M.Sc. Thesis

ESTIMATION OF WATER BUDGET FOR AN IRRIGATION CHANNEL (A CASE STUDY OF 3L, 4L DISTRIBUTARIES OF AHMADPUR CANAL)

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(2015-MS-WRE-08)

CENTRE OF EXCELLENCE IN WATER RESOURCES ENGINEERING

University of Engineering and Technology,

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ABSTRACT

The estimation of groundwater budget for a region/area is most important factor in hydrogeologic studies of water related projects. A groundwater budget is an analysis of ground basin's inflow and outflow to determine the change in groundwater storage.

In this study, initially past trends of rainfall and temperature was analyzed from 1961 to 2011 using MAKESENS 1.0 i.e. Mann-Kendal and Sen's slope estimation. Increasing and decreasing trends were analyzed using this software. Spatial trend analysis of observed data of temperature and rainfall data was also done by using Inverse Distance Weighted (IDW) interpolation in ArcGIS software using averagely data of 5 years interval from 1961 to 2011.

Groundwater level data is analyzed using MS Excel by making graphs between months and their respective groundwater levels. A long-term water budget (1996 to 2015) was calculated by using hydrologic water balance equation, i.e. subtracting total recharge and total well withdrawals in Southern Punjab Pakistan. Firstly, Rainfall-Runoff was estimated by using Hydrologic Engineering Centre – Hydrological Modeling System (HEC-HMS). Model was calibrated for year 1996 and validated for 1997 and simulated from year 1998 to 2015. Evapotranspiration was estimated by Cropwat 8.0 model by using input data like windspeed (km/day), sunshine (hours), humidity (%), minimum and maximum temperature (^{0}C). The estimated evapotranspiration was maximum for summer months (June to September) and minimum for winter months (November to December). Streamflow recharge of 3L and 4L distributaries of Ahmadpur canal is estimated by using continuity equation and other general formulas. Total recharge was calculated by adding both stream flow recharge and precipitation recharge. Total well withdrawals was estimated by multiplying number of wells to their averagely discharge. Number of wells in 1996 was 370 that increases to 935 in 2015 against a discharge of 0.7769 cusecs in 8 hours operation per day. Net budget was calculated by subtracting total well withdrawals into total recharge. Total water budget in 1996 was -1728.32mm and -2027.94mm in 2015. The result means that water level is decreasing day by day and it should be properly managed for its efficient utilization.

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Engr. Ahmad Mujtaba

Dedicated to my Parents,

Brothers and Sister

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LIST OF ABBREVIATIONS

GIS	Geographical Information System
IDW	Inverse Distance Weighted
HEC	Hydrological Engineering Centre
HMS	Hydrological Modeling System
UNESCO	United Nations Educational, Scientific and Cultural Organization
GNP	Gross National Product
MAF	Million Acre Feet
CWR	Crop Water Requirement
ANN	Artificial Neutral Network
BMDA	Bismarck-Mandan Development Association

Chapter I

INTRODUCTION

1.1 Water

Water is universal solvent, earth is approximately consisted of 71% of water, out of which 96.5 % of water is hold by oceans. Water is also available in the form of water vapors, in rivers, in glaciers, in aquifers as well as in human body too. Over total fresh water, 68 % consists of surface water and 30% consists of groundwater (United States Geological, 2016).

In Pakistan, about half of the labor is directly related to agricultural. Water plays an important role for them and also for the better economic development. Basic element for urban, rural water supply, industrial use and sanitation use, is water.

In Pakistani urban areas, groundwater is mostly used except some cities including Karachi, its nearby city Hyderabad and some portion of Islamabad. In these cities, surface water is mostly used. Groundwater is used in rural areas, in which irrigation system serve as the main source. For the domestic use in urban areas, people have about 84% access to water. Out of which 58.5 % of people get their water through piped supply and 7.6 % get their water through standposts and rest of the people use hand pumps, wells etc. In rural areas, 0.8 MAF is estimated to be the use for domestic purpose and about 50 % of people get their water through hand pumps (Pakistan Water, 2014).

1.2 Surface water

Indus River and all of its tributaries are the major sources of surface water supplies. Water supply is through melting of snow, seepage from physical foundations and runoff produced by precipitation in their specific areas. Indus river has a total catchment area of 970,468 sq. kilometers. Only 529,134 sq. kilometers lie in Pakistan. Indus River receives about 154 MAF (Million Acre Feet) annually, in which 144.91 MAF (94.09 %) is from western rivers (Indus, Jhelum and Chenab) and 9.14 MAF (5.91 %) is from eastern rivers (Sutluj, Beas and Ravi). In this 154 MAF water, 68 % is for Irrigation, 25.9 % flows towards sea and 6.4 % is for system losses (evapotranspiration, seepage etc.) (Pakistan Water, 2014).

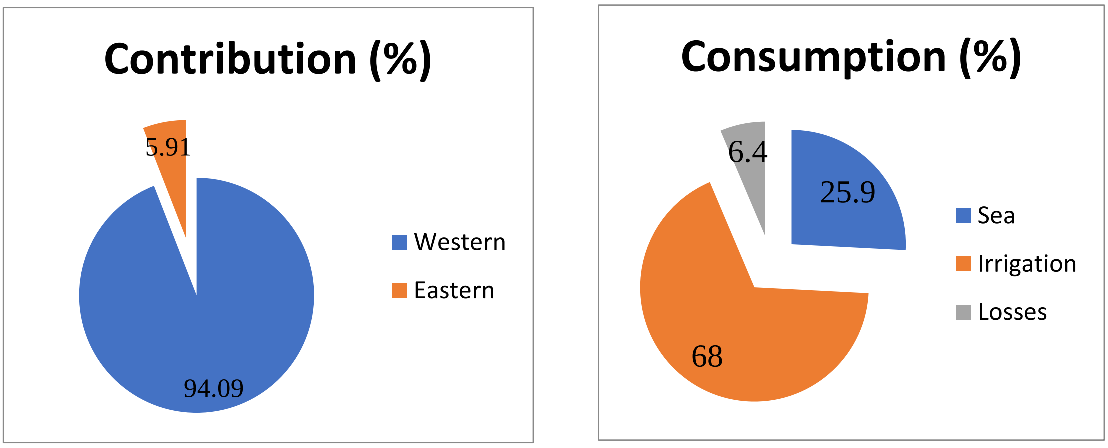


Figure 1-1: Contribution and Consumption in Indus River

1.3 Groundwater

According to United Nations Educational, Scientific and Cultural Organization (UNESCO), total world's freshwater consists of 98% groundwater. Due to its reliability, groundwater's use is increasing during the last few decades. (United Nations, 2006). Surface water doesn't meet the water requirement therefore, Groundwater is natural resource in most of urban areas. (Ritesh et al. 2011). Annual recharge is less than water requirement for agriculture, domestic and industrial use (Raghunath, 2007).

Agriculture is main part in Pakistan's budget which pays 24.7 % of Gross National Products (GNP) (Pakistan Water, 2002). During the last 30 years, groundwater has turn out to be an important source to canal supplies specifically in such areas where groundwater quality is good like in the Upper Indus Plain. In Pakistan, groundwater resources cover from Himalayan foothills to Arabian Sea. The number of tubewells also increases due to irrigation purposes. Approximately 550, 000 tubewells are installed in the Indus Basin Irrigation System (IBIS), and their annual pumpage is estimated as 41.6 MAF, out of which 90 % (37.44 MAF) is used for irrigation purposes (Pakistan Water, 2014).

1.4 Groundwater Fluctuations and Methods

Groundwater levels show active balance among recharge, extraction and storage. If groundwater recharge exceeds the extraction, then storage of groundwater will increase and its groundwater level will also increase. On the same way, when discharge exceeds the recharge by over pumping or some other method, then volume will decrease and its level will also decrease.

Due to following factors, groundwater usually fluctuates

a) Stream Flow
b) Evapotranspiration
c) Atmospheric pressure
d) Rainfall

Temperature, precipitation (rainfall) also effects the groundwater levels, during high temperature season (summer), there will be more crop water requirement (CWR), and there will be decrease in groundwater levels and vice versa. During high rainfall season, more and more water will seep down and become a part of groundwater and due to low

CWR, groundwater level will increase, as there will be increase in volume of groundwater.

1.5 Methods

Water levels are determined by following methods

a) Piezometer

b) Observation Well

Piezometers are used to

a) Measure water pressure

b) Obtain point water samples

c) Estimate hydraulic conductivity at a point

d) Locate the piezometric surface in an aquifer

For its construction, first of all 5 to 10 cm diameter hole is drilled in geologic stratum to the confined layer. A 3 to 5 cm perforated casing pipe of PVC or steel is lowered in the hole. At its lower end, a short screen of about 30cm long is provided. Space between screen and hole is filled with gravel or sand. There should be hydraulic contact with the zone. To protect vandals against filling the pipe with stones or something else, a protective cap is secured at the top of pipe (Tariq, 2008). The piezometric head 'h' is defined as

$$h = \frac{P}{\rho g} \tag{1.1}$$

here

P = Pressure (F/L^2)

ρ = Water Density (M/L^3)

g = gravity

1.6 Water Budget

A water budget is needed to determine the magnitude of inflows and outflows in a certain place. A water budget also defines the different water cycle parameters like

$P = Precipitation$

$ET = Evapotranspiration$

$E = Evaporation$

$SRO = Surface\ Runoff$

$GF = Groundwater\ Flow$

The water budget equation can be explained as follows

$$\Delta S = \pm SRO \pm GF - E + P - ET \qquad (1.2)$$

Here ΔS is the change in storage. In above equation, if right side of equation shows plus sign result, then ΔS will increase and piezometer level will also increase and vice versa (Land and Water Management, 2010). In the estimation of groundwater recharge, water budget is multiplied by the magnitude of water level fluctuations in wells (Cheng-Haw et al. 2006).

1.7 Groundwater Modeling

For the rationally forecasting of groundwater level, groundwater parameters (hydraulic conductivity, specific yield, specific storage) of MODFLOW should be accurately measured (Hunt et al. 2008). If any of the parameters like above are unknown, it creates a regular problem in MODFLOW, and then trial and error process is adopted while applying MODFLOW (Yao-Ming & Shiuan, 2011).

Static head can be obtained from MODFLOW (Ahmad et al. 2005). Geographic Information System (GIS) can use MODFLOW for different analysis of groundwater. Before this, MODFLOW should be properly managed and calibrated for better performance (Khadri et al. 2016).

For Ground water modeling, MODFLOW is usual model. Block-centered finite-difference method is used in MODFLOW for different analysis. MODFLOW can simulate confined layers, unconfined layers and can use both layers at a time. MODFLOW can also simulate many other parameters like total recharge in area, total extraction in area, total groundwater levels, total inflow as well as outflow in an area. Following equation (a partial differential equation) is used in MODFLOW

$$\frac{\partial}{\partial x}\left(K_{xx}\frac{\partial h}{\partial x}\right)+\frac{\partial}{\partial y}\left(K_{yy}\frac{\partial h}{\partial y}\right)+\frac{\partial}{\partial z}\left(K_{zz}\frac{\partial h}{\partial z}\right)+W=S_s\,\frac{\partial h}{\partial t} \qquad (1.3)$$

where

K_{xx} = Hydraulic Conductivities along x direction ($L\,T^{-1}$)

K_{yy} = Hydraulic Conductivities along y direction ($L\,T^{-1}$)

K_{zz} = Hydraulic Conductivities along z direction (LT^{-1})

S_s = Specific Storage of Porous material (1/L)

t = Time (T)

h = Potentiometer Head (L)

W = Volumetric Flux per unit volume (1/T)

1.8 Problem Statement

Ground water level usually fluctuates due to canal seepage; rainfall, percolation or irrigation etc. Water table level fluctuation varies seasonally and time by time. Its level varies by changing in rainfall, evapotranspiration (ET), crop water requirement (CWR), etc. This fluctuation causes a lot of problems regarding extraction and recharging. When recharging exceeds the extraction, then ground water level rises then salinity problems occur, which is considered as a big problem. In the same way when extraction exceeds the recharging, then ground water level lowers down then crops growth will be affected, drinking water supplies will also be affected.

In most cases, during periods of high evapotranspiration, groundwater fluctuates more and vice versa. If the water table is close to the surface, then evapotranspiration also increases, in the same way, when water table falls down, then evapotranspiration also decreases. In rural areas, tubewell/turbine are used to extract the ground water, because these wells are mostly used for drinking purposes as well as irrigation. Most of cities in Pakistan, all requirements are mostly completed by ground water. Groundwater also supports the different stages of crop, where the canal water supply is insufficient.

1.9 Study Area

Bahawalpur Canal Circle consists of four divisions namely Bahawalpur Canal Division, Ahmadpur Canal Division, Panjnad Headworks Division and Mailsi Syphon Division. The Sutlej Valley Canal system is operated and maintained in Bahawalpur canal circle. In Bahawalpur Canal Circle comprise main Canals, i.e. Bahawal Canal Upper, Qaim Canal, Bahawal Canal Lower, Abbasia Canal and Abbasia Link Canal. SMB (Sidhnai - Mailsi - Bahawal) link and P.I. (Pakpattan - Islam) link are the links, a portion of which also falls under jurisdiction of Bahawalpur Circle.

Ahmadpur Branch is an irrigation canal located in Punjab, Pakistan. The estimate terrain elevation above sea level is 110 meters. Ahmadpur Branch is also called: Bahawal Canal, Ahmadpur Branch. According to Punjab Irrigation Department, RD of 3L and 4L is 135000 for both and design discharges are 129 and 170 cusecs respectively.

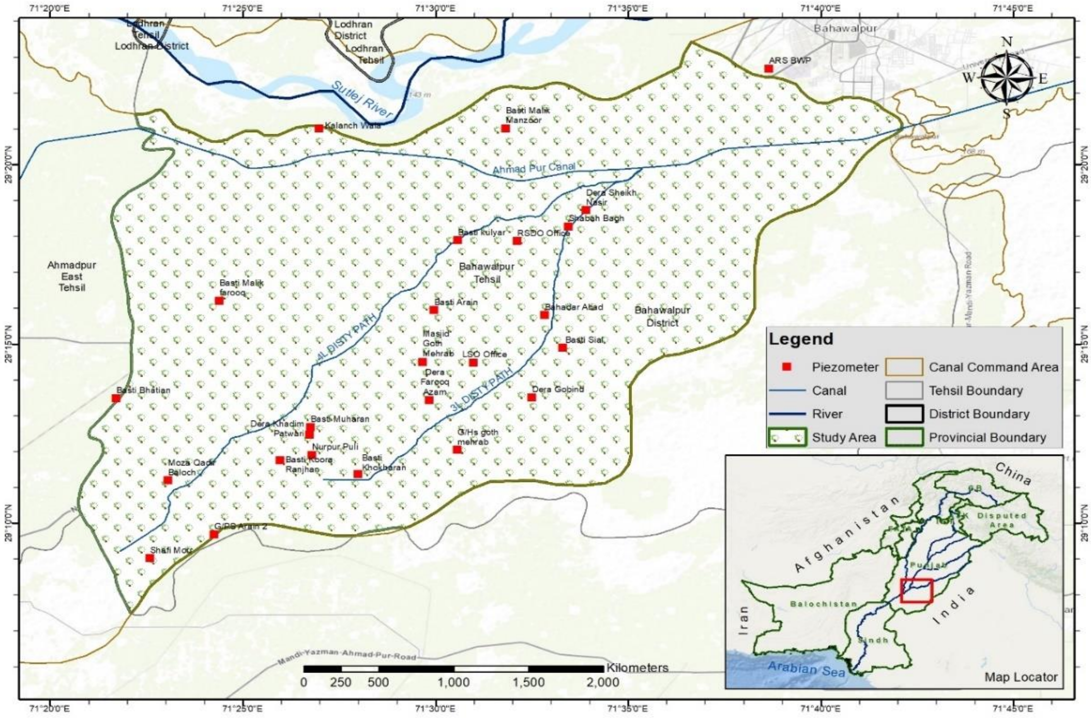


Figure 1-2: Description of Study Area

1.10 Objectives

The objectives of study include:

1. Identification of ground water fluctuation in the study area.
2. Estimation of water budget of selected canals.
3. Numerical simulation for ground water fluctuation and different options using MODFLOW.

1.11 Utilization of Research

This study will be utilized in future for further researches in any area. This study is useful for managing ground water techniques over there, if ground water effects or creates problems in that area, then this research will be helpful regarding their proper techniques. In that area, if recharging exceeds the extraction, then there will be proper technique adopted to discharge that area and vice versa. This research may be useful to evaluate the problems caused by more recharging or extraction of water and also identifying the best management options to minimize future problems in that area.

Chapter II

LITERATURE REVIEW

2.1 General

Groundwater is the only water which is mostly useful and natural (valuable) resource which is helpful for human health, for the development of economics of a country as well as its environmental assortment (Rejani et al., 2008). In India, 85% is for local uses in rural areas of water requirement. Groundwater extraction is used for an average of 55% of water for irrigation purposes and 50% of water for industrial and urban uses. (Ghosh & Sharma, 2006).

2.2 Groundwater Fluctuations

Chung-Yu Wu (2008) predicted the water table fluctuations using artificial neutral network. The viable option to predict water table fluctuation may be satellite remotely sensed data. In his study, Chung talked about two types of models (Groundwater Prediction Model) using ANN (Artificial Neutral Network) technology. This model was applied at two well locations in the area. One model was based upon the relation between brightness temperature and groundwater depth. Other model based upon the relation between change in soil moisture and groundwater depth.

For measuring the brightness temperature, A well known radiometer i.e. Advanced Microwave Scanning Radiometer (AMSR) was used. For the validation of Groundwater Prediction Model, soil moisture data was used. This data was measured by using Assimilation System (Land Data). Groundwater levels were observed at two different well locations. Thus 3 models were produced and all the models are well accurate for measuring groundwater fluctuations. All the models gave the values in between 0.043 and 0.047 meters. These results showed that high resolution data was not available, thus ANN model can be used.

Cuthbert M. O. (2009) presented a logical explanation to a Boussinesq equation, which is prolonged to present an expression for groundwater drainage using approximations of water table parameters. This was analyzed to make a modified groundwater fluctuation technique for the estimation of recharging of groundwater. This method / technique is mainly used, where the groundwater level is variable but on a small scale. This technique also doesn’t depend upon precipitation (rainfall) data. Catchment recharge was available. This technique can not be applied where the groundwater recharge is measured / estimated by any other methods to calculate the water table parameters. This recharge was measured by using groundwater levels. This is famous method to estimate recharge. But author presented 7 step method for its determination. Groundwater levels were used to estimate the recharge in the study area. Estimating recharge by using groundwater levels is a well common and famous method. He presented a seven step method to determine the recharge by using groundwater levels.

Maceo et al. (2009) studied about the groundwater fluctuations and evapotranspiration in their study area. In this study seven years of observed groundwater level data was used. These data were taken from 4 stations along with the corridor in Mexico. This observed data was then used to calculate the evapotranspiration. Daytime groundwater fluctuation measurements were used and compared with a famous method i.e. 'White method'. These observed data were used for estimating evapotranspiration to collocated measurements of all riparian evapotranspiration which was measured by eddy covariance method. Both methods (White and Eddy) were linked with each other.

Groundwater hydrograph estimation of evapotranspiration from groundwater seems to be higher as compared to tower evapotranspiration estimates. At one site, ET ranges from 91 to 164 percent averagely but it changes from 57 to 254 percent on remaining sites. There was improvement in comparing all the methods by water table with deeper depth, by comprising connection between groundwater and river.

By removing the vegetation on one location caused decrease in diel water level fluctuation amplitude of 19% to 21%. This diel groundwater fluctuation was helpful in evaluating the hydrological properties of removing vegetation. Riparian hydrographs were serious in exploring the hydrologic connection among groundwater and river, vegetative consumption pattern with respect to time, and monitoring fluctuations to the vegetation.

Keith Edwin (2009) studied hydrological processes inferred from water table fluctuations at selected sites. He said that groundwater recharge, base flow and evapotranspiration are expressed as following simple equation.

$$\mathrm{R} = \Delta S + E_t + B_F \qquad (2.1)$$

Where

R = Recharge

E_t = Evapotranspiration

B_F = Base flow

ΔS = Change in storage

These parameters are difficult to measure. In their study, there was evaluation that hydrological processes are indirect from groundwater measurement by high resolution.

which is measured at different sites of study area. Their study area was Walnut Creek Watershed situated in southern low. There were three main sites and 61, 714 different groundwater levels monitoring stations. Recharge was estimated from water table fluctuations. For the evaluation of potential surface and groundwater interaction, using Spectral methods hydraulic heads were analyzed. All data were analyzed for the development of model related to nitrate leaching to near stream. The result of this study is to indicate that for measuring water table levels at high frequency, there is important amount of information about hydrological processes.

Ritesh et al. (2011) said that groundwater is natural resource in mainly coastal urban area because surface water can't meet the water requirement to balance it. Ritesh selected Puri city located in the coast (eastern side) of India. In this city, groundwater is basic and important source for consumption due to its situation on sandy aquifer. Due to lack of sewerage system, the groundwater is worsening day by day. Groundwater fluctuations during monsoon season mainly in summer season was measured. This is done with hydrogeological conditions, groundwater consumption pattern and its topography. For the estimation of topography, Geographic Information system was used and using digital elevation model (DEM) and by developing groundwater contours with respect to space as well as time.

