RAINFALL ANALYSIS OF SUGUR SMALL HYDRO POWER PLANT

A

Thesis Report

Submitted in partial fulfilment of the requirement for the award of the degree of

Master of Technology

In

Hydro Power Engineering

Submitted By

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DECLARATION

I declare that the work presented in this thesis report titled *"***RAINFALL ANALYSIS OF SUGUR SMALL HYDRO POWER PLANT***"*. Department of Civil Engineering, Maulana Azad National Institute of Technology, Bhopal, for the award of the **Master of Technology** degree in **Hydropower Engineering**, is my original work. I have not plagiarized or submitted the same work for the award of any other degree. In case this undertaking is found incorrect, I accept that my degree may be unconditionally withdrawn.

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CERTIFICATE

*This is to certify that above statement in respect of dissertation entitled "***RAINFALL ANALYSIS OF SUGUR SMALL HYDRO POWER PLANT"** *submitted by* **Akanksh Mamidala**, *to the* **Civil Engineering Department, MANIT, Bhopal** *is correct to the best of my knowledge and is a record of bona fide work carried out by him under my supervision.*

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ABSTRACT

As the climate is changing day to day, monitoring of rainfall patterns and estimations of design storms should be done periodically. In such case, there is a necessity of updating or generating the IDF curves for an area to estimate the design storm as per the changing patterns or trends of rainfall events. An effort is made to generate IDF curves of different durations of 0.25 hr, 0.5 hr, 1 hr,2 hr, 3 hr, 4 hr, 5 hr, 6 hr, 7 hr, 8 hr, 9 hr, 10 hr, 11 hr, 12 hr,13 hr,14 hr, 15 hr, 16 hr, 17 hr, 18 hr, 19 hr, 20 hr, 21 hr,22 hr, 23 hr and 24 hours for return periods 5, 10, 20, 30, 40, 50, 60, 70, 80, 90 and 100 years for the catchment area of small hydro power plant "Sugur hydropower plant" and assess the hydro power potential of the plant in future. To generate IDF curves, past 25 years of rainfall data (1995–2020) are collected from IMD (Indian Meteorological Department) Pune. 11 IDF curves are constructed and observed that rainfall intensity values had been decreasing as the duration increases in all 11 curves and also observed that rainfall intensity values are increasing with increase in return period. Hydro power potential of the hydropower plant has also increased with increase in return period and the maximum hydropower potential is achieved for 100-year return period. Sugur small hydropower plant is capable of generating 37.454 MW of hydro power in future with the discharge of 948.355 m^3/sec coming to the plant.

Keywords:

Hydro Power Potential, Intensity-Duration-Frequency curves, Rainfall Analysis, Return period.

CHAPTER 1

INTRODUCTION

1.1. Hydropower:

In today’s world, most of the activities runs with the help of electricity. In such need, generation of electricity plays a vital role in development of a society. Generation of electricity by the conventional methods that are used by our mankind such as electricity from fossil fuels etc., are degrading the environment that we are living in.

Here comes the alternate to generate electricity and still not make our environment degrade and that alternate is generating electricity from renewable source of energy. The main advantage of renewable sources of energy is that they are never ending and they don’t cause harm to environment. There are many renewable sources of energies. Some of them are

a) Solar energy
b) Wind energy
c) Hydro energy

The use of water energy to generate electricity is termed as “HYDRO POWER”. Countries like INDIA who has large amounts of water bodies are benefitted from them by generating electricity through constructing hydro power plants for conversion of water potential energy into mechanical energy by using turbines and then converting this mechanical energy into electrical energy by the help of generators which are connected to these shafts of turbines.

1.2. Types Of Hydro Power Plants:

As we had discussed, Hydropower plants are constructed for the purpose of electricity generation. There are different types of hydro power plants because they are classified in many ways such as

1. Based on head available,
2. Based on characteristics of turbine that is used in the plant,
3. Based on the amount of electricity generated from the plant,
4. Based on hydraulic characteristics etc.,

The main two classifications of hydro power plants can be said as classification based on amount of current generated and classification based on hydraulic characteristics.

