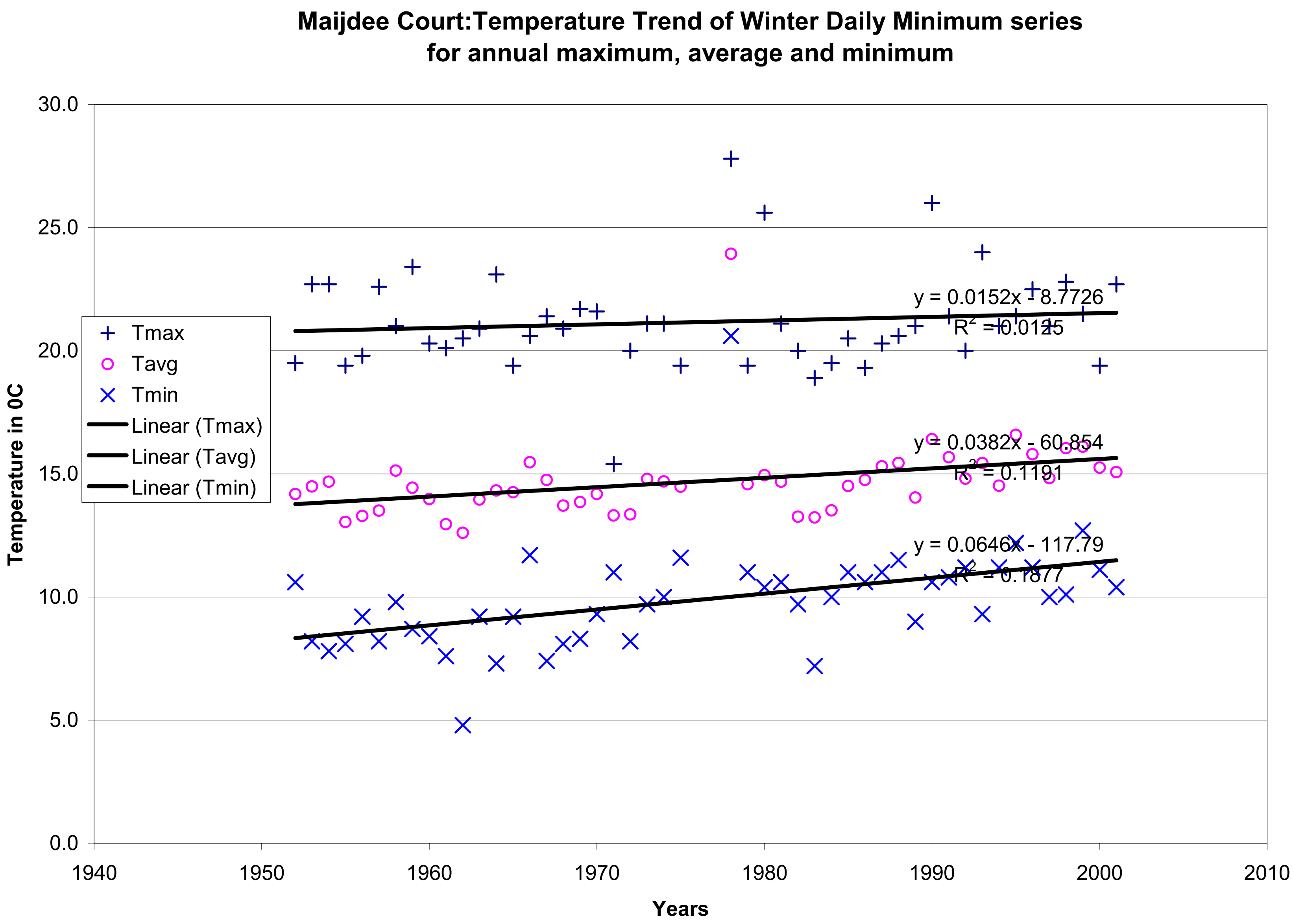

Maijdee Court:Temperature Trend of Winter Daily Maximum series for annual maximum, average and minimum
Temperature 0C
Years
40.0
35.0
30.0
25.0
20.0
15.0
10.0
1940
1950
1960
1970
1980
1990
2000
2010
max
avg
min
Linear (max)
Linear (avg)
Linear (min)
y = -0.0342x + 99.251
R2 = 0.1381
y = -0.0043x + 34.973
R2 = 0.0126
y = 0.0181x - 15.496
R2 = 0.0099