Aflatooni and Mardaneh (2011) presented time series analysis. This analysis was of groundwater fluctuation. Groundwater usually fluctuates due to variation in temperature and rainfall. The study area was Shiraz in Iran. The main objective of this study was forecasting groundwater fluctuations using time series analysis. Box Jenkin's time series model was used. The result of their study showed that annual groundwater elevation was approximate 1499 in year 2021. According to statistical analysis among 29 wells, it was shown that 89% had negative correlation with monthly temperature but positive correlation with change in rainfall of about 86%. It was on average 13 months interruption time of groundwater fluctuations due to change in temperature and 1 month due to change in rainfall.

Table 2-1: Respond time (Months) and Delay time (Months) of wells

Sr. No.	No. of wells (%)	Delay time (Months)	Respond time (Months)
1	44.8	0 to 2	
2	51	10 to 14	
3	3.6	26	
4	72.4		0 to 2
5	24.1		11 23
6	3.5		38

Karamat et al. (2012) studied the physicochemical profile of groundwater in Bahawalpur City. This study is helpful to evaluate its adoption for domestic use. Physicochemical investigation was applied to the water samples which were taken from all over the city. First of all, physical properties were determined by checking its color, odor, electrical conductivity, dissolved oxygen, alkalinity and total dissolved salts. Then chemical properties were evaluated by estimating the pH, Cl^{-1}, F^{-1}, No^3, SO^4, Na^+, K^+, Ca^{+2}, Mg^{+2}, Fe, Ni, Cr, As, Pb metals. Coliform bacteria were checked and due to which it was found that 75% samples were contaminated. According to WHO standards, physicochemical data was analyzed it was revealed that some parameters which were estimated were within the limit while others were out of limit. Different parameters were graphically drawn with the pH to check their changes with respect to limit. This study suggests the proper treatment of groundwater. So that it may be properly treated from hazardous effects and may become useful for the humans.

Wang et al. (2012) studied the loading effect and density effect on tidal head variations in a coastal aquifer system. As the variation in water table can also be varied by heaviness of pore water, in confined aquifer, this variation also affects the groundwater flow. Wang et al. presented a solution to this problem in an aquifer comprising of confined, unconfined aquifer, and an impervious layer in them. This is considerable only when it has a large tidal loading coefficient or the off-shore spreading length of aquifer is long or hydraulic conductivity and specific yield of unconfined aquifer has maximum values. An indication to numerical examination is to assume that density variation is ignored which cause the error not exceeding the 2.5 percent of amplitude.

Hasan et al. (2013) assessed the rainfall effect on groundwater level fluctuations. They selected Chapai Nawabgonj district as their study area. They collected rainfall and groundwater data from Bismarck-Mandan Development Association (BMDA), Rajshahi and data (evapotranspiration) was collected from Institute of Water Modeling (IWM), Dhaka. In data analysis, rainfall, runoff, infiltration and groundwater fluctuations were analyzed over intervals of year. According to these results, rainfall started usually from May to September and during rest of the year, there was just a little bit or no rainfall in the area. The study also showed that maximum rainfall occurs from June to August and due to this, maximum water table was observed from July to September. But in the months of March to May, due to irrigation period, there was minimum watertable in the study area. This study also showed that groundwater table was declining on daily basis due to its use for irrigation purposes, but there is no important change in rainfall and infiltration pattern.

Dinesh et al. (2013) predicted the water table elevation fluctuation using 10 Artificial Neutral Networks (ANN) models. As water table elevation is an important parameter in understanding the groundwater resources. Their study has main objective on different models and choosing a best fit model out of them. Data was available for Budaun District which was tested and validated on ten different ANN models. By comparing all the models, it was considered that developed Fuzzy model was better among 4 models and ANN shows better results for model-5. MATLAB was used to develop both the Fuzzy logic and ANN models. Conclusion of their study was that these techniques are more easier and reliable as compared other methods. This paper shows that ANN is suitable if number of inputs is more and more. But for less number of inputs, Fuzzy models show better performance.

Aarti et al. (2013) studied groundwater level fluctuations on seasonally and annually basis. They selected the Valsad district (VD) and Navsari District (ND) of Gujrat as their study area. They collected data of 20 years of approximately 100 wells. They also studied the rainfall effect on groundwater levels and its effects on study area. The result of their study showed that groundwater level is fluctuated on seasonal basis. The average water level trend variation is increasing in VD, while it is decreasing in ND. On the other hand, average groundwater level is decreasing in VD and Navsari district both. If we compare average annual water level and average annual rainfall, the rainfall is decreasing with the decrease in water level. For the monitoring of groundwater levels, automatic sensors were used to record them at higher frequency. These sensors give data on daily basis which can be used in stochastic periodic time analysis.

Pingwang and sergey (2014) developed a relation between daily groundwater levels and evapotranspiration. This relation was used in estimation of reduction in groundwater by phreatophytes. They reduce groundwater levels by evapotranspiration. Standard deviation of daily groundwater levels and evapotranspiration of short time period were used in this study. A comparison was established between groundwater evapotranspiration resulted from daily groundwater levels fluctuation with already predefined values. This comparison showed that this technique was vigorous and consistent. This technique can't be applied without the application of assumptions of White method. After this, method was practically applied at two sites in Mexico and they showed accurate results as compared to White method.

Shao-feng et al. (2014) studied on seasonal variations in groundwater levels and salinity. Their study area was Coastal plain region of Jiangsu Province, China. China's coastline is 18,000 kilometers long. Seawater intrusion is serious threat to groundwater level. To study the groundwater levels, nine shallow monitoring wells were constructed. In this area, evaporation, rainfall and different stages of river effects the water levels which causes the salinity in that area. According to results, precipitation has more effect than evaporation which has more effect than river stage. In rainy season, salinity increases as the water level decreases. But during thirsty seasons, groundwater salinity increases to its peak in December mostly. It was approximately 77 times lower in July as in December. These changes were completely affected by the change in season. Climatic factors also plays important role in fluctuation of groundwater level and salinity during rainy season, on the same way, seawater intrusion increases salinity in dry season.

Musa and lliyasu (2015) studied the effect on groundwater level fluctuations due to change in rainfall. They selected Terengganu, Malysia as their study area. Data used in this study was of 13 years from 2001 to 2013. This data includes the climatic parameters and groundwater fluctuation. This all parameters were analyzed to show their variation. First of all, after data collection homogeneity of data was done by using standard approaches (Von Neumann ratio and standard normal homogeneity test). Missing values were just 5% (i.e. 2000 to 2012). These missing values were estimated using inverse distance, correlation and normal ratio method. Then using excen and GIS, results were drawn in graphs. According to this study, maximum rainfall was from September to December. But maximum groundwater level was measured in January and February. It is owing to recharge by precipitation, runoff produced by rainfall or infiltration. Water level declining occurs from June and comes to lower level in August. Due to mishandling and excessive withdrawal for irrigation purposes, groundwater level decreases in this study area day by day.

Kuldeep and Upasana (2016) estimated the groundwater balance and resource by using the geospatial technology. This study is about the increase in demand of water resources for the security of food. They made their study by raster based modeling in ArcGIS. GEC-1997 method was used to produce thematic layers which were useful in estimation of groundwater balance and resource. According to this study, the results were 786.56 MCM, 379.29 MCM, 1165.85 MCM for net annual groundwater availability, annual groundwater draft and total groundwater potential respectively. According to Kuldeep, this method is well suited for better efficiency, quality and saving time.

2.3 Groundwater Modeling

Cheng-Haw et al. (2007) used two methods (soil moisture and base flow method) to measure groundwater recharge. They selected Ching Shui watershed in their study area. First of all, soil moisture budget method was used to measure seepage or percolation, Et_0, groundwater recharge and rainfall. Secondly, base flow model was used in measurement of groundwater recharge. Base flow is separated from stream flow discharge in this model. Base flow analysis (Stable) was used to calculate depth of recharge which is accepted using model analysis.

Vijai and Rohit (2011) gave a method of developing conceptual groundwater flow model. Before development of numerical model, the preliminary step is to develop conceptual groundwater flow model. Vijai and Rohit used spatially distributed values in replacement of average values of recharge, which was obtained from some methods. Geographical Information System was used for data analysis. Groundwater Modeling System (GMS) was used here, GMS tools created 7 types of data. By using different tools (3-D visualization) of GIS and GMS, it became possible to generate 3D images of study too. It is good for studying water table fluctuations, topology and hydrogeology.

Susilo et al. (2013) studied on modeling groundwater level fluctuation. They selected the tropical petland areas in in their study. This area was under the influence of E1 Nino Southern Oscillation. This area is in between two rivers namely Sebangau and Kahayan in Indonesia. They used Excel to make a model which was used to estimate the groundwater level fluctuations. This fluctuation was for the four observation wells namely, Swtr2, Swtr3, Swtr4 and Swtr6. Firstly the model was calibrated for 2011 in dry season. Aft that this model was used for the groundwater fluctuations. For these 4 observation wells, this model was best fit in dry season condition (Groundwater level was below the ground level elevation). Results of this model showed that the groundwater level falls down in dry season, it was just due to absenteeism of rainfall. This model was also helpful in predicting the fire risk too. Groundwater levels were 19.81, 20.16, 19.31 and 18.56 meters for the points Swtr2, Swtr3, Swtr4 and Swtr6 respectively. Vegetation was Natural forest for Swtr2 and Swtr3, but there were grassland for Swtr4 and Swtr6. The result of their study in determining of K_c and S_y are shown in table 2-2.

Table 2-2: Results of Kc and Sy

Sr. No.	Site	Initial Q	K_c	S_y
1	Swtr2	0.740	0.750	0.400
2	Swtr3	0.740	0.530	0.300
3	Swtr4	0.100	0.590	0.380
4	Swtr6	0.140	0.600	0.400

Surinadu et al. (2014) studied on hydrological and groundwater modeling. Godavari valley coal fields are in Andhra Pradesh, India covering approximately 5.33 km^2 which is being misused by Singareni Collieries Company Ltd. There are six number of workable coal layers in Barakar formation which was recognized by the study of 183 bore wells. They made a model with 20 conceptual layers with total thickness of 320m. For the calibration of model, steady state situations were used and measured groundwater inflows. The results are shown in table 2-3. These results can be applied to adopt strategies to pump groundwater and its location to dewater groundwater.

Table 2-3: Groundwater Inflow at Different Stages

Sr. No.	Stages m (amsl)	Groundwater Inflows (m^3)
1	+124	5877
2	+93	12818
3	+64	12910
4	+41	20428
5	+0	22617
6	-41	14504

Dhekale et al. (2015) analyzed the structural time series analysis. This study has main focus on modeling as well as forecasting of groundwater fluctuations. Their study area was Murshidabad. According to availability of groundwater data, it was firstly collected and then analyzed according to station wise in Murshidabad. Four months (January, May, August and November) data was collected for time series water table observations from 2005 to 2013. Only the data of 2013 was used for validation and rest of the data was used for analysis. Chi-square test was used to check the fitness of model. On the basis of importance of parameters, models were selected for forecasting determinations. The result of their study showed that water table level in August is 3.05m, while it is 5.62m in May (hottest month). Due to irregular behavior of monsoon, value of standard deviation for November is 0.64 as compared to other months. Skewness for May is negative which shows that water table depletion is more in area where groundwater values are less. Average groundwater depth in study area was 4.14m. The conclusion of their study showed that there are more differences among measurements and season. Maximum changes are in the month of November followed by August. It shows that groundwater recharge is different for different sites.

2.4 Water Budget

Scot et al. (2007) studied the water budget at forested plain watershed in South Carolina. As there is more demand of timber and development of urban areas since the last decade. So this demand has increased motivation about studies on the water budget and water quality. But there was limitation that study was executed for documentation and to present technique for quantification of water budget of study area.

There were 1671mm and 962mm annual rainfall and runoff coefficients were 0.47 and 0.08 for the year 2003 and 2004 respectively, which indicates a large variability of outflows. Their study tested a worksheet based water balance model on monthly basis using 3 different Et_p estimators, which are as follows.

a) Hamon estimation

b) Thomthwaite estimation

c) Penman Monteith (PM) estimation

Out of these three, first and third method performed good with avg deviations of 12.6mm and 13.9 mm respectively. An error of 9% was estimated for year 2003 and 2004 and seasonal water budgets too.

Rocio et al. (2016) studied analysis of water budget in UAE. The study focused on United Arab Emirates (UAE) where there is low precipitation but growth rate of humans and animals are high. The estimated Water budget represented the variation in groundwater storage which was compared with total rainfall (precipitation), evapotranspiration and desalinated water. There were a lot of parameters of budget which were attained through observation, data collected from old documents, models, remote sensing data and by using satellites. Groundwater storage was estimated by GRACE satellite. Precipitation and soil moisture data was collected by TRMM and GLDAS satellites. There was ½ cm per year reduction in groundwater which links to average decrease of 0.86 km^3 per year from 2003 to 2012. Results showed that there is deficiency in groundwater every year, so there should be some recharging techniques, which should be adopted to balance it.

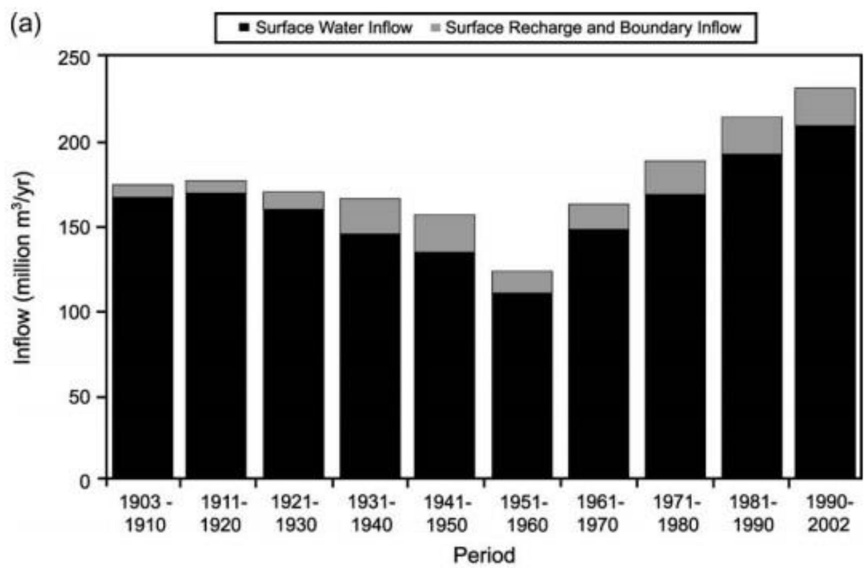
Water resources management plays a central part in watershed where the important interaction exists among water resources. Due to this reason, Ahmed et al. (2005) estimated the water budget and management techniques of water in Big Lost River Basin situated in Idaho. This river drains about 3, 730 km^2. The artificial storage in this basin is Mackay Dam. FIPR hydrological model (FHM) was used in this study. Model estimates ground water budget as well as the surface water. It has two components

a) HSPF (Hydrological Simulation Program Fortran)
b) MODFLOW

They measured the hydrological fluxes. In their study, it was shown that surface and ground water in this area are hydrologically associated and should be able to properly using some processes. This study was useful in determining water budget of Big Lost River as well as for other rivers too. The average precipitation was about 300 mm/year which was obtained from NOAA, 2001. For the calculation of evapotranspiration, Jensen and Haise (1963) equation was used. Digital Elevation Model, land use, slope, land cover and contours were determined by GIS which was also used like a processer for aquifer characteristics (Transmissivity, wells, rivers, ground water contours).

Initial static head was obtained from MODFLOW and recharge was from HSPF output. Maximum and minimum recharge was at Fork subbasin and Butte subbasin. Maximum base flow was 36.48 cumecs in month of May, major portion of this flow return as base flow and a slight portion of it i.e. 6.25 cumecs was used as extraction by wells. Seepage was 5.25 cumecs from streams. Evapotranspiration was 0.45 cumecs.

William and Hibbs (2008) did the groundwater flow modeling using Hueco Bolson (a latest version of MODFLOW). In this model, there were 10 layers, area consisted of 165 rows and 100 columns. The model was calibrated with data from 1903 to 1996. The groundwater budget on this calibrated model is shown in following figures representing influx, discharge and storage.



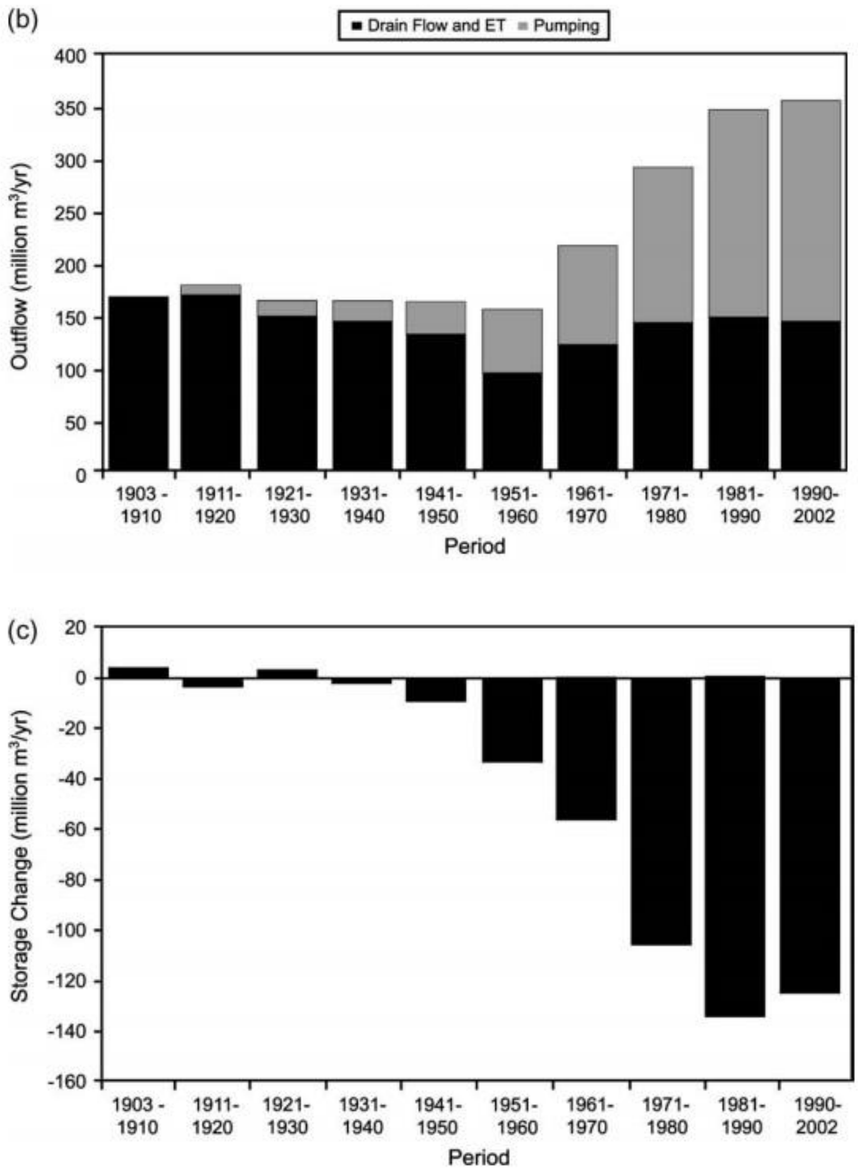


Figure 2-1: (a) Inflow in study area (b) Out flow in Study Area (c) Storage Change

Khadri et al. (2016) studied the groundwater flow modeling using MODFLOW at Mahesh River basin in India. For the groundwater resource management, MODFLOW can also be combined with Geographic Information System (GIS). Before use of groundwater, it should be properly managed. These models are useful in calculation of the rate and direction of the groundwater through water table. Different heads like water level heads, contours are the output of this model. These models keep a central part in management of groundwater resources. A mathematical ground water model was developed at the end of study. Groundwater modeling software (GMS) was needed for this study. This model was calibrated for the year of 2013 and 2014 against historical and observed water level data.

Chapter III

METHODOLOGY

3.1 Data Collection

For this research, climatic parameters (rainfall, maximum and minimum temperatures) were needed for Southern Punjab region comprises of Multan, Bahawalpur, Bahawalnagar and Khanpur cities. The data was available at Pakistan Meteorological Department (PMD) from 1961 to 2011 on daily basis. Groundwater data of Bahawalpur region was also needed, which was measured by Piezometers installed at 25 different sites with the help of World Wildlife Fund (WWF). Piezometers data is available on monthly basis from July 2015 to June 2016. Other climatic factors (humidity, sunshine, wind speed) were also used which were also available in Pakistan Meteorological Department (PMD). These data were available from 1996 to 2015. Infiltration rate of soil, distributaries data (length, width, depth), Discharge data on daily basis, of distributaries (3L, 4L) of Ahmadpur Branch on daily basis was taken from Punjab Irrigation Department (PID).