1.2.1. Based on Electricity generating capacity:

In India, Hydro power plants are classified as the following based on the amount of electricity generated from that respective hydro power plant:

- Micro power plant:

  The hydro power plants which have a capacity of generating electricity only up to 100 KW is termed as “Micro Power Plant”.

- Mini power plant:

  The hydro power plants which have a capacity of generating electricity only 100 KW to 25 MW is termed as “Micro Power Plant”.

- small power plant:

  The hydro power plants which have a capacity of generating electricity less than and equal to 25 MW is termed as “Small Power Plant”.

- Large power plant:

  The hydro power plants which have a capacity of generating electricity greater than 25 MW is termed as “Large Power Plant”.

  Micro and mini hydro power plants are also small hydropower plants which are further classified in small hydro power plant segment.

1.2.2. Based on hydraulic characteristics:

Hydro power plants are also classified based on hydraulic characteristics as given below:

- Run off river power plant:

  In this type of power plants, there is no construction of large reservoirs such as dams is needed because these type of power plants use the flow of the river and doesn’t store large amounts of water in most of the cases and even if they store, they store in very little amounts which can be achieved by construction of small weirs. As there is no need of large reservoirs, these type of power plants are eco-friendly by decreasing construction emissions but also these power plants can't have larger units of electricity generation as they are dependent on the flow of river or small pondages only.

- Storage type power plant:

  In this type of power plants, construction of large reservoirs such as dams are needed because as the name suggests large amounts of water is stored for the generation of electricity. The power house where the turbines and other hydraulic components are present is located at the toe of the hydraulic structure. These power plants have greater capacity to generate more electricity as the amount of water received by these plants is higher. The dams which are constructed for these power plants also used for multi purposes such as flood control, irrigation etc., These power plants are most commonly used for hydropower generation.

- Pumped storage type power plant:

  In this type of power plants, water that is used for generation of electricity will be stored and pumped back to reservoirs for further generation of electricity when required. These type of power plants are least common for hydropower generation.

1.3. Small hydropower plant with run off river type storage:

Large hydropower plants with large reservoirs have some disadvantages/problems. In construction of large reservoirs, lot of forest land is needed which is to be cut down and causing deforestation which is not good to our environment. Erosion of soil can take place near the toe of the hydraulic structure as heavy discharges of water are released from the structure with very high velocities. In some cases, local habitat/ people who resides near the location selected for construction of large reservoirs has to be relocated which may arises in protests and delay in construction of projects, and also the way of living and their professions may get effected in a very big manner. At the time of heavy rains, the water might be released from the hydraulic structures after reaching the limits of storage of reservoir, which might turn into floods due to sudden release of large amounts of water.

The above-mentioned disadvantages can be completely eliminated or can decrease their intensity by choosing small hydropower plants with run off river storage which doesn't require construction of large reservoirs. If required, small weirs and pondages may be constructed to cater daily requirement of electricity to store little amounts of water when there is less flow in the stream or river.

Now, the schematic diagram of a basic hydropower plant is shown below and further arrangement of a small hydro power plant with run off river storage is shown