Maijdee Court:Temperature Trend of Daily Minimum series
for annual maximum, average and minimum
Temperature in 0C
Years
35.0
30.0
25.0
20.0
15.0
10.0
5.0
0.0
1940
1950
1960
1970
1980
1990
2000
2010
max
avg
min
Linear (max)
Linear (avg)
Linear (min)
y = -0.0107x + 49.617
R2 = 0.0379
y = 0.0213x - 20.58
R2 = 0.2312
y = 0.0614x - 111.58
R2 = 0.3051


Maijdee Court:Temperature Trend of Summer Daily Minimum series
for annual maximum, average and minimum
35.0
30.0
25.0
20.0
15.0
10.0
5.0
Temperature in 0C
1940
1950
1960
1970
1980
1990
2000
2010
Years
max
avg
min
Linear (max)
Linear (avg)
Linear (min)
y = -0.0186x + 64.781
R2 = 0.0704
y = 0.0014x + 19.874
R2 = 0.0004
y = 0.022x - 28.605
R2 = 0.0234


Maijdee Court:Temperature Trend of Monsoon Daily Minimum series for annual maximum, average and minimum
Temperature in 0C
Years
35.0
30.0
25.0
20.0
15.0
10.0
1940
1950
1960
1970
1980
1990
2000
2010
y = -0.0014x + 30.942
R2 = 0.0007
y = 0.0146x - 3.4106
R2 = 0.2067
y = 0.0437x - 65
R2 = 0.1068
max
avg
min
Linear (max)
Linear (avg)
Linear (min)


Maijdee Court:Temperature Trend of Pre-monsoon Daily Minimum series for annual maximum, average and minimum
29.0
27.0
25.0
23.0
21.0
19.0
17.0
15.0
13.0
11.0
9.0
Temperature
1940
1950
1960
1970
1980
1990
2000
2010
Years
y = 0.0095x + 7.8412
R2 = 0.0417
y = 0.0423x - 61.536
R2 = 0.3458
y = 0.0667x - 115.97
R2 = 0.1796
Tmax
Tavg
Tmin
Linear (Tmax)
Linear (Tavg)
Linear (Tmin)


Maijdee Court:Temperature Trend of Winter Daily Minimum series
for annual maximum, average and minimum
Temperature in 0C
Years
30.0
25.0
20.0
15.0
10.0
5.0
0.0
1940
1950
1960
1970
1980
1990
2000
2010
Tmax
Tavg
Tmin
Linear (Tmax)
Linear (Tavg)
Linear (Tmin)
y = 0.0152x - 8.7726
R² = 0.0125
y = 0.0382x - 60.854
R² = 0.1191
y = 0.0646x - 117.79
R² = 0.1877