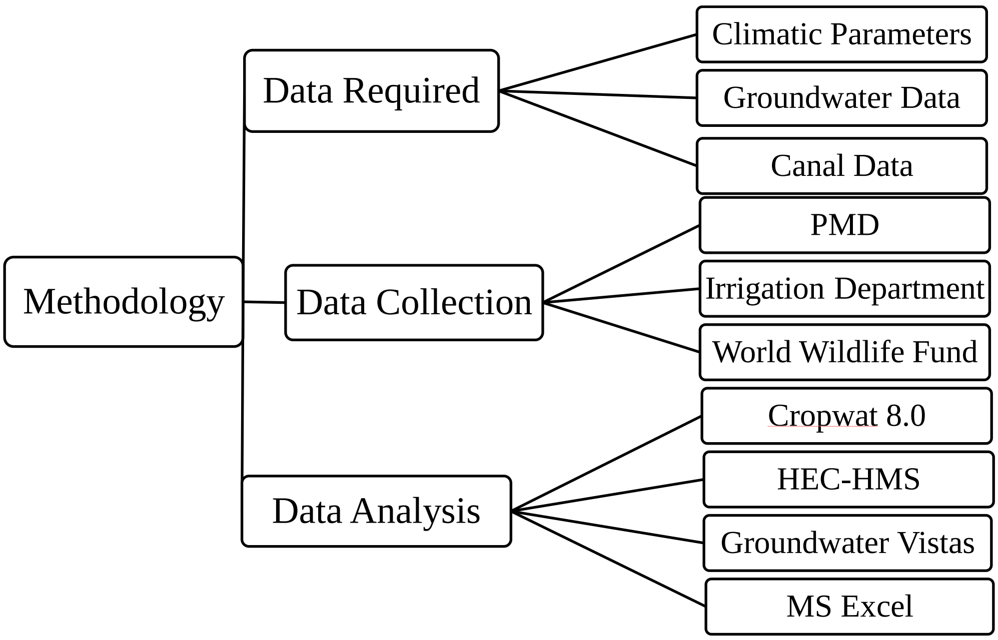


Figure 3-1: Flow Chart

3.2 Data Analysis

3.2.1 Trend Analysis

Trend of parameters were made and increasing, decreasing trend was analyzed. In this analysis, rainfall, maximum and minimum temperature of Bahawalpur region, MAKESENS 1.0 is used. Mann-Kendall and Sen's Slope is used in estimation of different trends of annual data on yearly basis. This is an MS Excel template developed for trends estimation of different parameters. Mann Kendall test requires minimum of four values and Sen' slope requires minimum 10 values for estimation (Timo et al. 2002).

3.2.2 Spatial Trend Analysis

Interpolation command is used for estimation of different parameters at four city locations (Multlan, Bahawalpur, Bahawalnagar, Khanpur). The climatic data (rainfall, minimum temperature and maximum temperature data) is interpolated using Inverse Distance Weighted (IDW) interpolation in Geostatistical Analyst Tools (GAT) technique in a widely used software i.e. ArcMap 10.2.2 (component of ArcGIS). First of all, five years average of all climatic data is calculated using MS Excel, then after adding excel sheet into ArcMap, IDW-GAT interpolation is used to interpolate all the values on whole South Punjab region.

Table 3-1: 5 years Averagely Rainfall Data

Sr. No.	Year	Multan	Bahawalpur	Bahawanlagar	Khanpur
1	1961-1965	155.95	85.20	90.36	162.86
2	1966-1970	211.48	84.30	108.86	93.34
3	1971-1975	107.40	88.42	155.06	59.29
4	1976-1980	231.92	286.24	170.20	55.00
5	1981-1985	200.52	129.18	143.76	133.92
6	1986-1990	177.42	169.58	276.00	105.94
7	1991-1995	303.10	193.72	399.86	106.32
8	1996-2000	196.37	170.00	237.72	76.90
9	2001-2005	209.88	150.40	220.00	96.14
10	2006-2011	205.28	192.46	278.90	230.33

Table 3-2: 5 years Averagely Min Temperature

Sr. No.	Year	Multan	Bahawalpur	Bahawanlagar	Khanpur
1	1961-1965	17.74	18.11	17.26	17.27
2	1966-1970	17.79	18.09	20.08	16.71
3	1971-1975	17.66	18.45	17.62	16.50
4	1976-1980	18.18	18.34	18.54	17.34
5	1981-1985	17.78	17.89	18.24	15.09
6	1986-1990	18.26	18.23	18.58	16.95
7	1991-1995	18.29	17.89	18.9	17.22
8	1996-2000	18.40	18.04	18.98	17.53
9	2001-2005	18.73	18.68	19.06	18.36
10	2006-2011	19.21	19.06	19.54	18.86

Table 3-3: 5 years Averagely Max Temperature

Sr. No.	Year	Multan	Bahawalpur	Bahawanlagar	Khanpur
1	1961-1965	32.36	33.33	32.10	33.36
2	1966-1970	32.49	33.73	32.19	33.52
3	1971-1975	32.59	33.39	32.35	33.70
4	1976-1980	32.79	32.94	32.27	33.16
5	1981-1985	32.54	32.51	32.12	32.70
6	1986-1990	32.78	32.75	32.24	33.37
7	1991-1995	32.23	32.79	32.02	33.05
8	1996-2000	32.52	33.02	32.47	33.47
9	2001-2005	32.78	33.75	33.48	33.61
10	2006-2011	32.58	33.05	33.09	33.33

3.2.3 Groundwater Fluctuation

Groundwater level data is measured from different piezometers at different sites of study area. This data was analyzed using MS Excel by making graphs between months and their groundwater levels of different locations. This trend is also drawn by taking averages of groundwater levels of two-two months, and plotting them against their respective months.

3.2.4 Evapotranspiration Estimation

Cropwat 8.0 model uses Penman-Montieth method (wubengeda, 2014) for estimation of evapotranspiration, Equation used in this method is as follows.

$$Et_o = \frac{\left(0.408\Delta(R_n - G) + \gamma\left(\frac{900}{T+273}\right)u_2(V_s - V_a)\right)}{\Delta + \gamma(1 + 0.34u_2)} \quad (3.1)$$

Where,

Et_0 = Reference evapotranspiration (mm / day)

R_n = Net radiations at crop surface (MJ / m^2 / day)

G = soil heat flux density (MJ / m^2 / day)

T = mean daily air temperature at 2 m height (^{0}C)

U_2 = wind speed at 2 m height (m / s)

V_s = saturated vapor pressure (k Pa)

V_a = actual vapor pressure (k Pa)

Δ = slope vapor pressure curve (k Pa / ^{0}C)

γ = psychrometric constant (k Pa / ^{0}C)

In Cropwat 8.0 model, data is entered in different units, like minimum and maximum temperature is in ^{0}C, Humidity is in %, wind speed as km/day and Sunshine is in hours as shown in following table 3-4.

Table 3-4: Estimation of ET_0

Sr. No.	Time	Min Temp	Max Temp	Humidity	Wind	Sun	Radiation	ET_o
	Months	^{0}C	^{0}C	%	km/day	Hours	MJ/m^2/day	mm/day
1	Jan	5.7	21.5	40	40	8.4	14.2	1.67
2	Feb	8.5	24.2	41	75	7.7	15.7	2.56
3	March	14.8	29.2	42	71	8.2	19	3.51
4	April	18.4	36.2	22	75	9.8	23.4	4.93
5	May	22.1	39.8	23	111	10	24.8	6.43
6	June	25.6	40.5	39	120	9.2	23.9	6.64
7	July	26.5	40.5	40	155	9.8	24.6	7.32
8	Aug	25.6	37.9	50	93	9.9	23.9	5.93
9	Sep	22.8	37	48	80	9.9	32.9	5.14
10	Oct	16.6	33.6	38	67	9.8	18.9	3.85
11	Nov	10.2	28.3	34	31	9.4	15.7	2.16
12	Dec	4.7	24.9	39	31	5.9	11	1.54
13	Avg	16.8	32.8	38	79	9	19.8	4.31

3.2.5 Rainfall-Runoff Estimation

The rainfall-runoff in study area was estimated by using Hydrologic Modeling System (HEC-HMS) for 20 years separately (year by year). Different parameters were used in this model. Rainfall data of 20 years, Imperviousness was 10%, curve number was 76, lag time was 15 min. The model was calibrated for 1996 as shown in table 3-5.

Table 3-5: Calibration of HEC-HMS (1996)

Parameters	Observed	Simulated	Error %
Peak Discharge	54.30	51.70	4.79
Precipitation Volume	90.00	84.30	6.33
Direct Runoff Volume	40.93	37.12	9.31

Then the model was validated for year 1997, here curve number was 76 against total rainfall of 304.2mm, the results are shown in table 3-6.

Table 3-6: Validation of HEC-HMS

Parameters	Observed	Simulated	Error %
Peak Discharge	266.20	255.90	3.87
Precipitation Volume	295.20	280.56	4.96
Direct Runoff Volume	224.69	210.69	6.23

The result from 1998 to 2015 estimated are shown in results and discussions.

3.2.6 Streamflow Recharge Estimation

Streamflow recharge was calculated for both distributaries i.e. 3L and 4L distributaries of Ahmadpur canal in Bahawalpur division. Authorized discharge, depth and length was available for both distributaries. Cross sectional area was calculated by dividing authorized discharge by its velocity, width of channel was calculated by dividing cross sectional area to depth of water, by multiplying wetted perimeter to length of distributary, wetted area was calculated and finally stream flow recharge (seepage) was calculated by multiplying permeability to wetted area. Detailed description is shown in table 3-7.

Table 3-7: Description of 3L and 4L Distributary

Sr. No.	Description	3L Distributary	4L Distributary
1	Authorized Discharge (cusecs)	129	170
2	Velocity (ft/sec)	4.5	5.24
3	Depth of water (ft)	3.8	4.2
4	Length of distributary (km)	24.08	33.59

3.2.7 Groundwater Modeling

Groundwater Vistas is graphical design system for MODFLOW and other similar models. It displays the model design in both plan and cross-sectional views. Model results are presented using contours, shaded contours, velocity vectors, head, drawdown, concentration, flux contours and detail mass balance analysis.

Initially, the whole area was divided into rows and columns and their relative extent. Then shape file (created by GIS) of study area is imported in Groundwater Vistas. Other parameters like total recharge, hydraulic conductivity and coordinates of study area were given initially. All the boundary conditions (Constant head boundary, River head boundary, General head boundary and No flow boundary) were applied in the model. These boundaries are represented by green dots. All the wells in the study area was imported as a shape file represented by red dots. Then model was run, all the contours including water level contours.

3.2.8 Water Budget

Total precipitation recharge is calculated by subtracting evapotranspiration and runoff into total rainfall. Recharge through rainfall and stream flow recharge is sum up to give total recharge.

$$\text{Inflow} - \text{Outflow} = \text{Storage} \tag{3.2}$$

In 1996, total tube well in study area were 370 which increases to 935 in 2015 with average discharge of 0.7769 cusecs averagely 8 hours per day operation. Total water extracted is then subtracted from total recharge to give annual water budget in corresponding study area.

Table 3-8: Wells along with their Discharge

Year	Wells	Discharge (cusecs)	Year	Wells	Discharge (cusecs)
1996	370	287.46	2006	603	468.24
1997	389	301.83	2007	633	491.66
1998	408	316.93	2008	664	516.24
1999	428	332.77	2009	698	542.05
2000	450	349.41	2010	733	569.15
2001	472	366.88	2011	769	597.61
2002	496	385.23	2012	808	627.49
2003	521	404.49	2013	848	658.87
2004	547	424.71	2014	890	691.81
2005	574	445.95	2015	935	726.40

Chapter IV

RESULTS AND DISCUSSIONS

4.1 Trend Analysis

In the trend analysis, MAKESENS 1.0 is applied on all the rainfall, temperature (both min and max) data on study area. Firstly, data (1961-2011) is divided into four groups in fifteen years intervals (1961-1975, 1976-1990, 1991-2005 and 1997 to 2011). The overall Z-value of different data of fifteen years interval is shown in table 4-1. In this table, positive Z-value shows the increasing trend while negative value shows the decreasing trend.

Table 4-1: Z value estimated from MAKESENS

Year		Z-Value (MAKESENS)		
From	to	Rainfall	Max Temp	Min Temp
1961	1975	0.4	0.15	0.3
1976	1990	-1.48	-0.1	0.3
1991	2005	0	2.18	2.08
1997	2011	0.79	-0.99	2.38

4.1.1 Rainfall

In Bahawalpur, fifty years trend shows an increasing trend as shown in figure 4-1. The maximum value to be noted is 398 mm in year 1977 and the minimum value is 10 mm in 1968.

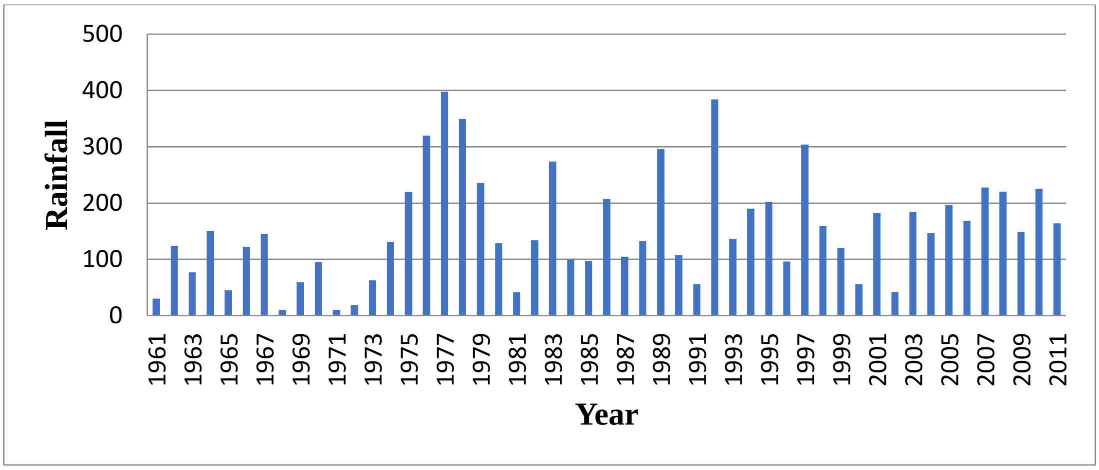


Figure 4-1: Rainfall Trend from 1961 to 2011

Ten years trend is also drawn, which shows that period (1971-80) was the wettest period with 0.51mm rainfall, while 1961-70 was the period, in which average rainfall is very small and received only 0.23mm rainfall. Ten years trend is shown in figure 4-2.

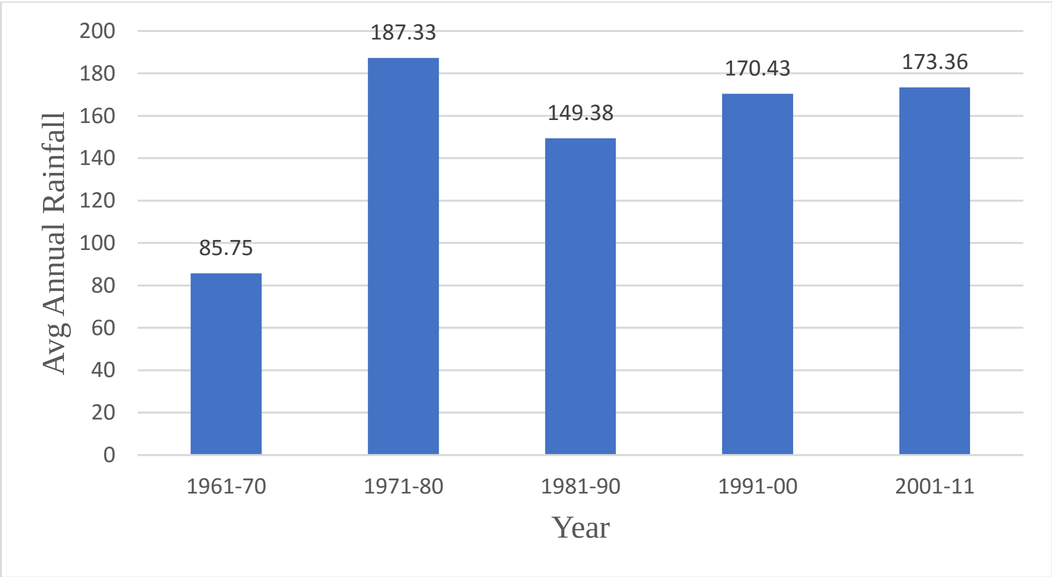


Figure 4-2: 10 years averagely Average Annual Rainfall Trend

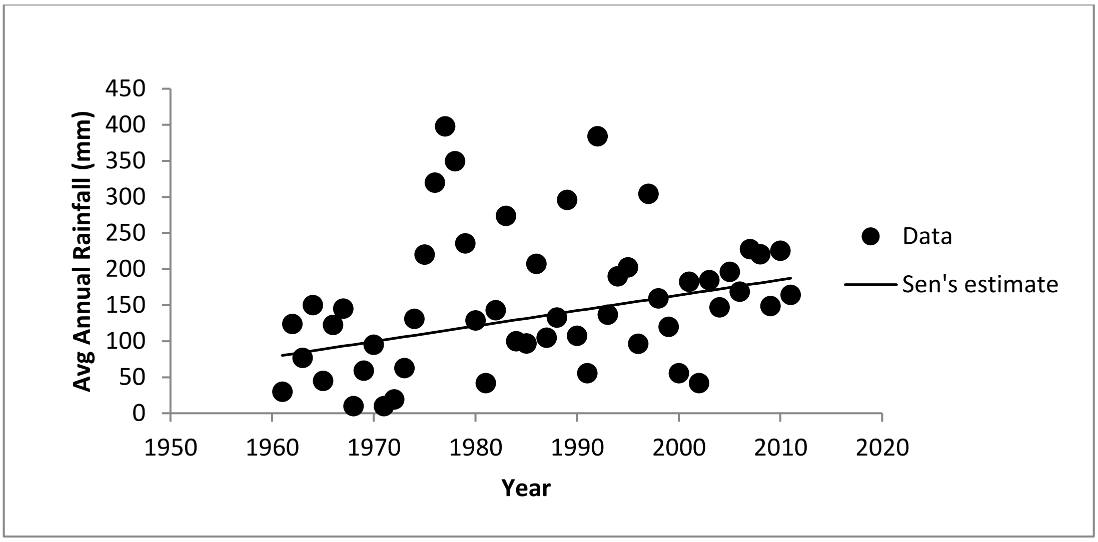


Figure 4-3: Average Annual Rainfall by MAKESENS

4.1.2 Maximum Temperature

In Bahawalpur, fifty years trend shows an increasing trend as shown in figure 4-4. The maximum value to be noted is 34.53 ^{o}C in year 2002 (hottest year) and the minimum value is 31.57 ^{o}C in 1997.

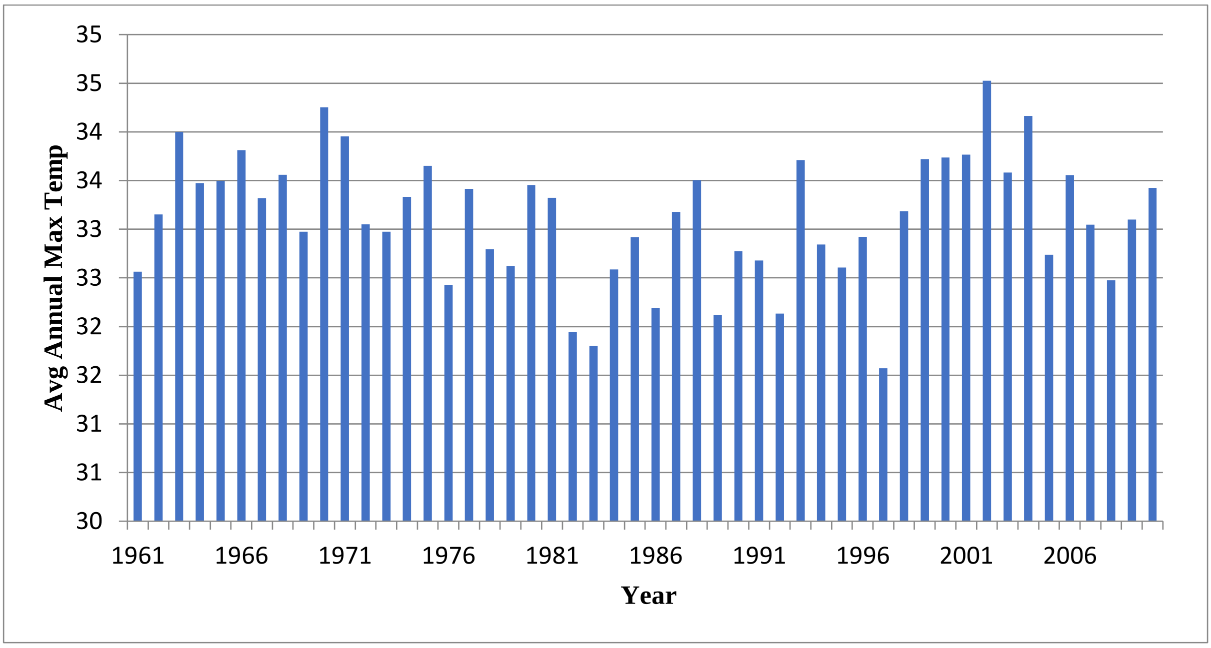


Figure 4-4: Maximum Temperature Trend from 1961 to 2011

Ten years trend is also drawn, which shows that period (1961-70) was the hottest period with 33.51 ^{o}C temperature, while 1981-90 was the period, in which average maximum temperature is very less i.e.32.63 ^{o}C. Ten years trend is shown in figure 4-5.