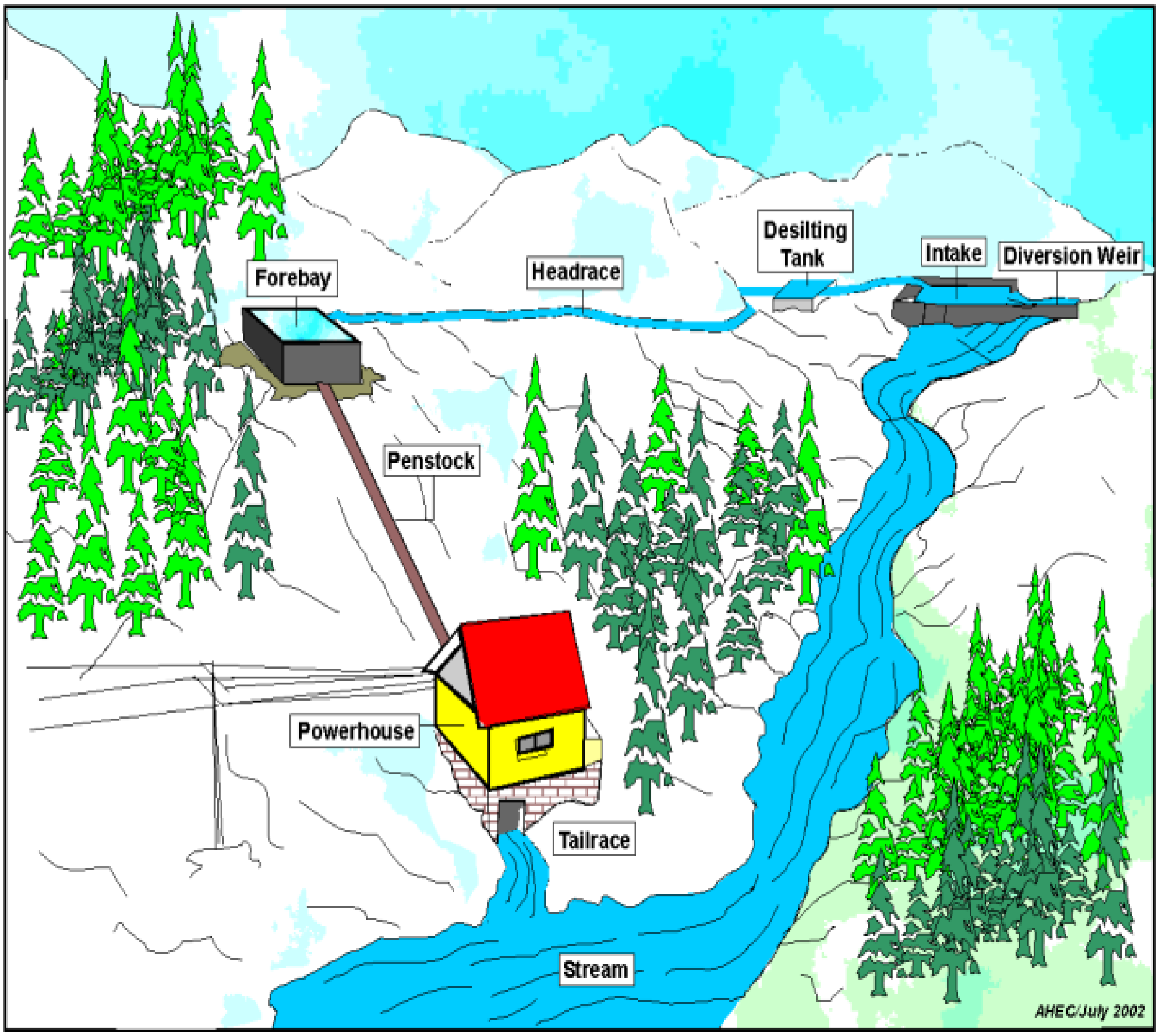


Figure 1. 1. schematic diagram of a basic hydropower (Hydropower Engineering)

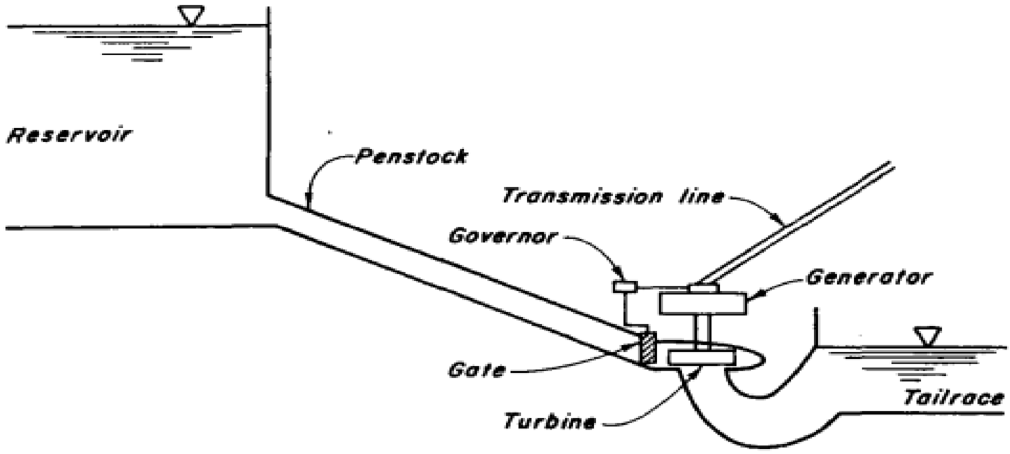


Figure 1. 2. Small hydropower plant with run off river type storage (Source: Applied Hydraulic Transients)