Annex B1: Temperature Forecast Daily max series at Maijdee Court

DataSerie	Season	Statistics	Year	Forecast	Diff1990	Formula
Daily	Annual	avg	1990	30.06	0.00	y = 0.0146x +
Daily	Annual	avg	2030	30.64	0.58	y = 0.0146x +
Daily	Annual	avg	2050	30.94	0.88	y = 0.0146x +
Daily	Annual	avg	2100	31.67	1.61	y = 0.0146x +
Daily	Annual	max	1990	36.42	0.00	y = 0.0089x +
Daily	Annual	max	2030	36.78	0.36	y = 0.0089x +
Daily	Annual	max	2050	36.96	0.53	y = 0.0089x +
Daily	Annual	max	2100	37.40	0.98	y = 0.0089x +
Daily	Annual	min	1990	20.20	0.00	y = 0.0182x -
Daily	Annual	min	2030	20.93	0.73	y = 0.0182x -
Daily	Annual	min	2050	21.29	1.09	y = 0.0182x -
Daily	Annual	min	2100	22.20	2.00	y = 0.0182x -
Daily	Summer	avg	1990	32.06	0.00	y = 0.0094x +
Daily	Summer	avg	2030	32.43	0.38	y = 0.0094x +
Daily	Summer	avg	2050	32.62	0.56	y = 0.0094x +
Daily	Summer	avg	2100	33.09	1.03	y = 0.0094x +
Daily	Summer	max	1990	36.21	0.00	y = 0.0042x +
Daily	Summer	max	2030	36.38	0.17	y = 0.0042x +
Daily	Summer	max	2050	36.47	0.25	y = 0.0042x +
Daily	Summer	max	2100	36.68	0.46	y = 0.0042x +
Daily	Summer	min	1990	25.09	0.00	y = -0.0149x +
Daily	Summer	min	2030	24.50	-0.60	y = -0.0149x +
Daily	Summer	min	2050	24.20	-0.89	y = -0.0149x +
Daily	Summer	min	2100	23.45	-1.64	y = -0.0149x +
Daily	Monsoon	avg	1990	30.78	0.00	y = 0.0203x -
Daily	Monsoon	avg	2030	31.59	0.81	y = 0.0203x -
Daily	Monsoon	avg	2050	32.00	1.22	y = 0.0203x -
Daily	Monsoon	avg	2100	33.01	2.23	y = 0.0203x -
Daily	Monsoon	max	1990	44.58	0.00	y = 0.0182x -
Daily	Monsoon	max	2030	45.47	0.90	y = 0.0182x -
Daily	Monsoon	max	2050	45.92	1.34	y = 0.0182x -
Daily	Monsoon	max	2100	47.04	2.46	y = 0.0182x -
Daily	Monsoon	min	1990	25.83	0.00	y = 0.0123x +
Daily	Monsoon	min	2030	26.32	0.49	y = 0.0123x +
Daily	Monsoon	min	2050	26.57	0.74	y = 0.0123x +
Daily	Monsoon	min	2100	27.18	1.35	y = 0.0123x +
Daily	Post-	avg	1990	30.19	0.00	y = 0.0328x -
Daily	Post-	avg	2030	31.51	1.31	y = 0.0328x -
Daily	Post-	avg	2050	32.16	1.97	y = 0.0328x -
Daily	Post-	avg	2100	33.80	3.61	y = 0.0328x -
Daily	Post-	max	1990	34.12	0.00	y = 0.0342x -
Daily	Post-	max	2030	35.49	1.37	y = 0.0342x -
Daily	Post-	max	2050	36.18	2.05	y = 0.0342x -
Daily	Post-	max	2100	37.89	3.76	y = 0.0342x -
Daily	Post-	min	1990	24.93	0.00	y = 0.0141x -
Daily	Post-	min	2030	25.49	0.56	y = 0.0141x -
Daily	Post-	min	2050	25.77	0.85	y = 0.0141x -
Daily	Post-	min	2100	26.48	1.55	y = 0.0141x -
Daily	Winter	avg	1990	26.42	0.00	y = -0.0043x +
Daily	Winter	avg	2030	26.24	-0.17	y = -0.0043x +
Daily	Winter	avg	2050	26.16	-0.26	y = -0.0043x +
Daily	Winter	avg	2100	25.94	-0.47	y = -0.0043x +
Daily	Winter	max	1990	31.19	0.00	y = -0.0342x +
Daily	Winter	max	2030	29.83	-1.37	y = -0.0342x +
Daily	Winter	max	2050	29.14	-2.05	y = -0.0342x +
Daily	Winter	max	2100	27.43	-3.76	y = -0.0342x +
Daily	Winter	min	1990	20.52	0.00	y = 0.0181x -
Daily	Winter	min	2030	21.25	0.72	y = 0.0181x -
Daily	Winter	min	2050	21.61	1.09	y = 0.0181x -
Daily	Winter	min	2100	22.51	1.99	y = 0.0181x -