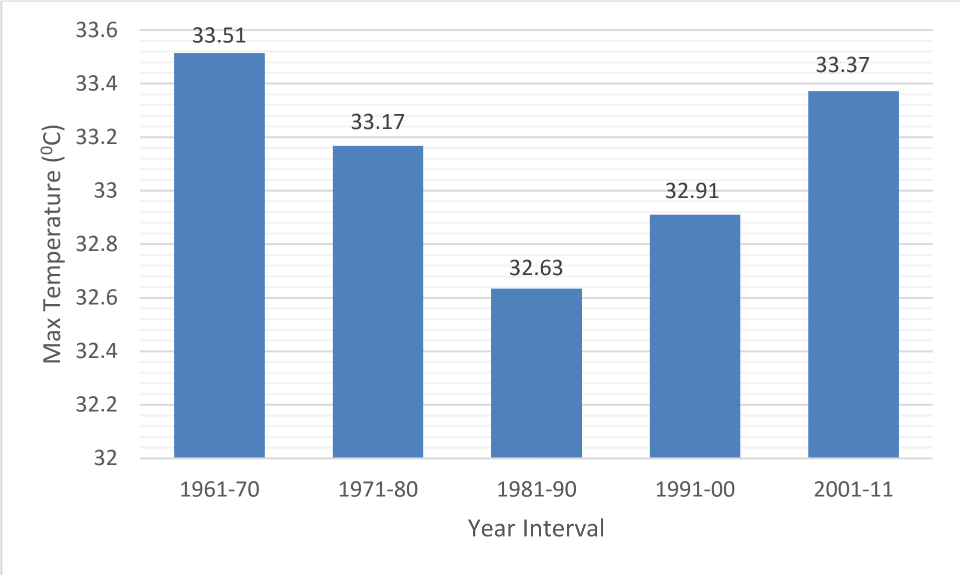


Figure 4-5: 10 years averagely Average Annual Max Temperature Trend

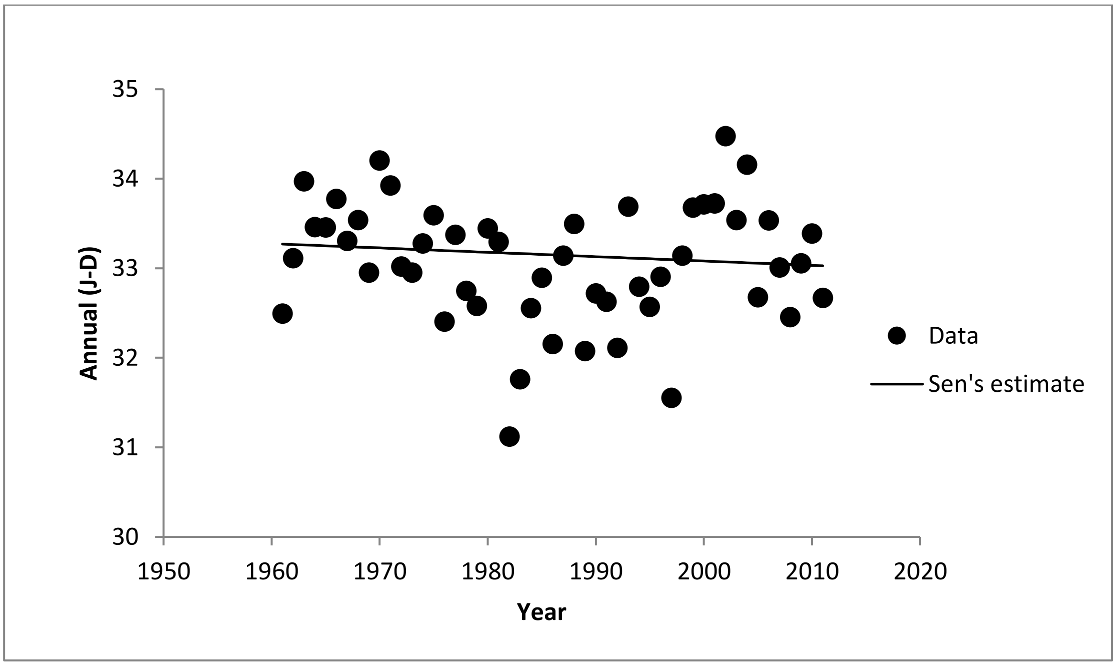


Figure 4-6: Average Annual Maximum Temperature by MAKESENS

4.1.3 Minimum Temperature

In Bahawalpur, fifty years trend shows an increasing trend as shown in figure 4-7. The maximum value to be noted is 19.80 ^{o}C in year 2006 and the minimum value is 17.09 ^{o}C in 1996.

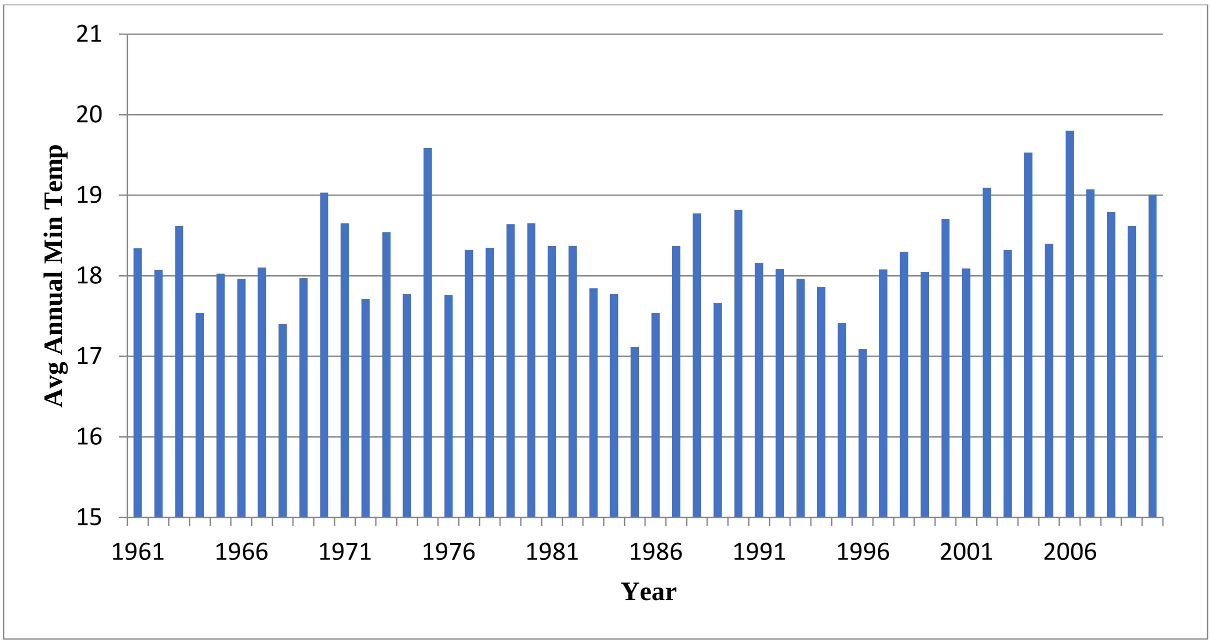


Figure 4-7: Minimum Temperature Trend from 1961 to 2011

Ten years trend is also drawn, which shows that period (1991-00) was the period with 17.97 ^{o}C minimum temperature, while 2001-11 was the period, in which average minimum temperature is maximum i.e.18.89 ^{o}C. Ten years trend is shown in figure 4-8.

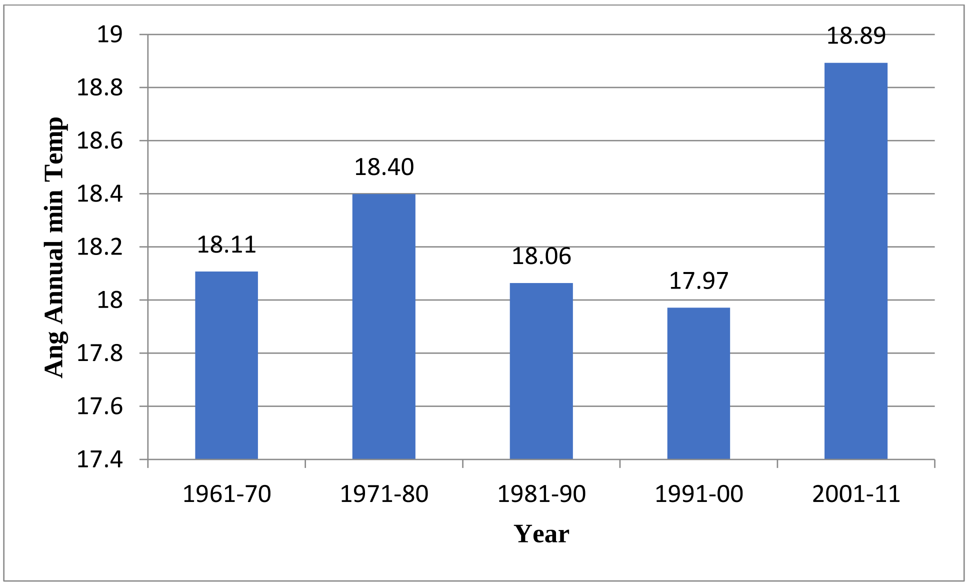


Figure 4-8: 10 years averagely Average Annual Minimum Temperature Trend

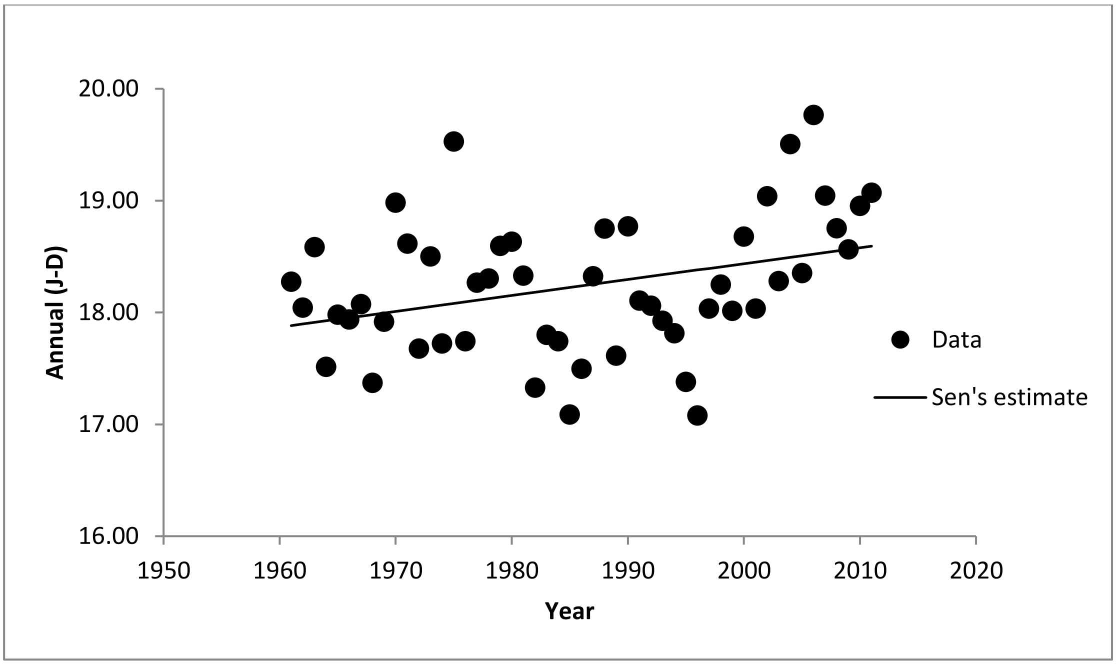


Figure 4-9: Average Annual Minimum Temperature by MAKESENS

4.2 Groundwater Fluctuation

Data collected from different piezometers at different sites in study area is analyzed by making their graph on MS Excel which is shown in figure 4-10.

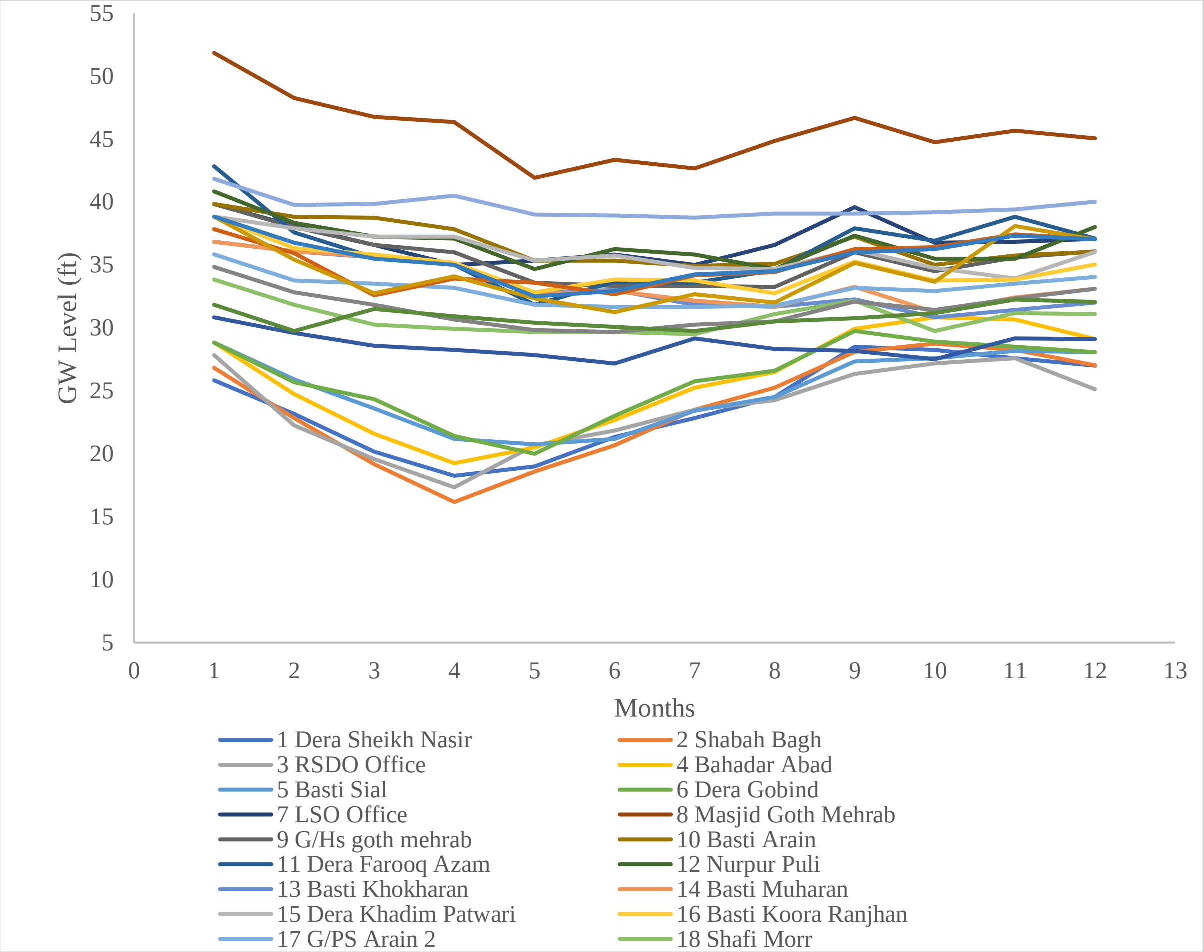


Figure 4-10: Groundwater Levels at Different Piezometer Locations

4.3 Evapotranspiration Estimation

Evapotranspiration measured by Cropwat 8.0 model is shown in table 4-2, from 1996 to 2015 which shows that maximum values are in summer months and minimum values are in winter months.

Table 4-2: Detailed Description of Observed Evapotranspiration

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1996	1.67	2.56	3.51	4.93	6.43	6.64	7.32	5.93	5.14	3.85	2.16	1.54
1997	1.6	2.73	3.36	5.09	6.36	7.2	7.44	7.04	6.3	3.56	2.38	1.74
1998	1.65	2.86	3.40	5.76	6.97	7.65	7.89	7.63	5.46	4.23	2.23	1.62
1999	1.71	2.19	3.61	5.08	7.81	8.91	8.10	7.23	5.88	3.49	2.59	1.81
2000	1.88	2.47	4.18	5.25	11.34	12.43	8.06	7.85	6.15	3.39	2.29	1.94
2001	1.68	2.51	3.88	5.09	8.08	7.25	6.16	6.50	5.31	3.36	2.50	1.68
2002	1.67	2.33	3.67	5.19	8.31	7.77	10.60	6.79	4.67	3.19	2.40	1.45

2003	1.63	2.28	3.53	5.59	5.32	8.75	5.88	5.81	5.82	3.78	2.02	1.48
2004	1.55	2.33	3.70	6.24	8.02	8.11	9.22	5.97	5.77	3.52	1.98	1.76
2005	1.45	1.96	3.43	5.15	5.65	8.24	6.50	8.24	5.51	4.53	2.21	1.50
2006	1.34	2.19	3.68	5.35	7.24	6.97	7.24	5.62	5.09	3.82	2.13	1.55
2007	1.31	2.26	3.02	4.84	4.30	11.91	7.63	7.61	5.06	3.17	2.10	1.32
2008	1.42	2.45	3.51	4.83	7.92	8.97	8.06	6.29	5.59	4.10	2.24	1.65
2009	1.55	2.42	3.84	5.04	5.81	7.13	6.9	7.73	5.41	3.54	1.82	1.28
2010	1.33	1.98	2.96	4.32	5.6	7.80	6.87	5.22	5.14	3.47	2.00	1.34
2011	1.19	1.88	3.06	4.69	6.81	7.82	6.66	5.49	4.79	3.67	2.26	1.34
2012	1.20	1.98	2.91	4.03	6.27	8.32	8.36	6.14	4.62	2.93	1.99	1.3
2013	1.30	2.09	2.37	4.77	6.21	6.81	6.95	5.90	5.46	3.34	1.96	1.27
2014	1.15	2.14	2.72	4.85	4.90	9.57	8.03	7.41	6.34	3.45	1.87	1.41
2015	1.18	1.91	2.82	4.08	5.47	5.98	5.73	6.67	5.84	3.57	2.03	1.51

Table 4-3: Detailed Description of Actual Evapotranspiration

	Class Name	Sugar cane	Wheat	Orchard (citrus)	Natural veg. (trees, grass)	Orchard	Natural veg. (grass)	Wheat and rice (maize)	Wheat and cotton	Triple rice
Year	**Eto/Kc Values**	1.30	1.20	0.85	1.05	1.10	1.15	1.20	1.25	1.20
1996	4.31	5.60	5.17	3.66	4.52	4.74	4.95	5.17	5.38	5.17
1997	4.57	5.94	5.48	3.88	4.80	5.02	5.25	5.48	5.71	5.48
1998	4.78	6.21	5.74	4.06	5.02	5.26	5.50	5.74	5.97	5.74
1999	4.87	6.33	5.84	4.14	5.11	5.35	5.60	5.84	6.08	5.84
2000	5.60	7.28	6.72	4.76	5.88	6.16	6.44	6.72	7.00	6.72
2001	4.50	5.85	5.40	3.83	4.73	4.95	5.18	5.40	5.63	5.40
2002	4.84	6.29	5.80	4.11	5.08	5.32	5.56	5.80	6.05	5.80
2003	4.32	5.62	5.19	3.68	4.54	4.76	4.97	5.19	5.41	5.19
2004	4.85	6.30	5.82	4.12	5.09	5.33	5.57	5.82	6.06	5.82
2005	4.53	5.89	5.44	3.85	4.76	4.98	5.21	5.44	5.66	5.44
2006	4.35	5.66	5.22	3.70	4.57	4.79	5.00	5.22	5.44	5.22
2007	4.54	5.91	5.45	3.86	4.77	5.00	5.23	5.45	5.68	5.45
2008	4.75	6.18	5.70	4.04	4.99	5.23	5.47	5.70	5.94	5.70
2009	4.37	5.68	5.25	3.72	4.59	4.81	5.03	5.25	5.47	5.25
2010	4.00	5.20	4.80	3.40	4.20	4.40	4.60	4.80	5.00	4.80
2011	4.14	5.38	4.97	3.52	4.35	4.55	4.76	4.97	5.17	4.97
2012	4.17	5.42	5.01	3.55	4.38	4.59	4.80	5.01	5.21	5.01
2013	4.04	5.25	4.84	3.43	4.24	4.44	4.64	4.84	5.04	4.84
2014	4.49	5.83	5.38	3.81	4.71	4.94	5.16	5.38	5.61	5.38
2015	3.90	5.07	4.68	3.31	4.09	4.29	4.48	4.68	4.87	4.68

Table 4-4: Average Actual Evapotranspiration

Year	Et_a	Year	Et_a
1996	4.87	2006	4.92
1997	5.16	2007	5.13
1998	5.40	2008	5.37
1999	5.50	2009	4.94
2000	6.33	2010	4.52
2001	5.09	2011	4.68
2002	5.47	2012	4.71
2003	4.89	2013	4.56
2004	5.48	2014	5.07
2005	5.12	2015	4.41

4.4 Rainfall-Runoff Estimation

Direct runoff volume from year 1996 to 2015 is show in figure 4-11, representing 486 as peak value in year 2015.