1.4. Rainfall Analysis:

As water is the main component in generating electricity in hydro power plants, the understanding of lifetime circulation of water is needed. Rainfall is the major source of water flow in a stream excluding mountain ice melts. This makes analysis of rainfall a mandatory task. Generally what rainfall analysis means is estimating the storm which is going to be occurred in future at the selected location for a particular duration after ‘n’ number of years. Intensity-duration-frequency curves takes the major part in rainfall analysis.

- Rainfall intensity:

  Rainfall intensity is the amount of rainfall in millimetres that has occurred for a unit period of time that is for one hour. It is denoted by ‘i’.

- Rainfall Duration:

  The total time from starting to ending of a rainfall event at a particular location is called “Rainfall Duration”. It is denoted by ‘t’.

- Frequency or Return period:

  The time interval between the occurrence of a storm of particular intensity and duration from present to the storm with same intensity and duration occurring again in the future is called “Frequency of storm”. In general terms, we can say that frequency of a storm is that the time period for occurrence of similar rainfall event in future i.e., how frequently that particular rainfall of same intensity and duration is occurring. It is also called as “Return period”. It is denoted by term ‘T’.

- Intensity – Duration – Frequency curves:

The curves which are obtained by plotting a graph between the rainfall intensity and the duration of the same rainfall for a particular return period or frequency are called “Intensity-Duration-Frequency curves”. In short, they are called “IDF CURVES”. There can be more than one idf curve in a graph. For each return period, separate curve will be generated, so if we consider more than one return periods while plotting the idf curves, we will obtain more than one curve which is because every return period has a curve.

For conducting rainfall analysis of a particular site, first we need to collect the previous records of rainfall at that particular site and find the statistical values from those datasets by using a software and estimate the rainfall intensity of a particular duration occurs with what frequency.

1.5. Software for analysis:

When we talk about finding the statistical values such as mean and standard deviation of long periods of rainfall data from many numbers of rain gauge stations, there is a wide scope of occurrence of error in manual method because of enormous data. In such situation, statistical computer software/applications come into picture to ease the calculations, reduce the time requirement of calculations and to eliminate the errors which can be had occurred in manual calculations.

In the market, there are many software’s which can perform statistical calculations as per our requirement. Some of the mostly famous or commonly used software/applications are given below

a) Microsoft Excel,
b) Minitab,
c) SAS (Statistical Analysis Software),
d) Stata,
e) Wolfram Mathematica etc.,

In the above-mentioned applications/software, some are available for free such as MS Excel, some are paid such as Minitab and some are mainly designed to do data analysis and some are capable of many advanced coding and calculations by using artificial intelligence.

1.6. Hydropower potential:

It is also called capacity of the hydro power plant. It is the amount of electricity produced by the hydro power plant from the discharge that is available at the plant. It is measured in Kilowatts (KW) and Megawatts (MW). Large and small hydropower plants are classified by the criteria of hydropower potential/capacity. Hydropower potential of the hydropower plant depends on lot of factors, the main factors that effects the capacity of a plant are given below

a) Discharge that is inflowing into the plant,
b) Types of turbines used for converting hydraulic energy into mechanical energy,
c) Head that is available at turbine (the vertical distance between the water level and the turbine,
d) Efficiency of the turbine in converting hydraulic energy into mechanical energy,
e) Number of turbines used.