Annex B2: Temperature Forecast Daily min series at Maijdee Court

DataSerie	Season	Statisti	Year	Forecast	Diff19	Formula
Daily	Annual	avg	1990	21.81	0.00	y = 0.0213x -
Daily	Annual	avg	2030	22.66	0.85	y = 0.0213x -
Daily	Annual	avg	2050	23.09	1.28	y = 0.0213x -
Daily	Annual	avg	2100	24.15	2.34	y = 0.0213x -
Daily	Annual	max	1990	28.32	0.00	y = -0.0107x +
Daily	Annual	max	2030	27.90	-0.43	y = -0.0107x +
Daily	Annual	max	2050	27.68	-0.64	y = -0.0107x +
Daily	Annual	max	2100	27.15	-1.18	y = -0.0107x +
Daily	Annual	min	1990	10.61	0.00	y = 0.0614x -
Daily	Annual	min	2030	13.06	2.46	y = 0.0614x -
Daily	Annual	min	2050	14.29	3.68	y = 0.0614x -
Daily	Annual	min	2100	17.36	6.75	y = 0.0614x -
Daily	Summer	avg	1990	22.66	0.00	y = 0.0014x +
Daily	Summer	avg	2030	22.72	0.06	y = 0.0014x +
Daily	Summer	avg	2050	22.74	0.08	y = 0.0014x +
Daily	Summer	avg	2100	22.81	0.15	y = 0.0014x +
Daily	Summer	max	1990	27.72	0.00	y = -0.0186x +
Daily	Summer	max	2030	26.97	-0.74	y = -0.0186x +
Daily	Summer	max	2050	26.60	-1.12	y = -0.0186x +
Daily	Summer	max	2100	25.67	-2.05	y = -0.0186x +
Daily	Summer	min	1990	15.18	0.00	y = 0.022x -
Daily	Summer	min	2030	16.06	0.88	y = 0.022x -
Daily	Summer	min	2050	16.50	1.32	y = 0.022x -
Daily	Summer	min	2100	17.60	2.42	y = 0.022x -
Daily	Monsoon	avg	1990	25.64	0.00	y = 0.0146x -
Daily	Monsoon	avg	2030	26.23	0.58	y = 0.0146x -
Daily	Monsoon	avg	2050	26.52	0.88	y = 0.0146x -
Daily	Monsoon	avg	2100	27.25	1.61	y = 0.0146x -
Daily	Monsoon	max	1990	28.16	0.00	y = -0.0014x +
Daily	Monsoon	max	2030	28.10	-0.06	y = -0.0014x +
Daily	Monsoon	max	2050	28.07	-0.08	y = -0.0014x +
Daily	Monsoon	max	2100	28.00	-0.15	y = -0.0014x +
Daily	Monsoon	min	1990	21.96	0.00	y = 0.0437x - 65
Daily	Monsoon	min	2030	23.71	1.75	y = 0.0437x - 65
Daily	Monsoon	min	2050	24.59	2.62	y = 0.0437x - 65
Daily	Monsoon	min	2100	26.77	4.81	y = 0.0437x - 65
Daily	Post-	avg	1990	22.64	0.00	y = 0.0423x -
Daily	Post-	avg	2030	24.33	1.69	y = 0.0423x -
Daily	Post-	avg	2050	25.18	2.54	y = 0.0423x -
Daily	Post-	avg	2100	27.29	4.65	y = 0.0423x -
Daily	Post-	max	1990	26.75	0.00	y = 0.0095x +
Daily	Post-	max	2030	27.13	0.38	y = 0.0095x +
Daily	Post-	max	2050	27.32	0.57	y = 0.0095x +
Daily	Post-	max	2100	27.79	1.05	y = 0.0095x +
Daily	Post-	min	1990	16.76	0.00	y = 0.0667x -
Daily	Post-	min	2030	19.43	2.67	y = 0.0667x -
Daily	Post-	min	2050	20.77	4.00	y = 0.0667x -
Daily	Post-	min	2100	24.10	7.34	y = 0.0667x -
Daily	Winter	avg	1990	15.16	0.00	y = 0.0382x -
Daily	Winter	avg	2030	16.69	1.53	y = 0.0382x -
Daily	Winter	avg	2050	17.46	2.29	y = 0.0382x -
Daily	Winter	avg	2100	19.37	4.20	y = 0.0382x -
Daily	Winter	max	1990	21.48	0.00	y = 0.0152x -
Daily	Winter	max	2030	22.08	0.61	y = 0.0152x -
Daily	Winter	max	2050	22.39	0.91	y = 0.0152x -
Daily	Winter	max	2100	23.15	1.67	y = 0.0152x -
Daily	Winter	min	1990	10.76	0.00	y = 0.0646x -
Daily	Winter	min	2030	13.35	2.58	y = 0.0646x -
Daily	Winter	min	2050	14.64	3.88	y = 0.0646x -
Daily	Winter	min	2100	17.87	7.11	y = 0.0646x -