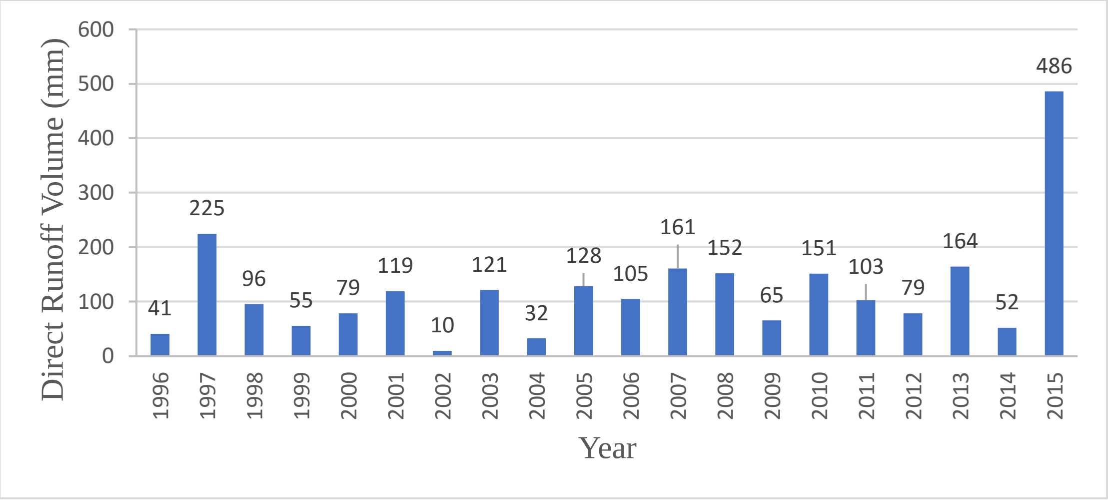


Figure 4-11: Direct Runoff Estimated using HEC-HMS

4.5 Streamflow Recharge Estimation

Streamflow recharge is calculated for both 3L and 4L distributaries of Ahmadpur canal. Detailed description of 3L and 4L is shown in table 4-5.

Table 4-5: Detailed Description of 3L and 4L Distributaries

Sr. No.	Description	Units	3L Distributary	4L Distributary
1	Authorized Discharge	cusecs	129	170
2	Velocity	ft/sec	4.5	5.24
3	Depth of water	ft	3.8	4.2
4	Length of distributary	km	24.08	33.59
5	Cross Sectional Area	ft^2	28.67	32.39
6	Width of channel	ft	7.54	7.71
7	Wetted perimeter	ft	15.14	16.11
8	Wetted Area	ft	1196098	1775219
9	Permeability	ft/sec	0.0000164	0.0000164
10	Total Seepage	cusec	19.616	29.114
11	Total Study Area	km^2	961	961
12	Stream flow recharge	mm	18.23	27.06

4.6 Groundwater Modeling

Total study area was divided in 100 rows and 100 columns, In figure 4-12, red dots represent the wells from where the water was extracted, green dots represent the boundary conditions.

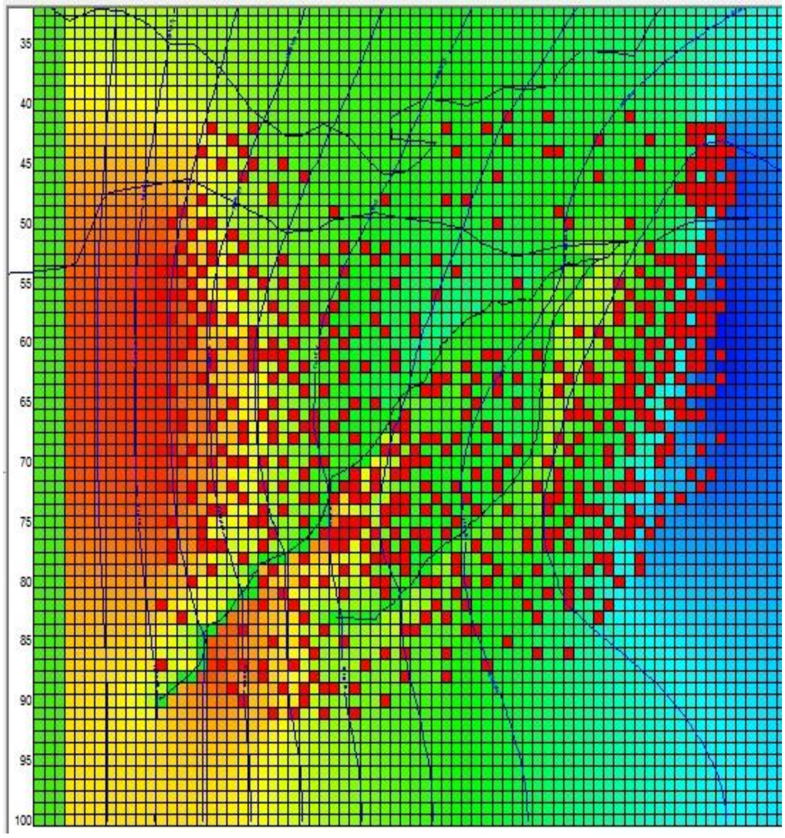


Figure 4-12: Detailed Input in Groundwater Vistas

Model was applied and water level contours was drawn, which shows that water level is high near 3L and 4L distributaries and low outside the area as shown in figure 4-13.

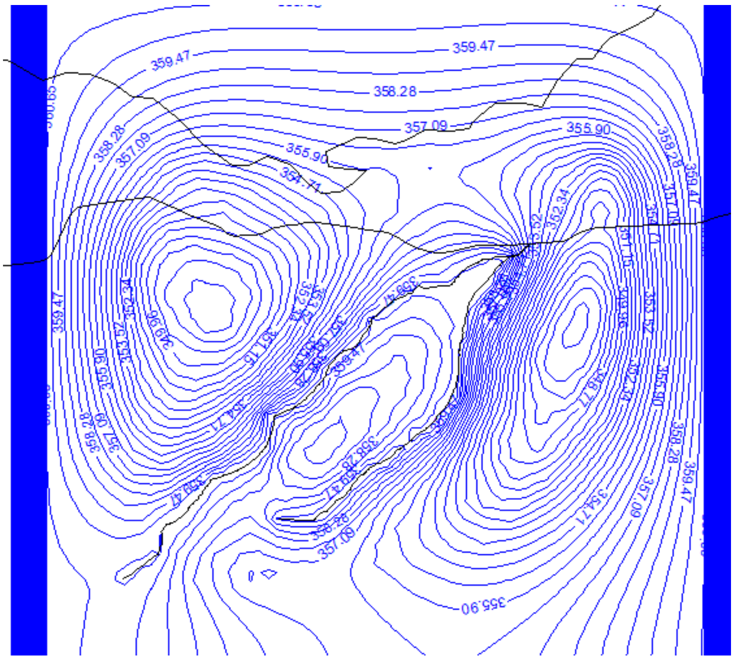


Figure 4-13: Water level Contours

4.7 Water Budget

Recharge through precipitation is calculated by subtracting evapotranspiration and runoff through total rainfall. Stream flow recharge is added up into recharge through rainfall to give total recharge in study area. Then total recharge is subtracted through well withdrawals which gives net budget as shown in table 4-6.

Table 4-6: Detailed Water Budget

Year	Rainfall (mm)	ET_a (mm)	Runoff (mm)	Ppt Recharge (mm)	Streamflow Recharge (mm)	Total Recharge (mm)	Well Withdrawals (mm)	Net Deficit (mm)
1996	106.50	1776.28	40.93	-1710.71	45.31	-1665.41	267.26	-1932.67
1997	304.20	1883.52	224.69	-1804.01	45.31	-1758.71	280.62	-2039.33
1998	159.40	1971.17	95.50	-1907.27	45.31	-1861.96	294.65	-2156.61
1999	120.60	2007.60	55.41	-1942.41	45.31	-1897.11	309.38	-2206.49
2000	112.30	2310.75	78.56	-2277.01	45.31	-2231.71	324.85	-2556.56
2001	182.40	1856.03	119.26	-1792.89	45.31	-1747.58	341.10	-2088.68
2002	62.90	1994.88	9.86	-1941.84	45.31	-1896.54	358.15	-2254.69
2003	184.60	1783.50	121.25	-1720.15	45.31	-1674.85	376.06	-2050.91
2004	155.80	1999.35	32.39	-1875.94	45.31	-1830.64	394.86	-2225.50
2005	197.30	1868.74	128.25	-1799.69	45.31	-1754.39	414.60	-2168.99
2006	167.70	1794.84	104.98	-1732.12	45.31	-1686.82	435.33	-2122.15
2007	227.60	1874.24	160.82	-1807.46	45.31	-1762.16	457.10	-2219.26
2008	219.50	1960.17	152.08	-1892.75	45.31	-1847.44	479.96	-2327.40
2009	145.80	1803.44	65.48	-1723.12	45.31	-1677.81	503.95	-2181.77
2010	227.40	1650.83	151.42	-1574.85	45.31	-1529.55	529.15	-2058.70
2011	167.20	1706.86	102.93	-1642.59	45.31	-1597.28	555.61	-2152.89
2012	199.10	1720.26	78.56	-1599.72	45.31	-1554.42	583.39	-2137.81
2013	149.60	1664.58	164.36	-1679.34	45.31	-1634.03	612.56	-2246.59
2014	81.20	1850.53	52.12	-1821.45	45.31	-1776.14	643.19	-2419.33
2015	511.30	1608.21	486.00	-1582.91	45.31	-1537.61	675.35	-2212.95

This budget shows a net deficit starting from -1728.32mm in 1996 to -2027.94 in 2015. This deficit can be increased if proper management techniques are not done in that area. Total net deficit along with their recharge is shown in figure 4-14.

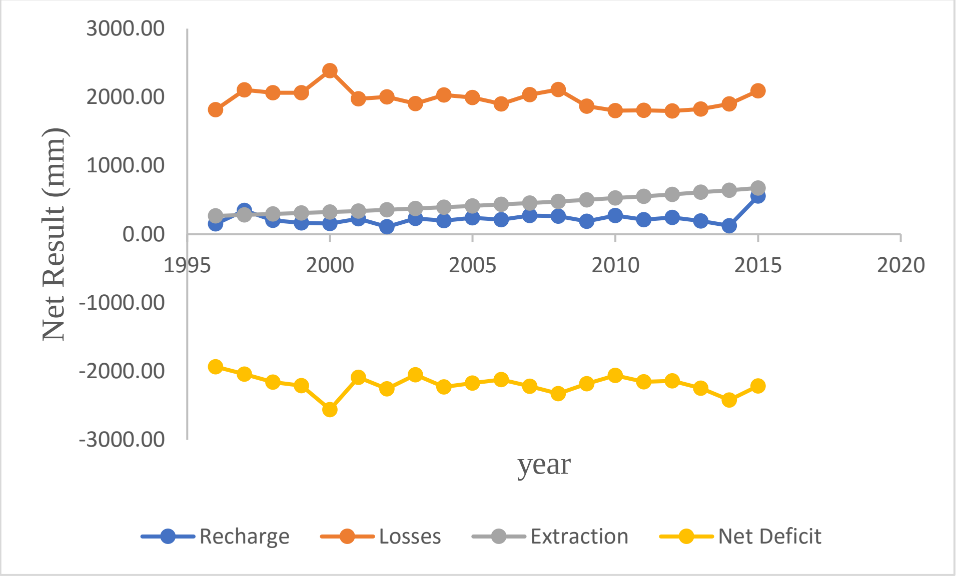


Figure 4-14: Different Parameters used in Water Budget

Chapter V
CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

a) Groundwater fluctuation varies from 33.43 ft to 33.62 ft on average.

b) Canal water supply and rainfall are less as compared to requirement in that area resulting reduction in groundwater level.

c) Excessive pumping results in decrease in groundwater budget by 14.50% during 1996-2015.

d) Groundwater is decreasing at the rate of 0.19 ft/year continuously which causes problem for drinking purposes of humans and animals.

e) Crops growth may also be effected by decrease in groundwater levels in study area.

5.2 Recommendations

a) Proper management techniques should be adopted for efficient use of groundwater.

b) Groundwater recharge should be adopted in monsoon seasons, because excess water is available during this season.

c) As in existing scenarios, sugarcanes are abundantly grown which is high delta crop and need to be replaced with low delta crop like wheat and cotton. This will help to meet available water resources and growth of crop will not be affected.