1.7. Objective of present study

As the climate is changing day to day, monitoring of rainfall patterns and estimations of design storms should be done periodically. In such case, there is a necessity of updating or generating the IDF curves for an area to estimate the design storm as per the changing patterns or trends of rainfall events which in return make us ready for the changes that had to be implemented if needed.

The main objective of this study is to generate IDF curves of different return periods 5,10,20,30,40,50,60,70,80,90 and 100 years for the catchment area of small hydro power plant “Sugur hydropower plant” and assess the hydro power potential of the plant in future.

1.8. Thesis Framework/Layout:

There are 5 chapters in this thesis and they are given below

Chapter1, this chapter introduces the topics that are going to be dealt in the thesis in a brief manner to get an understanding of what this thesis is about.

Chapter2, discusses about the literature study that had been done for completing of this thesis work.

Chapter3, explains the complete methodology that is followed to achieve the thesis objectives.

Chapter4, show the results that are obtained from the analysis that is carried out.

Chapter5, states the conclusions that are made upon the obtained above results.

CHAPTER 2

LITERATURE REVIEW

- **Vijay Kumar.et.al., (2010) [1]** had determined the rainfall trends in India by dividing into 36 sub divisions, 5 regions and also all India by Sen's estimator and significance of those trends were analysed by MK (Mann-Kendall) test. For observing the trends and their significances, monthly rainfall data of past 135 years in India from 306 stations is obtained from IMD (Indian Meteorological Department) after applying the quality checks to validate data that is used. Trends were determined and the found that east Madhya Pradesh, Nagaland, Manipur, Mizoram subdivisions has significant negative trends and whereas Punjab subdivision has a significant increase trend.

- **Sunguen Jung.et.al., (2021) [2]** had emphasised the importance of discharge of river basin in the calculation of hydropower potential and tried to obtain best method to calculate discharge values from rainfall data for ungaged sites with less errors and high accuracy. For the above objective, they had selected three hydropower plants with gaged sites (Deoksong, Hanseok, socheon) and calculated hydropower potential for those plants by measured discharge value and with calculated discharge value which is obtained by using formulas (kajiyama formula and tank model) and used blending techniques (Multi model super ensemble, simple model average, mean square error) to reduce error of these formulas. After comparison of hydropower potentials with measured and formula based, they concluded that mean square error blending technique is best to calculate discharge values for ungaged basins to calculate hydropower potential.

- **J.A. Otun.et.al., (2012) [3]** pointed out the need and necessity of small hydropower plants in these modern days for rural areas which makes them self-reliant in generation of power. They had selected Kangimi reservoir in Nigeria which doesn't have hydropower plant as of now and tried to assess the hydropower potential of the reservoir to find whether it is feasible to plan hydropower plant or not and concluded that Kangimi reservoir has a hydropower potential of 1.1 MW and can help in satisfying the electricity needs of its surrounding regions.

- **D.S. Pai.et.al., (2014) [4]** had developed high spatial resolution (0.25° × 0.25°) gridded data for India by using 110 years rainfall data from IMD (Indian Meteorological Department) of 6955 rain gauge stations. The rainfall data collected from these rain gauge stations has been interpolated to gridded data using Inverse Distance Weighted interpolation method to interpolate accurately. This newly generated gridded data was compared with previously developed gridded data of resolutions 1°×1° and 0.5°×0.5° and concluded that newly developed data was more accurate than the previous due to its high resolution and higher number of rain gauges used.

- **Munshi.Md.Rasel.et.al., (2015) [5]** had developed R-IDF (Rainfall Intensity-Duration-Frequency) curves for Bangladesh country by dividing into 7 divisions which are Dhaka, Chittagong, Barisal, Khulna, Rajshahi, Rangpur and Sylhet. The rainfall data for developing these curves is obtained from BMD (Bangladesh Meteorological Department) which includes 35 rain gauge stations and the data collected was of 41 years. IMD Reduction Formula was used to convert available data into short duration rainfall data and Gumbel's probability distribution was fitted to data and the curves are generated.