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APPENDIX A

Seasonal Trends of Minimum Temperature

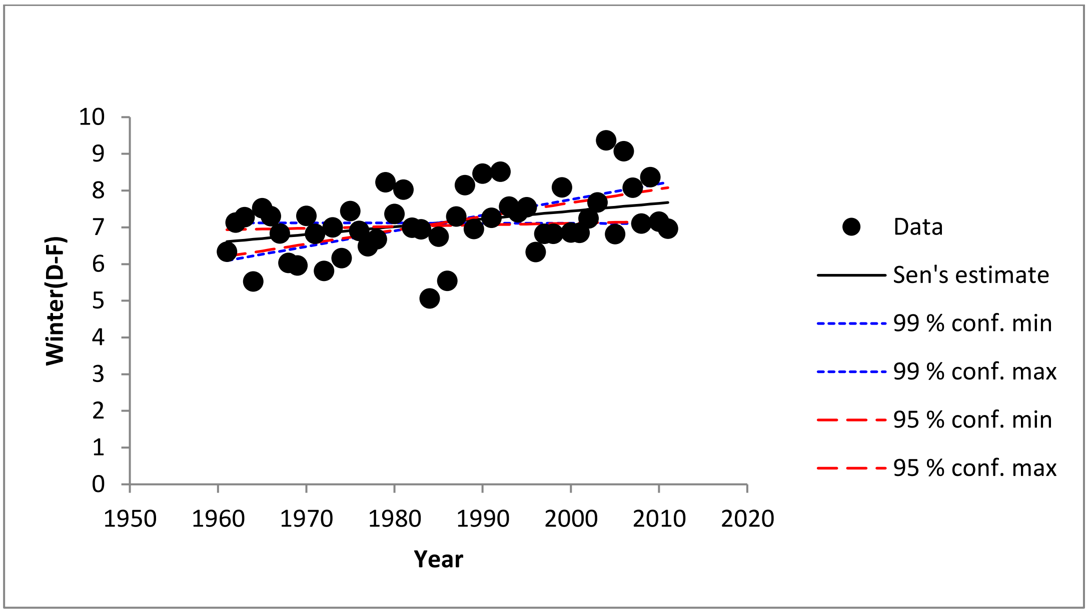


Figure A-1: Winter Trend of Minimum Temperature

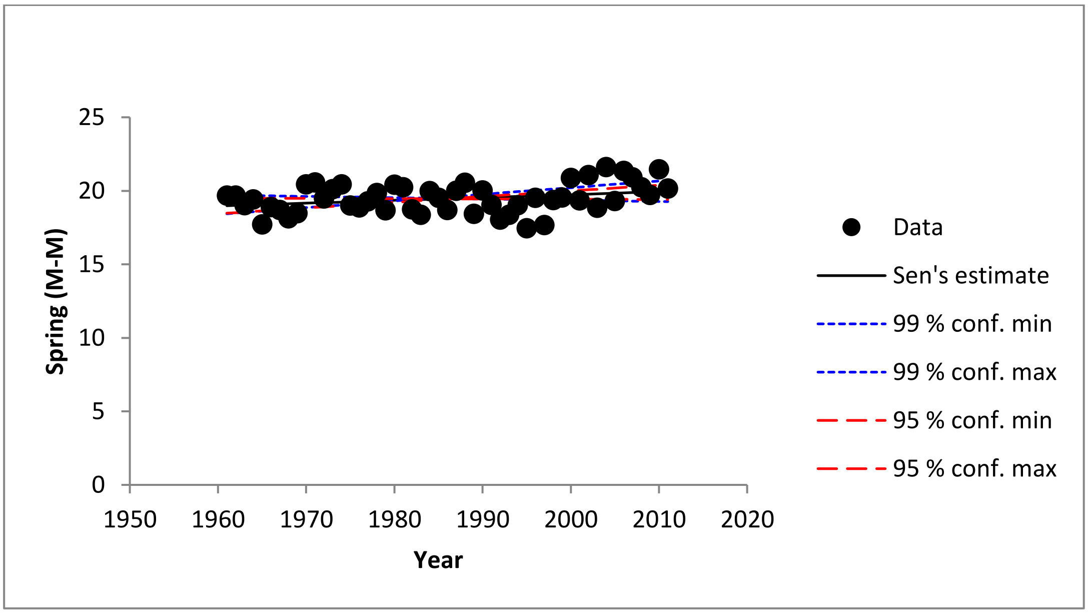


Figure A-2: Spring Trend of Minimum Temperature

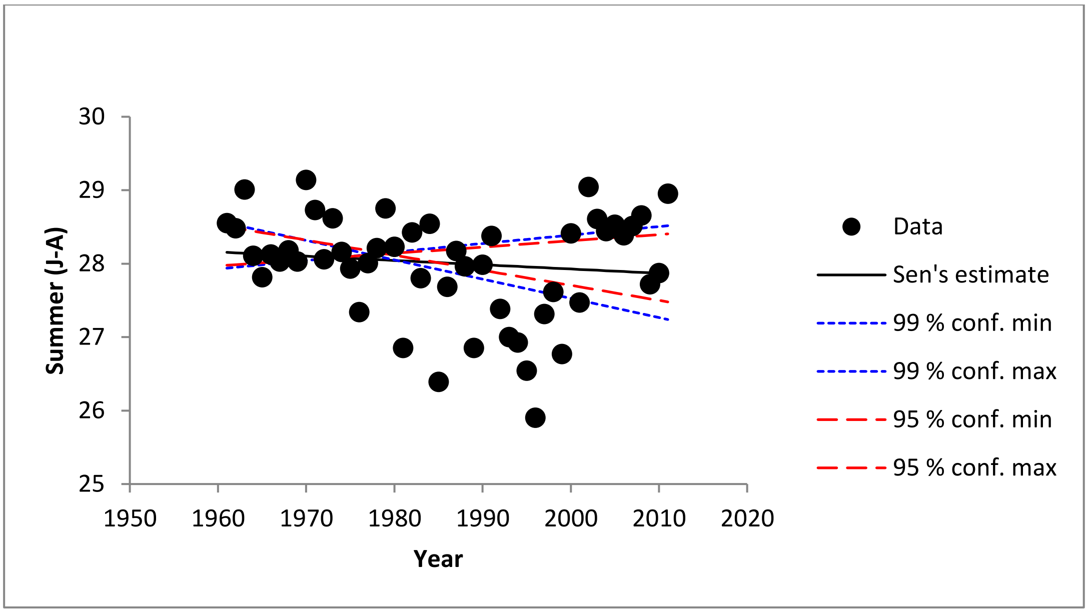


Figure A-3: Summer Trend of Minimum Temperature

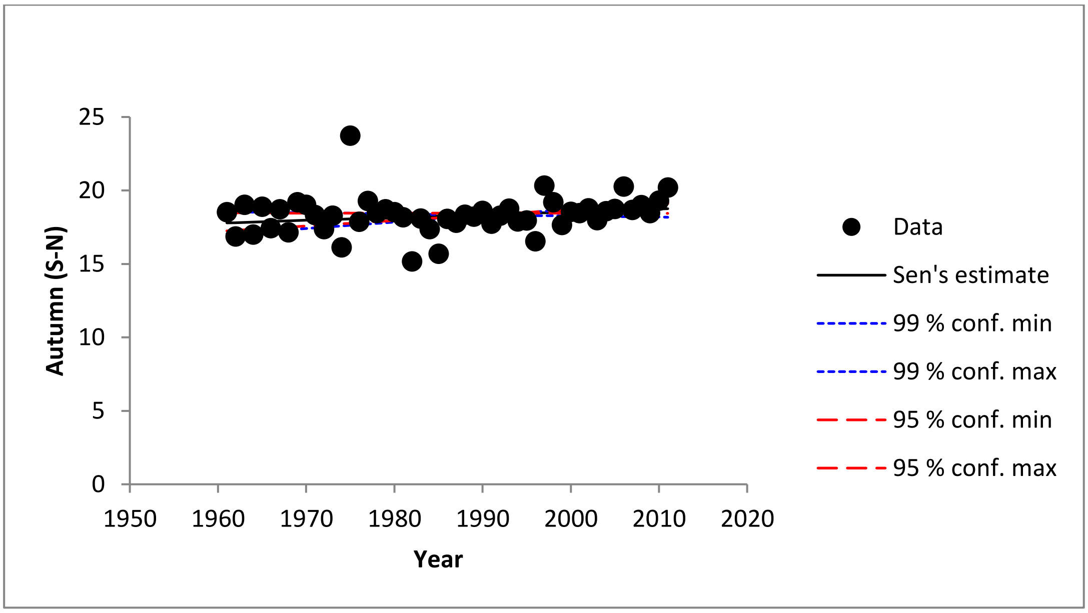


Figure A-4: Autumn Trend of Minimum Temperature

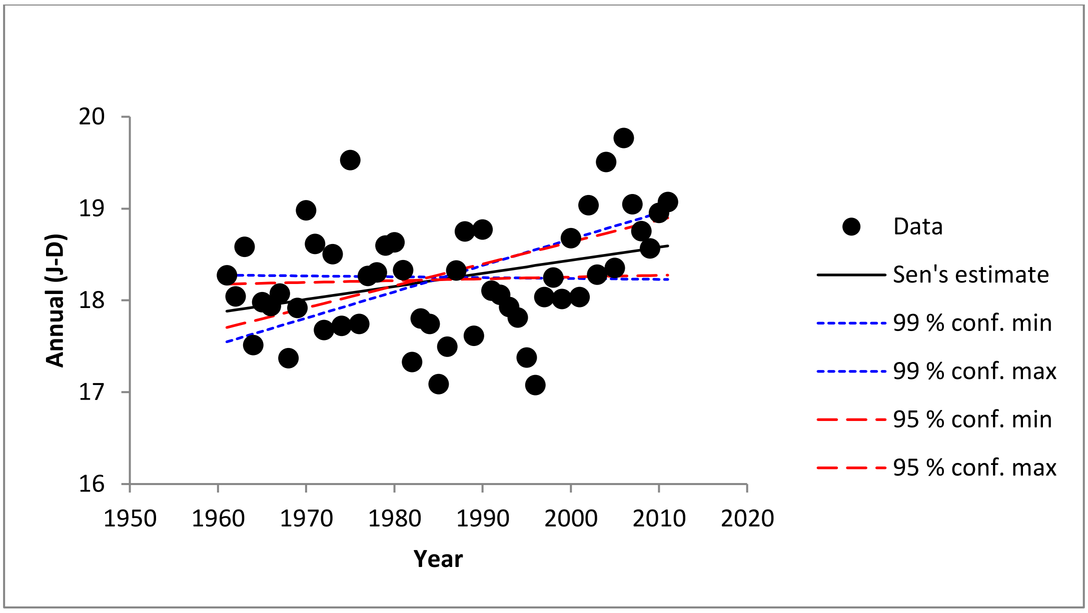


Figure A-5: Annual (Jan to Dec) trend of Minimum Temperature

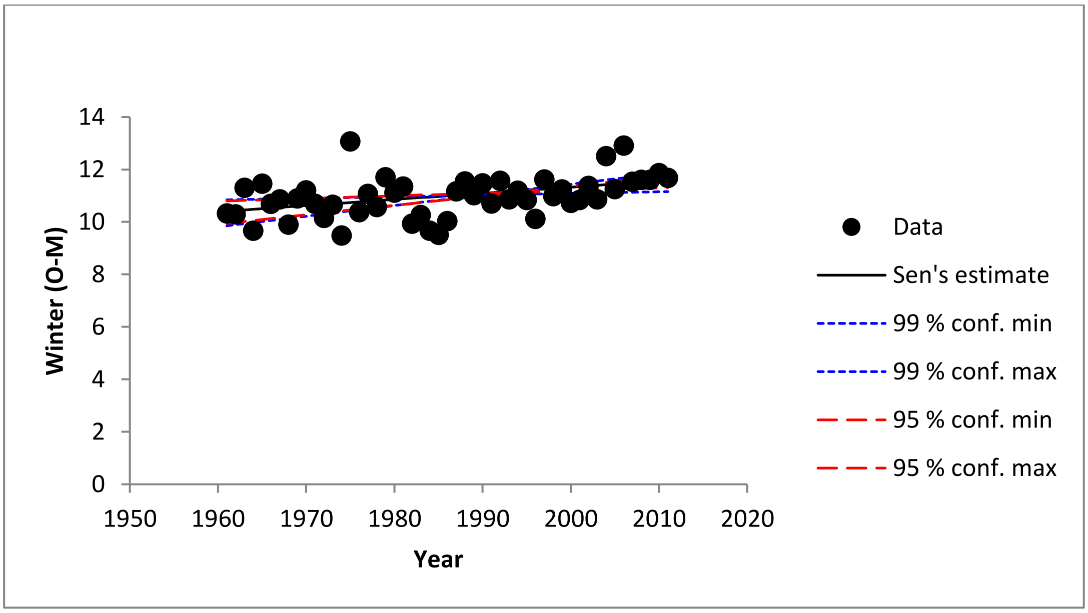


Figure A-6: Winter (Oct to March) Trend of Minimum Temperature

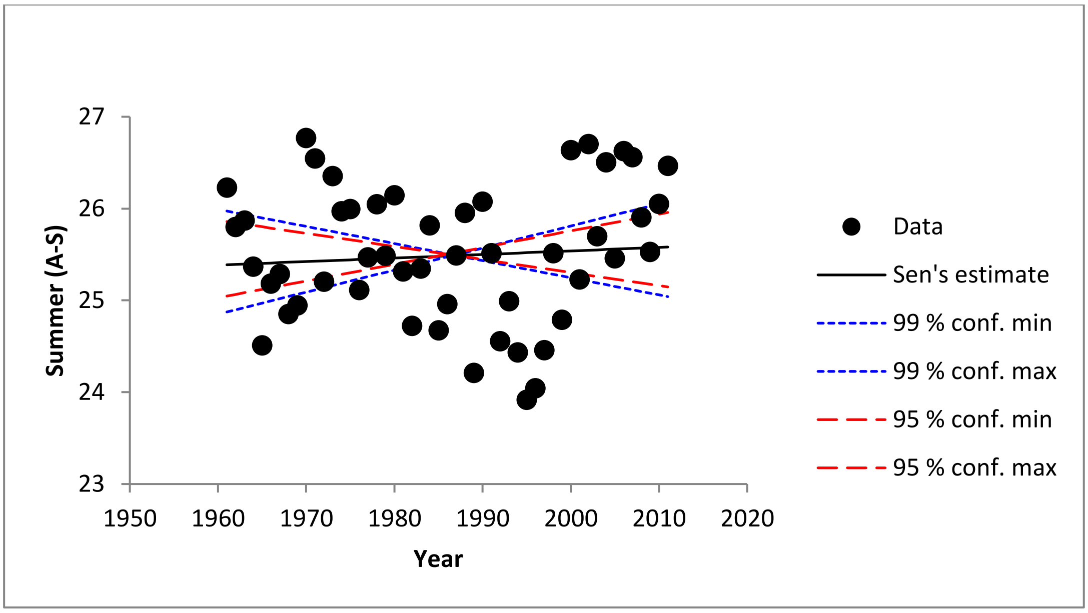


Figure A-7: Summer (April to September) Trend of Minimum Temperature

APPENDIX B

Seasonal Trends of Maximum Temperature

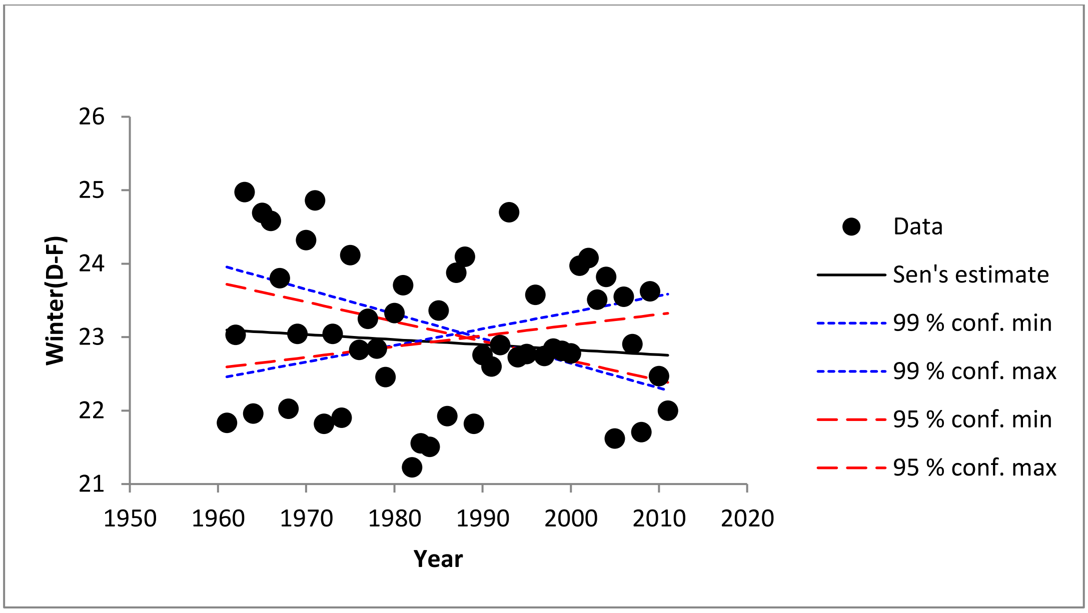


Figure B-1: Winter Trend of Maximum Temperature

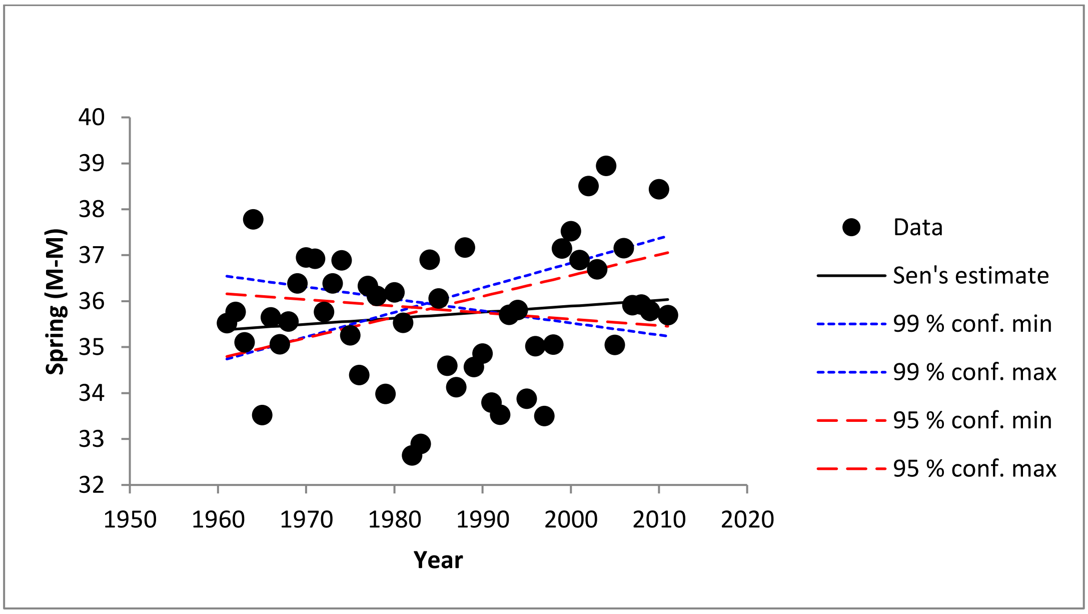


Figure B-2: Spring Trend of Maximum Temperature

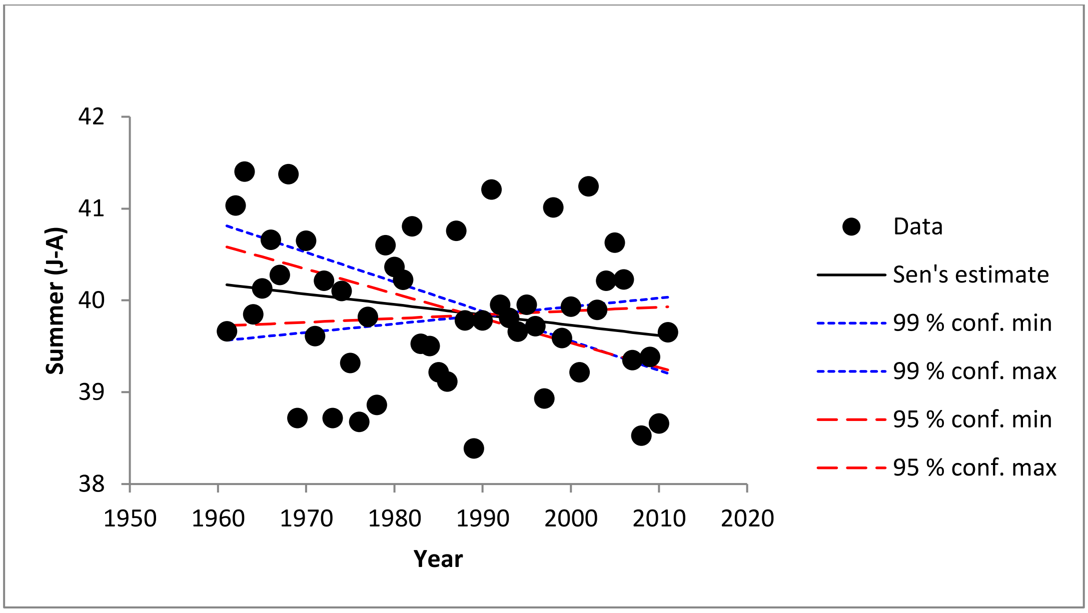


Figure B-3: Summer Trend of Maximum Temperature

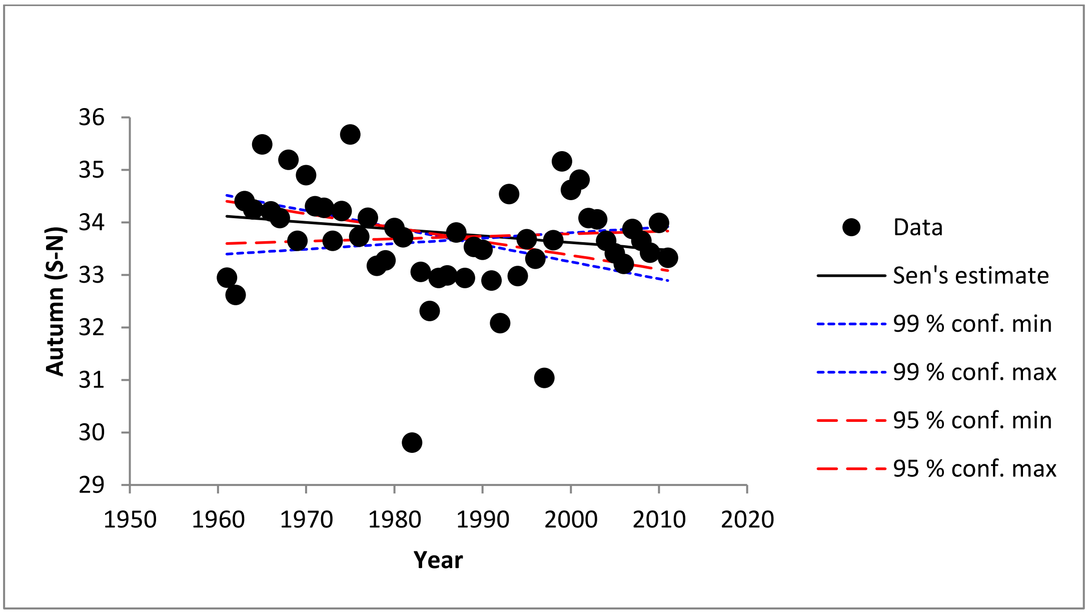


Figure B-4: Autumn Trend of Maximum Temperature

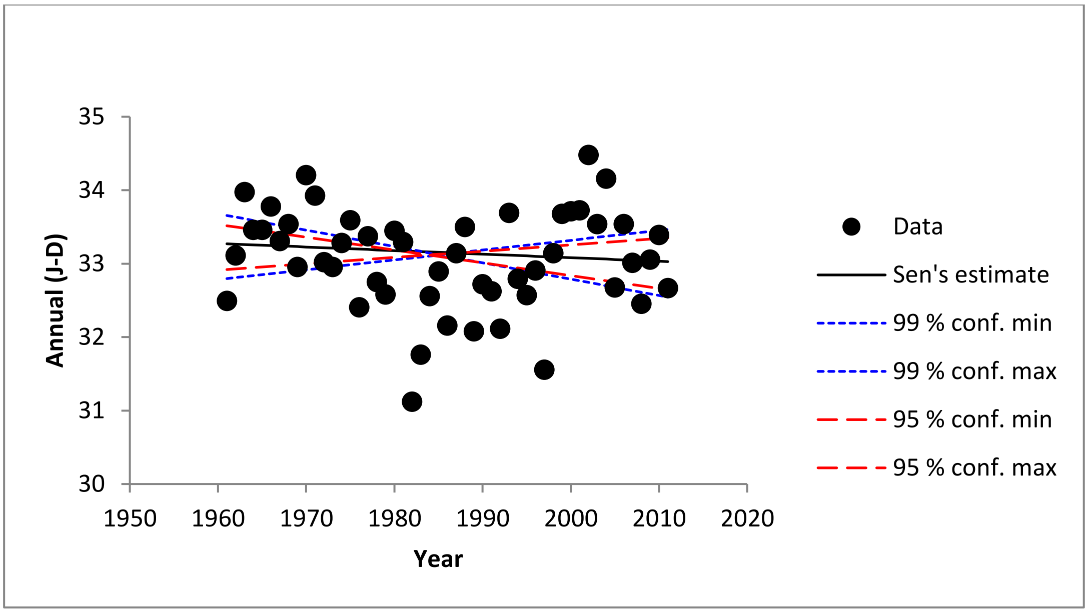


Figure B-5: Annual (Jan to Dec) Trend of Minimum Temperature

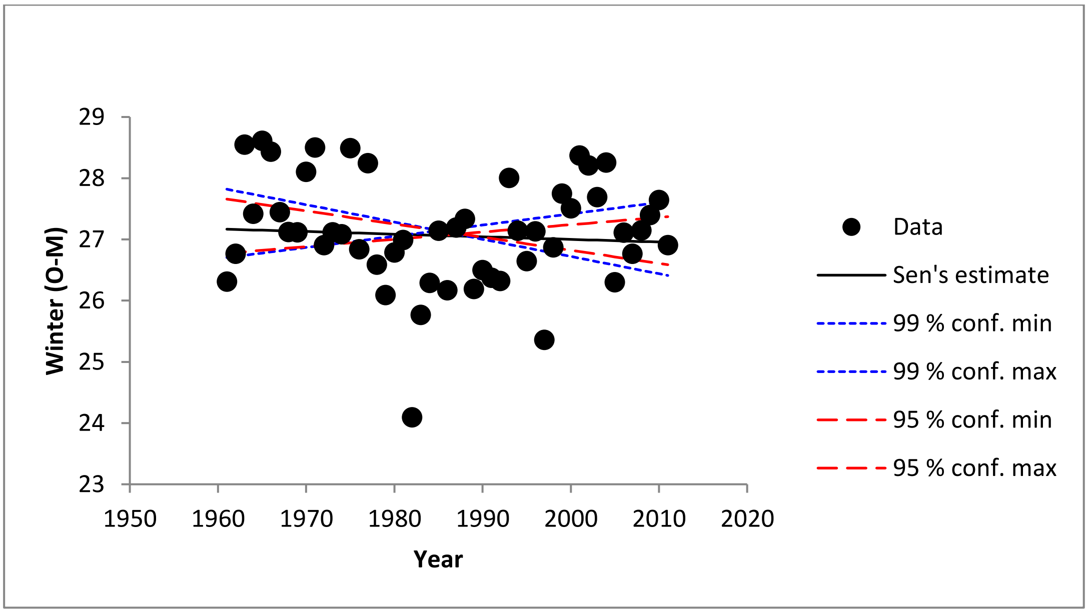


Figure B-6: Winter (October to March) Trend of Minimum Temperature

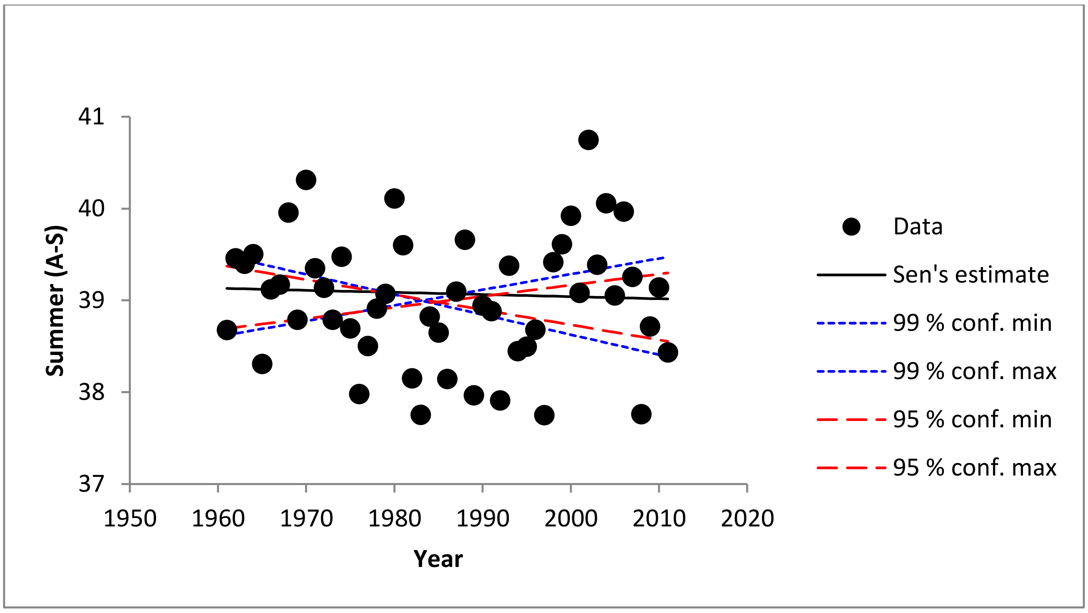


Figure B-7: Summer (April to September) Trend of Minimum Temperature

APPENDIX C

Seasonal Trends of Rainfall

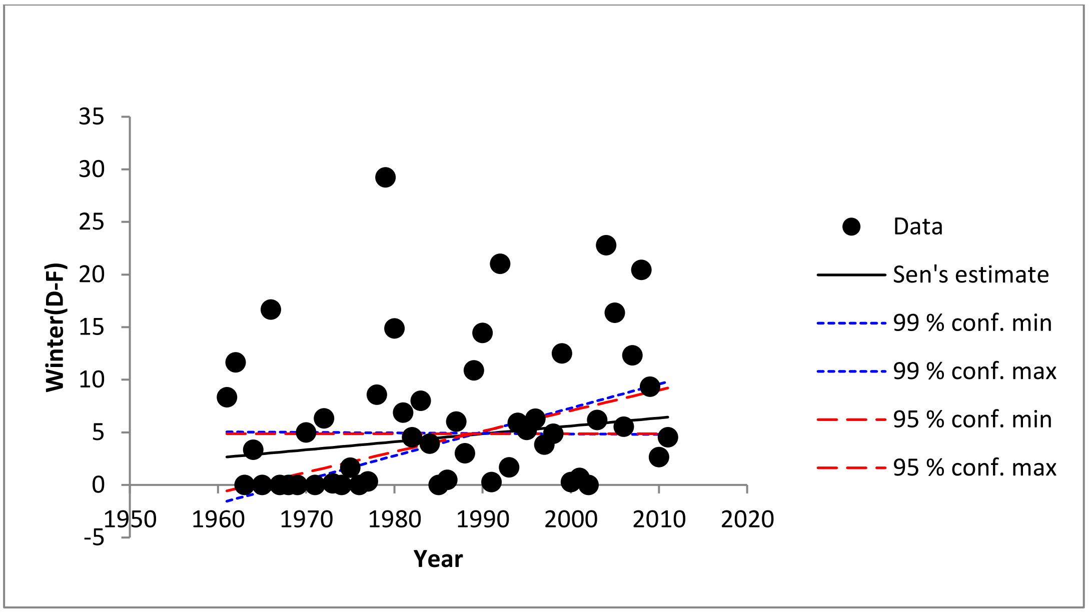


Figure C-1: Winter Trend of Rainfall

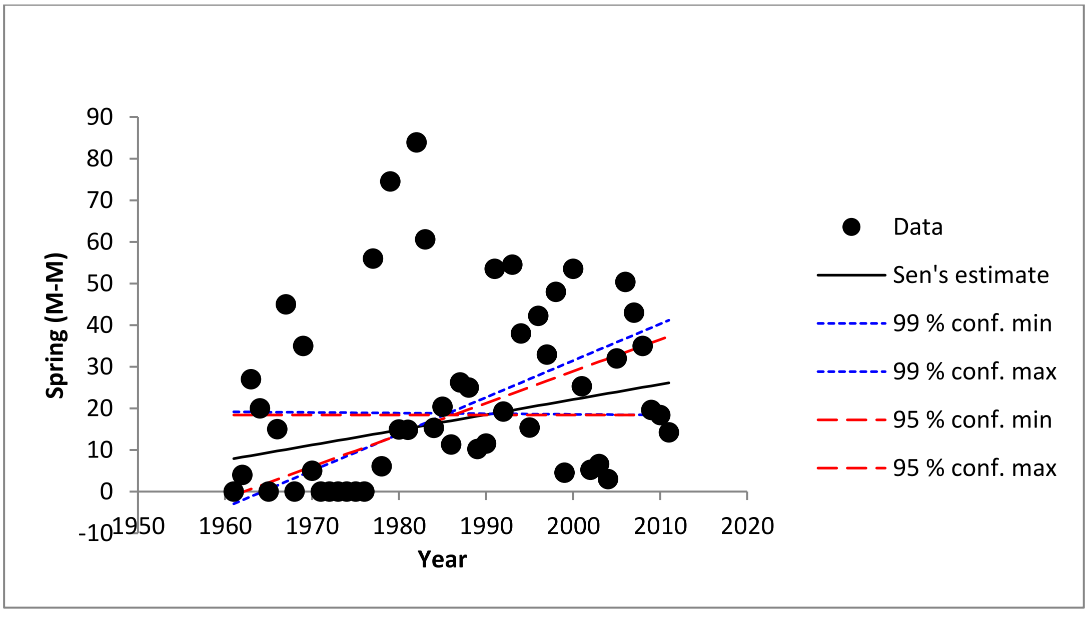


Figure C-2: Spring Trend of Rainfall

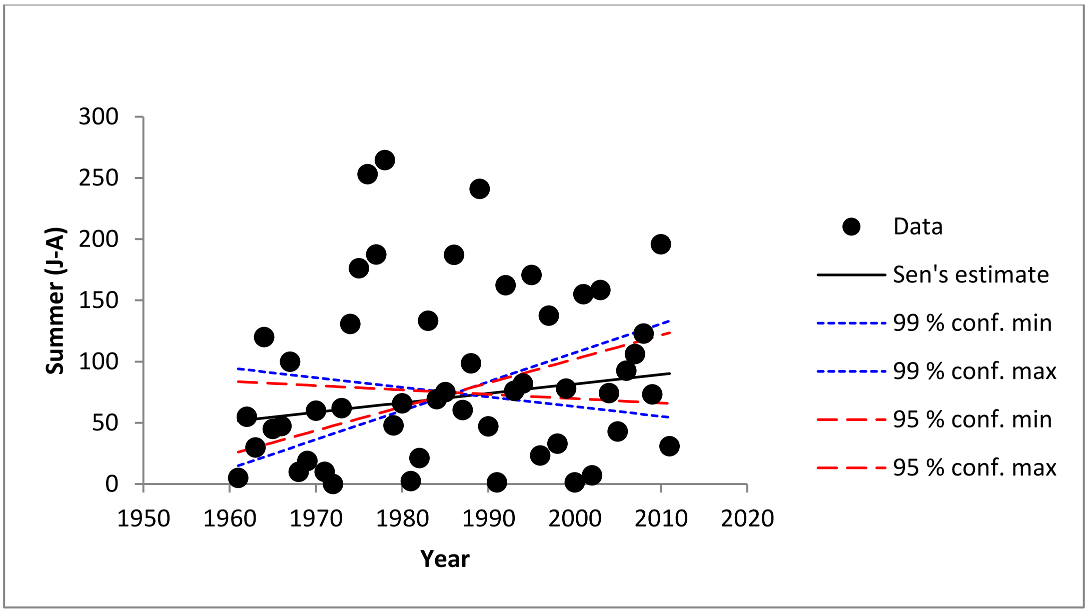


Figure C-3: Summer Trend of Rainfall

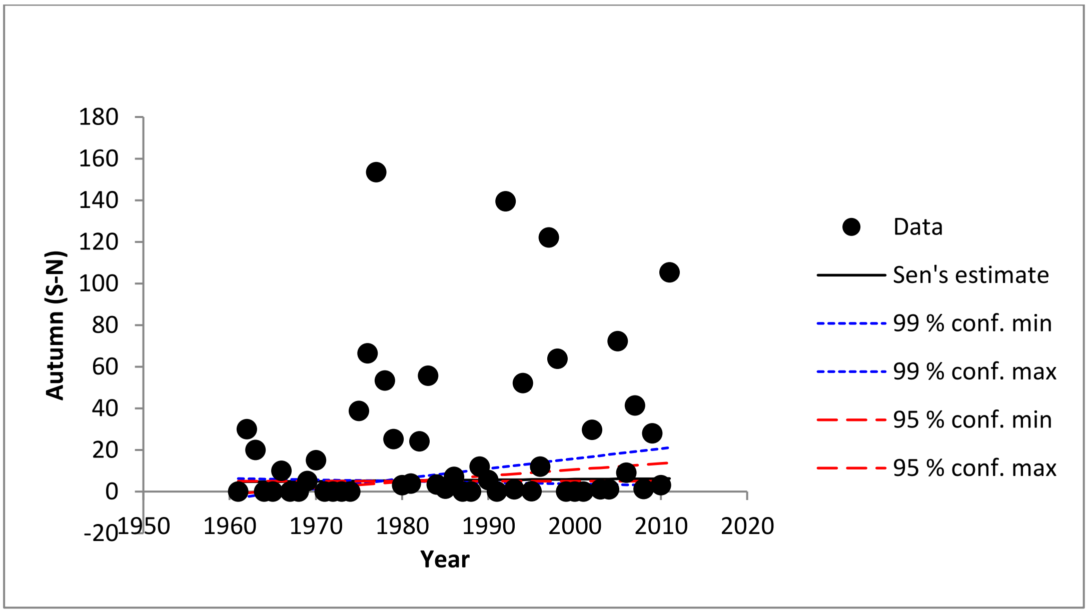


Figure C-4: Autumn Trend of Rainfall

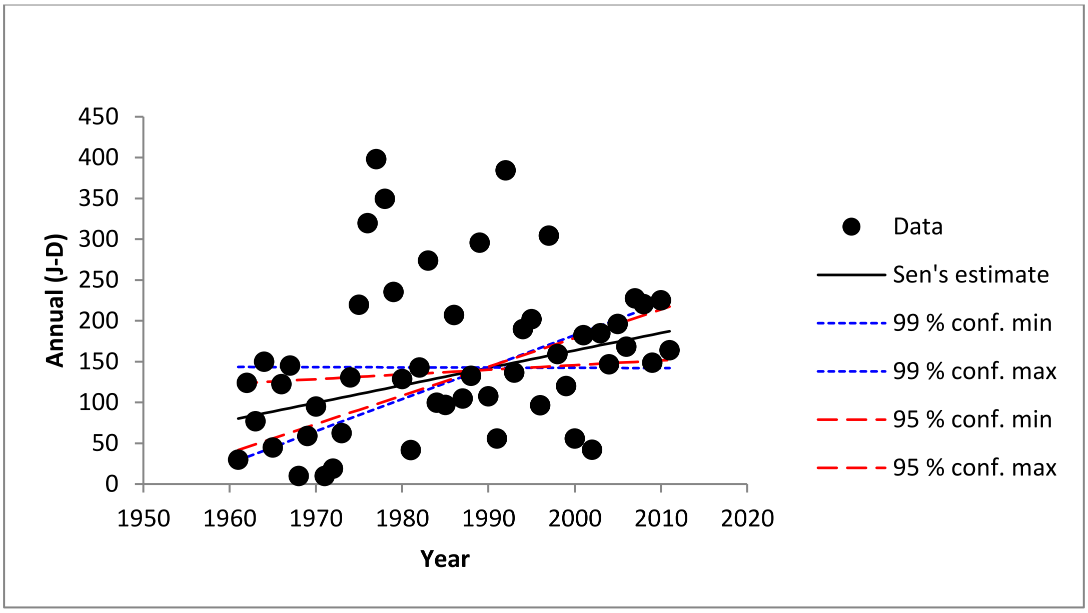


Figure C-5: Annual (January to December) Trend of Minimum Temperature

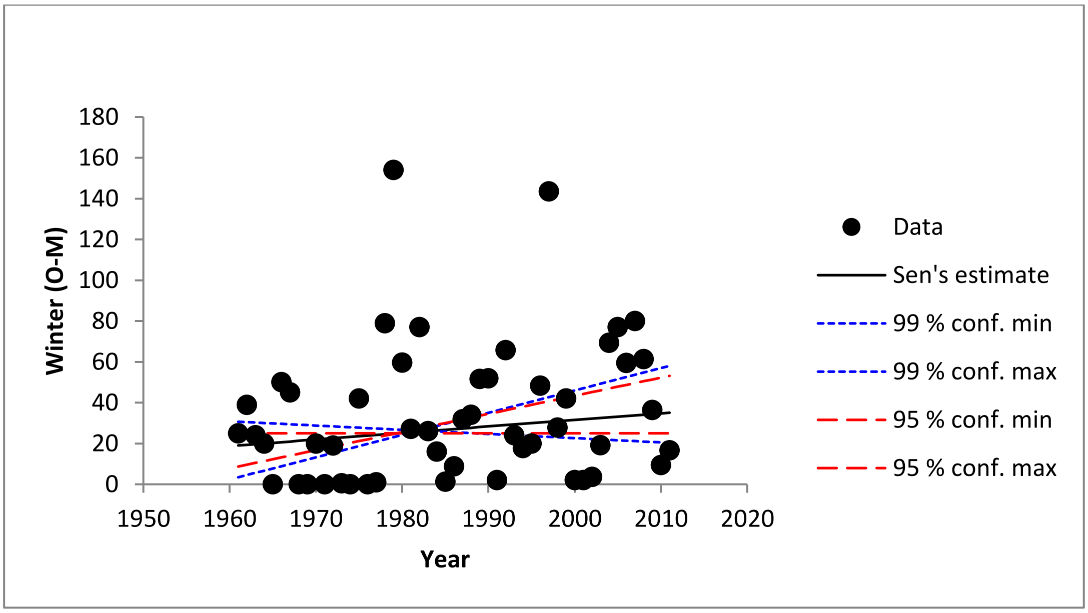


Figure C-6: Winter (October to March) Trend of Minimum Temperature

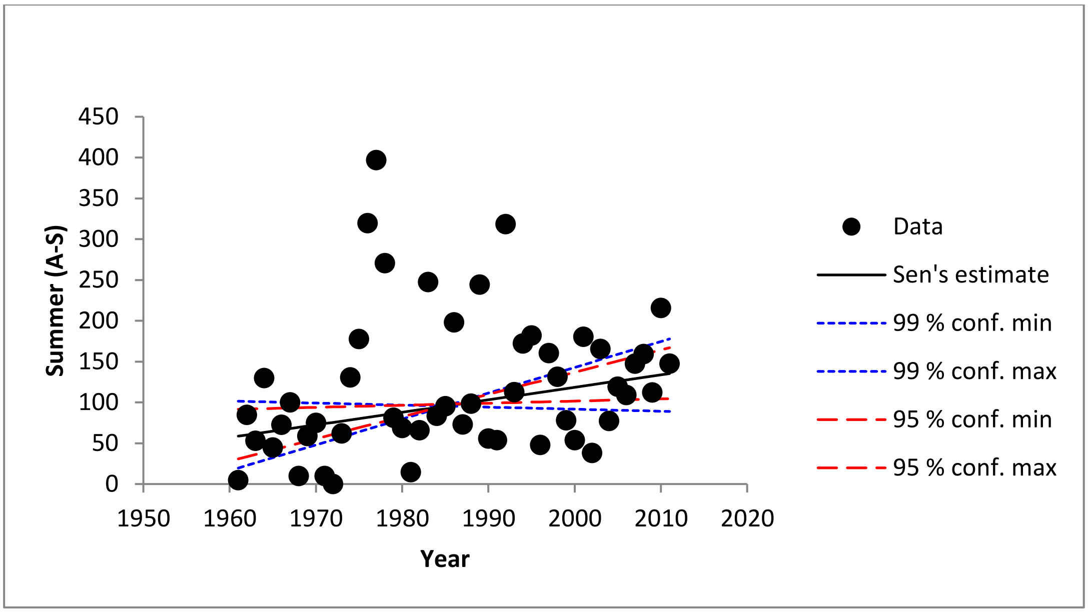


Figure C-7: Summer (April to September) Trend of Minimum Temperature

APPENDIX D

Spatial Trend Analysis of Maximum Temperature, Minimum Temperature and Rainfall

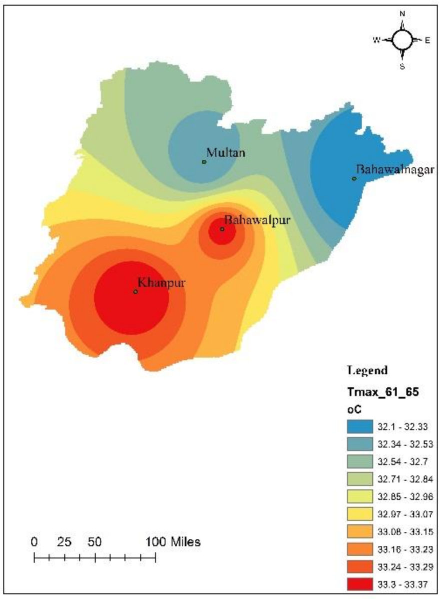
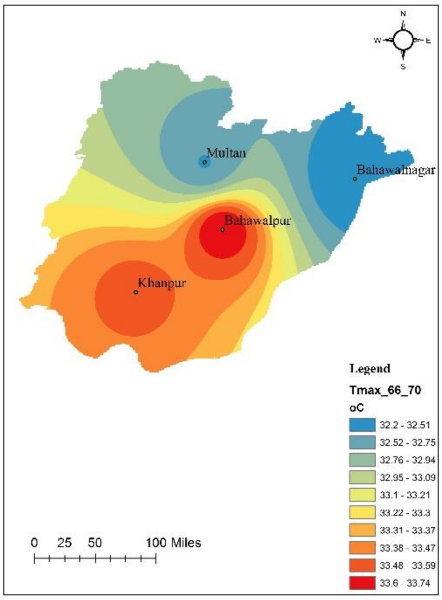


Fig (a)



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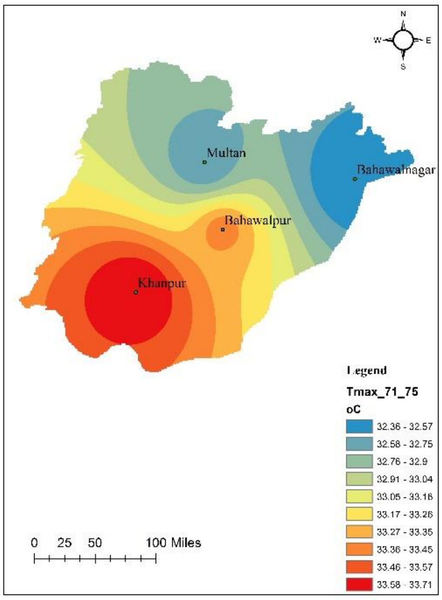
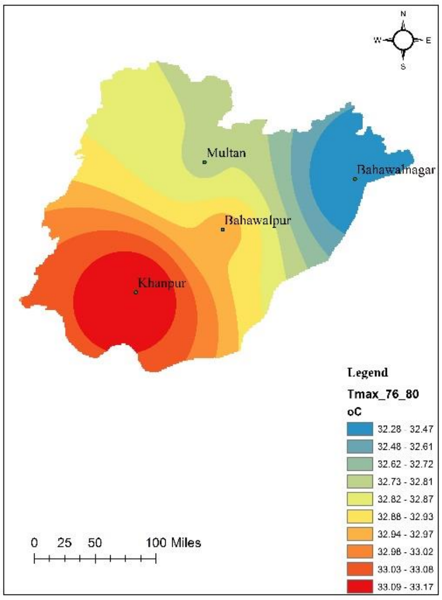


Fig (c)



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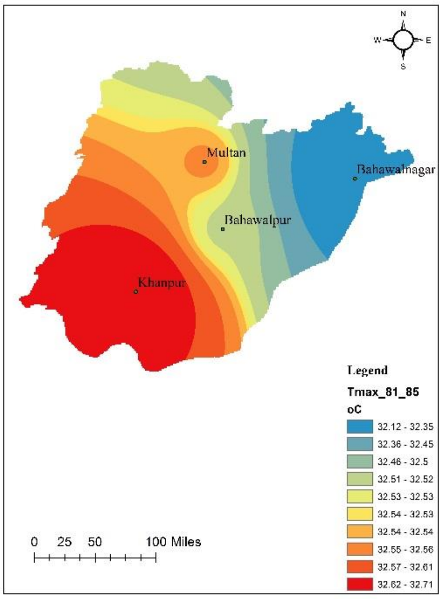

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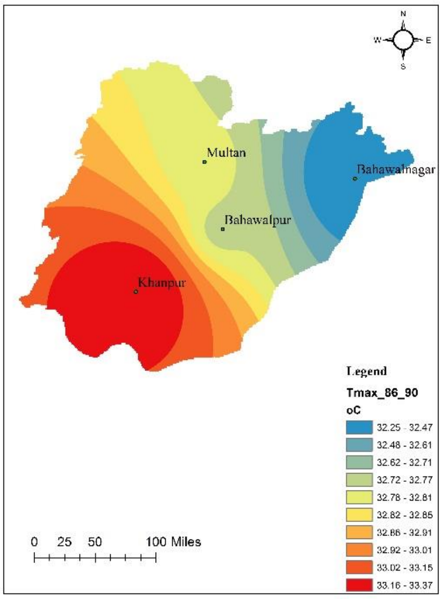