- **Pradeep Kumar.et.al., (2007) [6]** had mentioned an important aspect of run off river type or diverted scheme hydropower plants which is to maintain a minimum flow in the river basin for the benefit or safety of aquatic life of river basin and for aesthetic river conditions of river basin. For that, they had selected Nathpa reach near the Nathpa Jhakri hydropower plant and concluded that the minimum flow in the river has to be 7 cumecs with 1 metre per second velocity after conducting habitat analysis.

- **Kyu Kyu Thin.et.al., (2020) [7]** estimated the hydropower potential from non-existing small hydropower plants of run off river type plants in Myitnge river basin located in Myanmar by using GIS for locating potential sites for construction of small hydropower plants and SWAT model to assess discharge/flow rates of those sites and concluded that Myitnge river basin has 20 potential sites which can generate 292 MW of electricity collaboratively.

- **Anushka Perera.et.al., (2020) [8]** had established the relationships between the rainfall and the hydropower generation for a gauged station named Denawaka Ganga mini hydropower plant of Sri Lanka. The relationship was determined by ANN (Artificial Neuron Networks) and a significant positive correlation with a correlation coefficient greater than 0.57 and mean square error of 1.19 was observed between the rainfall values and hydropower generated at that hydropower plant.

- **Daniel Dourte.et.al., (2013) [9]** had emphasized the importance of updating IDF relationships for a location time to time. They had selected two data sets of rainfall for Hyderabad city in Telangana of different time periods which are 1993 to 2011 and 1982 to 2011 and the dataset from 1993 to 2011 are used to develop and update previous IDF curves for that location and observed that the difference between the rainfall intensities from previous generated IDF curves and the rainfall intensities from updated IDF curves is on average 24 mm/hr i.e., updated intensities are 114 % greater than the previous intensities which makes the point that IDF curves should be updated frequently.

- **Sagarika Patowary. et.al., (2016) [10]** had considered the effect of climate change in increasing the intensities of hydraulic events i.e., rainfall events and decided to update new IDF curves for Guwahati city and forecasted future rainfall for that city for years 2006 to 2100. The projection of future rainfall is done using ESM2G Global Circulation Model for downscaling the rainfall values and for climate impact, RCP8.5 was considered which is constituted as highest greenhouse gas emissions pathway. After downscaling, the future time period was divided into 3 parts i.e.,2012 to 2040, 2041 to 2070 and 2071 to 2100 years and IDF curves are generated for them. They predicted that there will be high intensity rainfall values in 2012 to 2070 and from 2071, the intensity values are going to be lesser than the rainfall intensity values that were predicted for the time period 2012 to 2070 and suggested Guwahati city to update the hydraulic structures according to the increasing intensity values.

- **Varun.et.al., (2008) [11]** had done Life Cycle Analysis for three small hydropower plants which are Karmi-III, Jakhna and Rayat to estimate the environmental impact of small hydropower plants throughout their life period. Average life time period was taken as 30 years and for Life Cycle Analysis, EIO (Economic input output) method is used and obtained Energy payback period (EPBT) and Green House Gases(GHG) emissions for Karmi-III, Jakhna, Rayat as 2.71, 1.99, 1.28 years and 74.88, 55.42, 35.29 gCO_{2eq}/KWh_c respectively and concluded that there is less environmental impacts for small hydropower plants compared to large hydropower plants.

- **A.S. Suchithra.et.al., (2020) [12]** had developed IDF curves for Krishna district in Andhra Pradesh state residing to Krishna River basin by using previous years rainfall data of 38 years of the given location for 2,5,10,25,50 and 100 years of return periods. They compared three probability distributions Log-Normal, Normal and Gumbel's distributions by fitting them to rainfall data and constructing IDF curves and concluded that Gumbel's probability distribution had given the maximum rainfall intensity values for that particular location.

- **Ministry of Housing & Urban Affairs. (2019) [13]** explains the complete process of conducting rainfall analysis including constructing IDF curves and IDF relationships for Indian sub-continent. They suggested or recommended Gumbel's probability distribution on rainfall data series that is collected daily from rain gauge stations for constructing IDF curves in India. Estimation of runoff from the rainfall intensities is also explained in detail in this paper.

CHAPTER 3

METHODOLOGY & CALCULATIONS

3.1. Selection of site:

Sugur small hydropower plant is selected to determine the hydropower potential of the plant in the future and to construct IDF curve to predict rainfall intensities for return periods up to 100 years. Sugur small hydropower plant is located near M. Sugur village, Bellary district, Karnataka state. The longitudinal and latitudinal position of Sugur hydropower plant is 15.49°N, 76.75°E. Sugur hydropower plant is constructed on the banks of river Tungabhadra with a power generating capacity of 4.5 MW (each turbine of capacity 1.5 MW) and has 3 vertical Kaplan turbines with synchronous generator. Sugur hydropower plant is a small hydropower plant and has run off river type storage and has a penstock with 4 metre inlet diameter and 6 metre length connected from water level in basin to turbine and has a head of 6.2 metre.

Sugur small hydropower plant is maintained by Bhoruka Power Corporation Limited (BPCL) which is a private hydropower generating corporation. Google earth satellite images were captured for this small hydropower plant shown in fig.3.1. and fig.3.2.

Figure 3. 1. Sugur small hydropower plant with surroundings (source: Google Earth)

Figure 3. 2.Sugur small hydropower plant (Source: Google Earth)

For IDF curve construction, the rainfall data is analysed is for the area 231 square kilometre bounded in 15.4°N,76.55°E and 15.5°N,76.75°E. The area between these points is calculated from website https://www.nhc.noaa.gov/gccalc.shtml by "NATIONAL HURRICANE CENTER AND CENTRAL PACIFIC HURRICANE CENTER".