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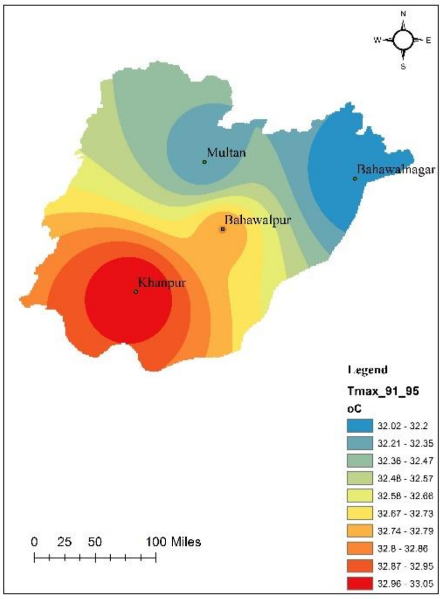
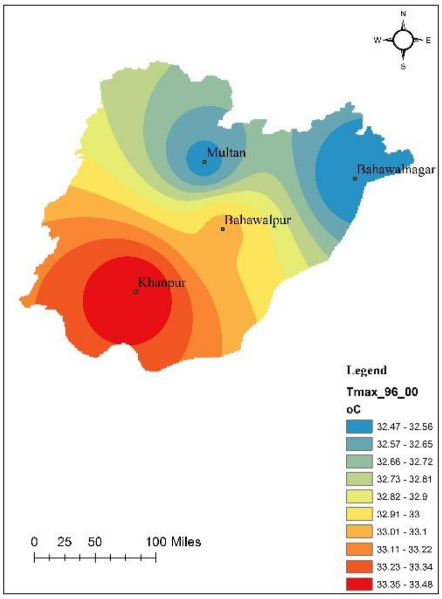


Fig (g)



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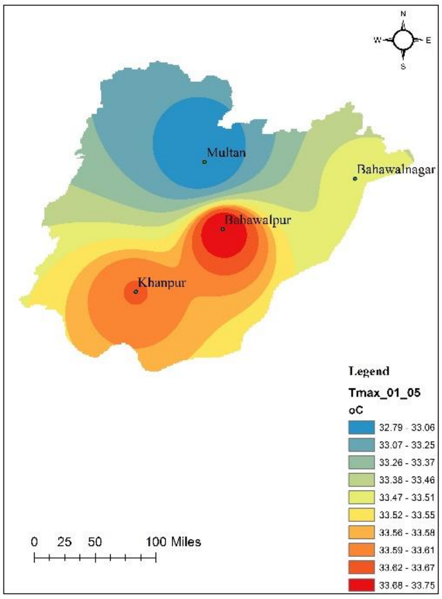


Fig (i)

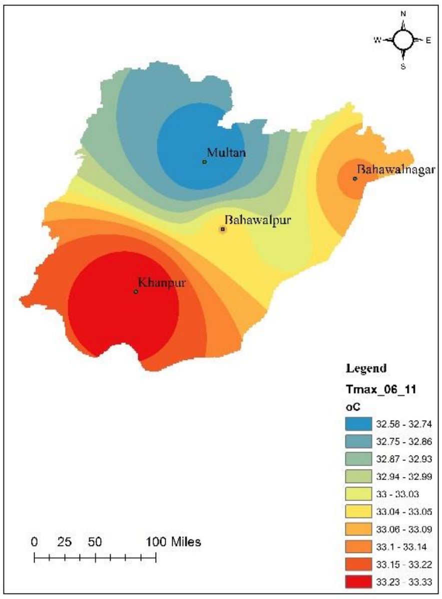


Fig (j)

Figure D-1: Five years Spatial trends of Average Annual Maximum Temperature of South Punjab ((a): 1961-1965, (b): 1966-1970, (c): 1971-1975, (d): 1976-1980, (e): 1981-1985, (f): 1986-1990, (g): 1991-1995, (h): 1996-2000, (i): 2001-2005, (j): 2006-2011

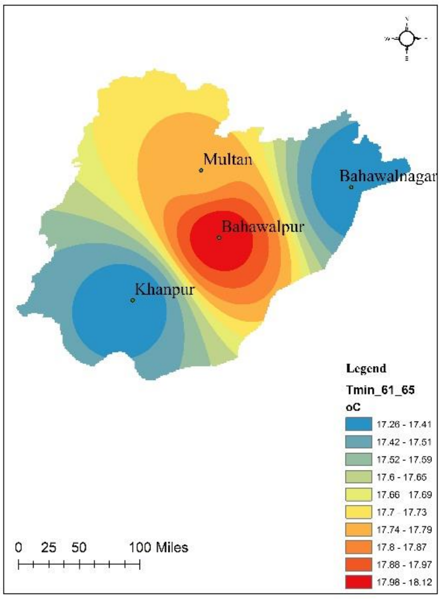
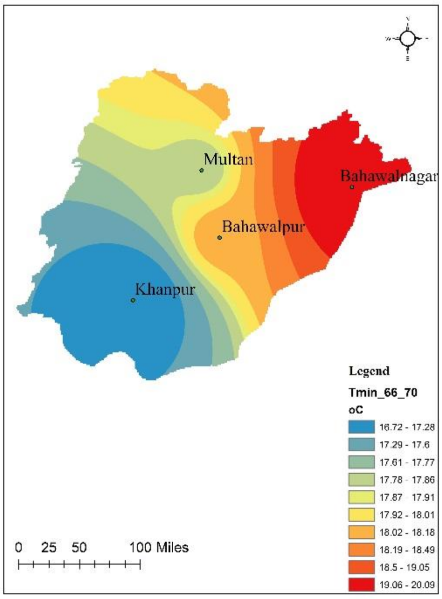


Fig (a)



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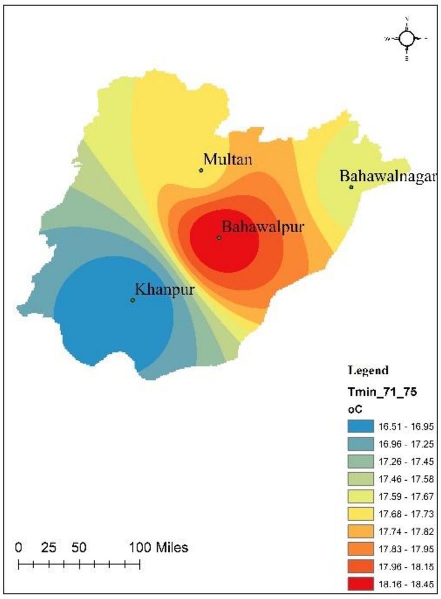

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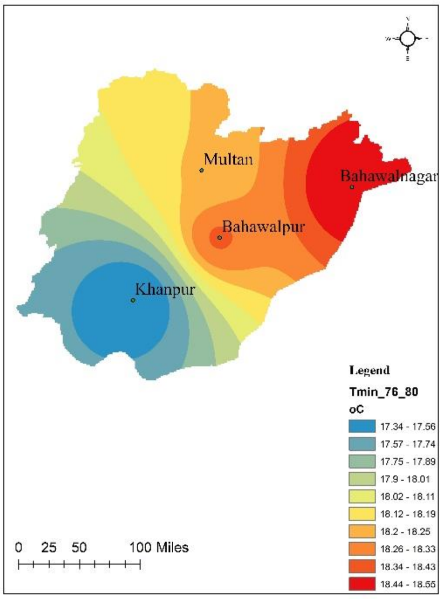

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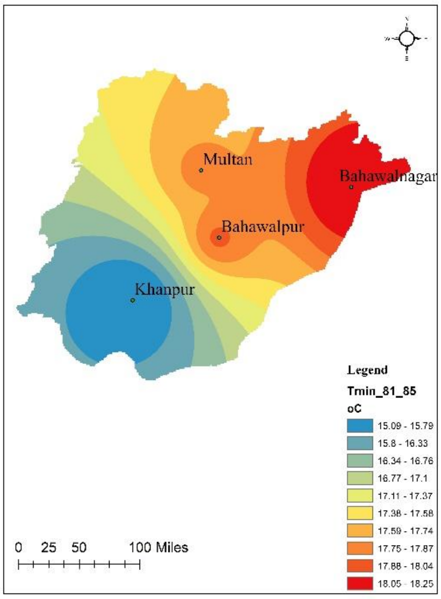

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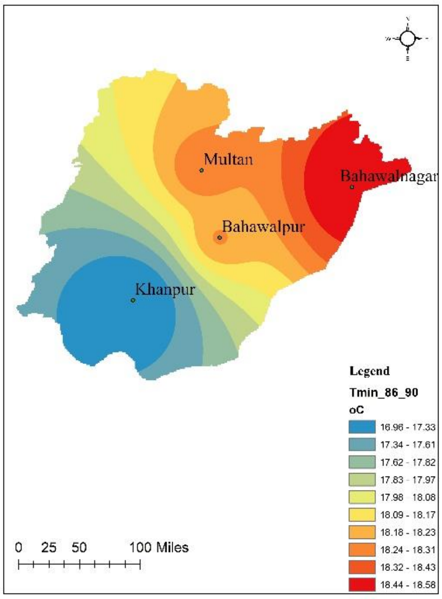

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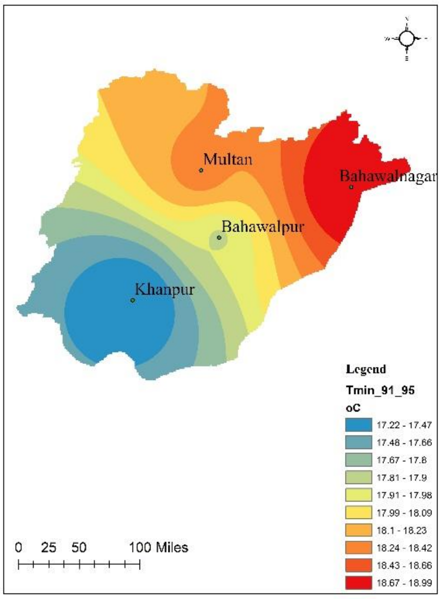

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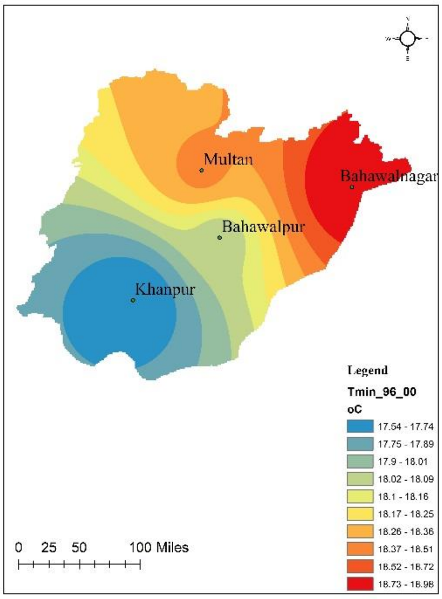

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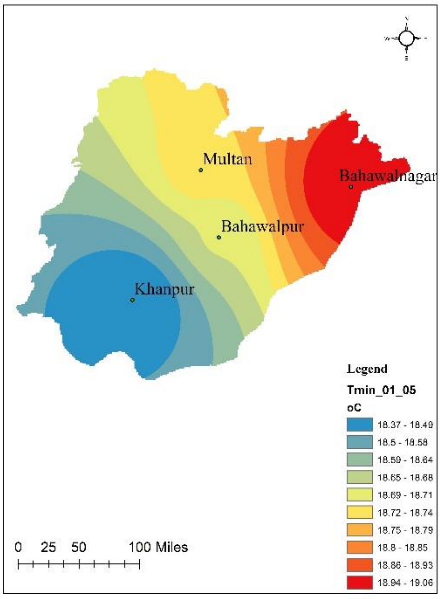

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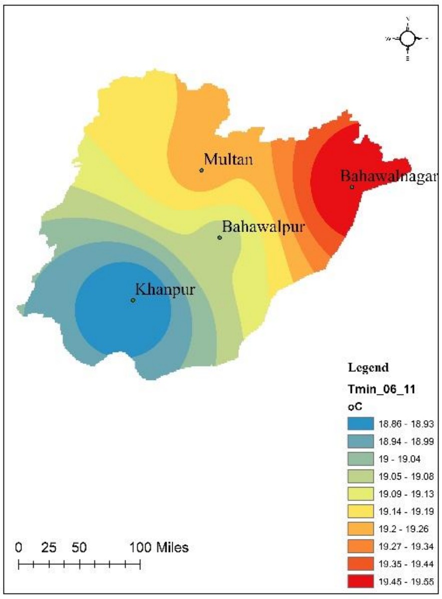


Fig (j)

Figure D-2: Five years Spatial trends of Average Annual Minimum Temperature of South Punjab ((a): 1961-1965, (b): 1966-1970, (c): 1971-1975, (d): 1976-1980, (e): 1981-1985, (f): 1986-1990, (g): 1991-1995, (h): 1996-2000, (i): 2001-2005, (j): 2006-2011

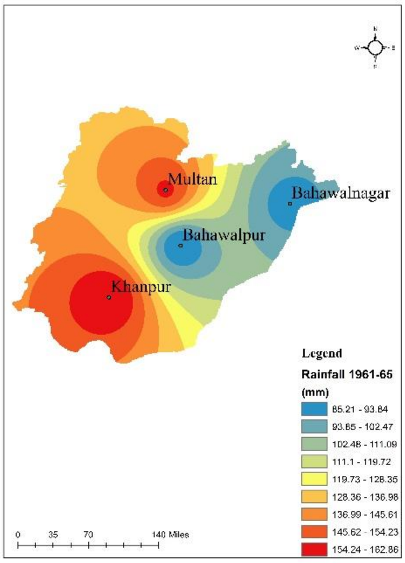
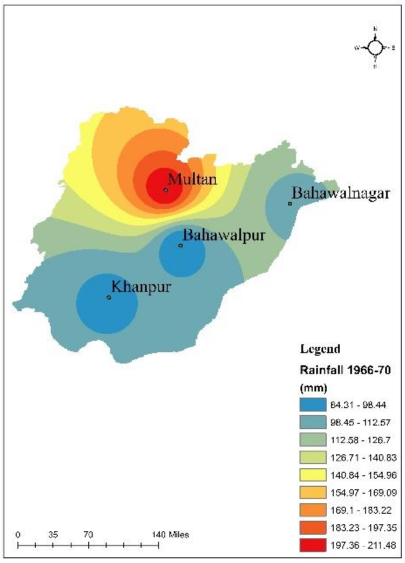


Fig (a)



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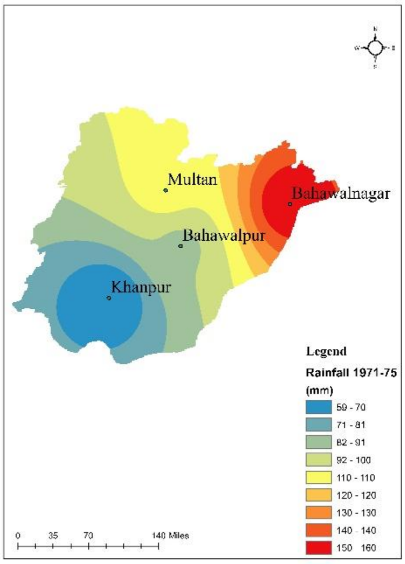

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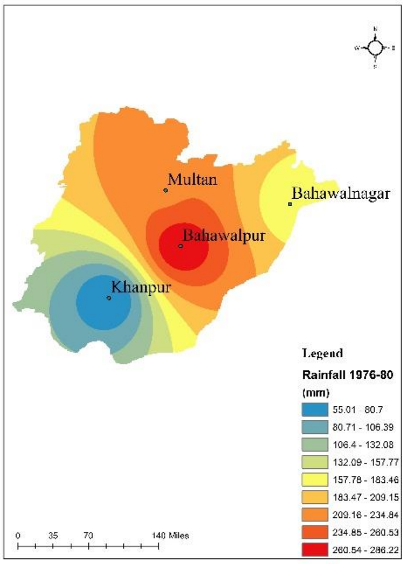

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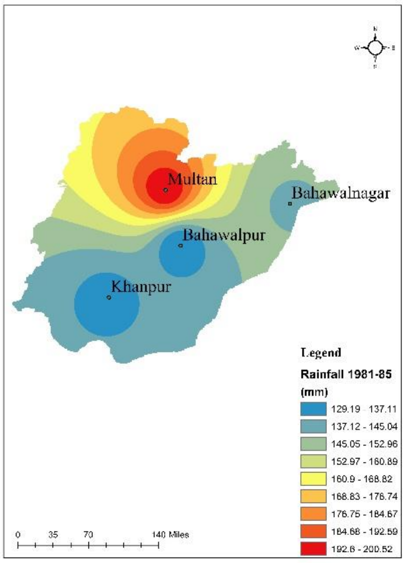

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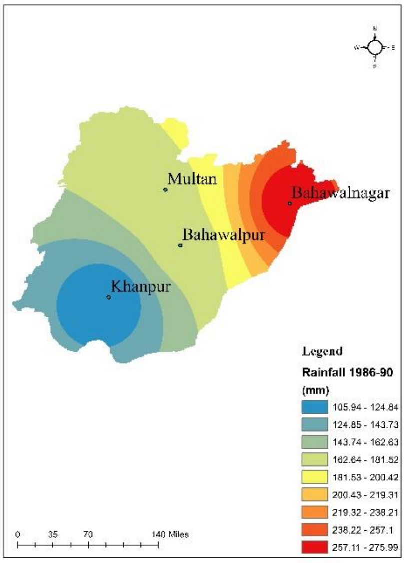

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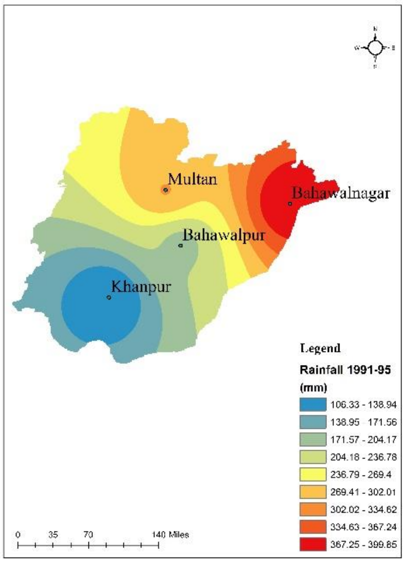

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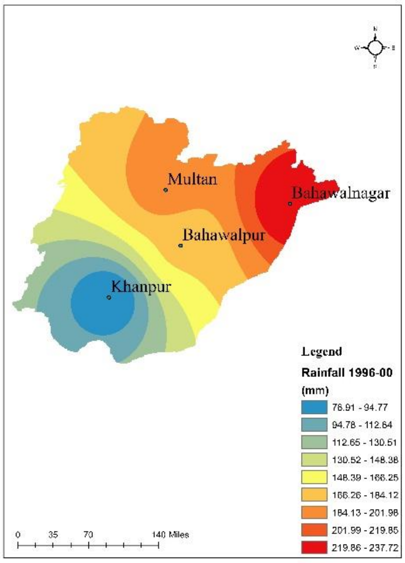

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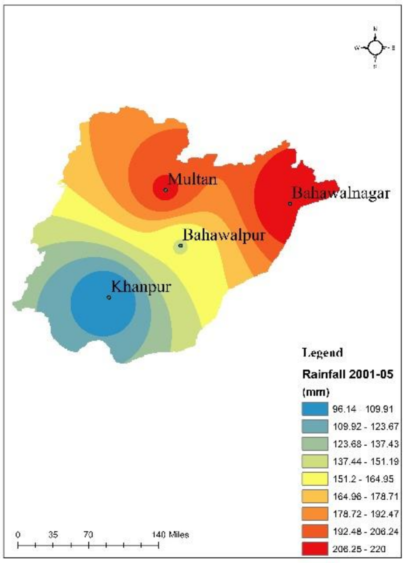

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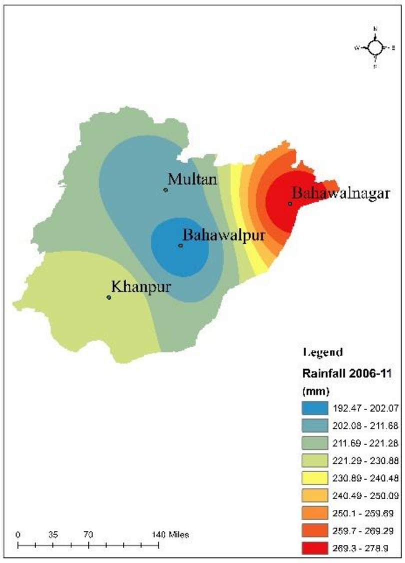

Fig (j)

Figure D-3: Five years Spatial trends of Average Annual Rainfall of South Punjab ((a): 1961-1965, (b): 1966-1970, (c): 1971-1975, (d): 1976-1980, (e): 1981-1985, (f): 1986-1990, (g): 1991-1995, (h): 1996-2000, (i): 2001-2005, (j): 2006-2011