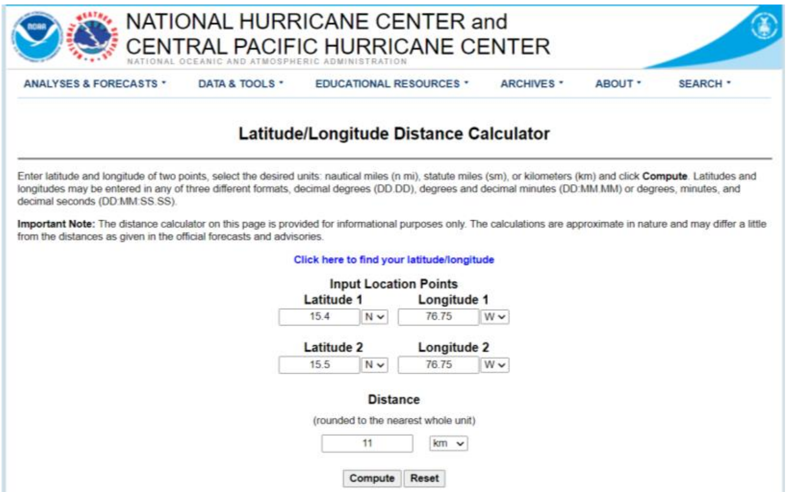


Figure 3. 3.Distance between latitudes

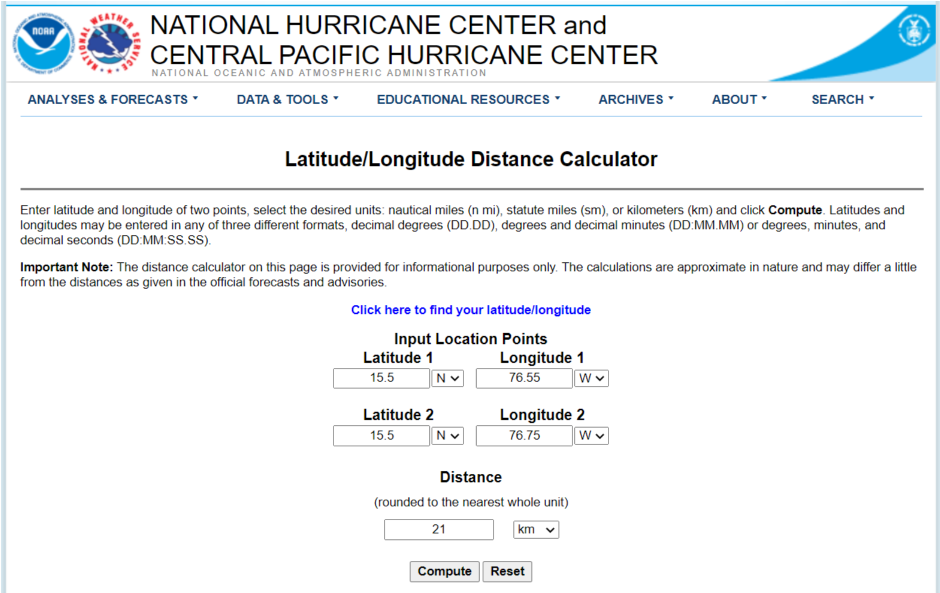


Figure 3. 4. Distance between Longitudes

Area is obtained by multiplying the longitudinal and longitudinal distances obtained from the above-mentioned website.

3.2. Collection Of Rainfall Data:

3.2.1 Selection of source:

As the complete study is based upon the data is collected, there must be very accurate source with no errors or manipulations in our rainfall data. IMD (Indian Meteorological Department) is the most trusted source for any meteorological data in India which is run by Indian government.

Rather than collecting data of rain gauge stations, the rainfall data which is modified in gridded higher resolutions of 0.25°×0.25° can be downloaded from IMD Pune official website "https://www.imdpune.gov.in/Clim_Pred_LRF_New/Grided_Data_Download.html".

Previous years of daily maximum rainfall data from 1995 to 2020 were downloaded from the above-mentioned site and are available in the GRD format.

3.2.2 Conversion of data into required format:

To analyse the rainfall data, MS Excel software was selected because it is a free resource and user friendly. Data that is in GRD format cannot be opened in MS Excel software, we need to convert the data into Csv format or Xlsx format to perform analysis on data in MS Excel.

To convert GRD file to Csv file, the following python code is executed in PyCharm and our required conversion is done.

```
import imdlib as imd
start_yr = 1995
end_yr = 2020
variable = 'tmax'
file_format = 'yearwise'
file_dir = 'E:/imd_data/'
data = imd. open_data (variable, start_yr, end_yr,’ yearwise', file_dir)
if variable == 'rain':
    grid_size = 0.25
    y_count = 129
    x_count = 135
    x = 66.5
    y = 6.5
elif variable == 'tmax' or variable == 'tmin':
    grid_size = 1
    y_count = 31
    x_count = 31
    x = 67.5
    y = 7.5

#Print (grid_size, x_count, y_count, x, y)
data
data. shape
np_array = data. data
#Print (np_array [0,0,0])
# xr_objecct = data.get_xarray ()
# type (xr_objecct)
```

```
#xr_objecct. mean('time'). plot()
years_no = (end_yr - start_yr) + 1
#print(years_no)
day = 0
for yr in range (0, years_no):
    f = open("E:/imd_data/"+str(start_yr+yr) +"_"+str(variable)+".csv",'w')
    if ((start_yr+yr) % 4 == 0) and ((start_yr+yr) % 100! = 0):
        days = 366
        count = yr + days
    elif ((start_yr+yr) % 4 == 0) and ((start_yr+yr) % 100 == 0) and ((start_yr+yr) % 400 ==
0):
        days = 366
        count = yr + days
    else:
        days = 365
        count = yr + days

    day = day + days

    f. write ("X, Y,")
    for d in range (0, days):
        f. write (str(d+1))
        f. write (",")
    f. write("\n")
    #Print (np_array [364,0,0])
    for j in range (0, y_count):

        for i in range (0, x_count):

            f. write (str ((i * grid_size) + x))
            f.write(",")
            f.write (str ((j * grid_size) + y))
            f.write(",")
            time = 0
```

```
            for k in range (day-days, day):

                val = np_array [k, i, j]
                if val == 99.9000015258789 or val == -999:
                    f.write(str (-9999))
                    f.write(",")
                else:
                    f.write(str(val))
                    f.write(",")



            f.write("\n")
    print ("File for " + str (start_yr + yr) + "_" + str(variable) + " is saved")
print ("CSV conversion successful!")
```

3.3 Data cleaning:

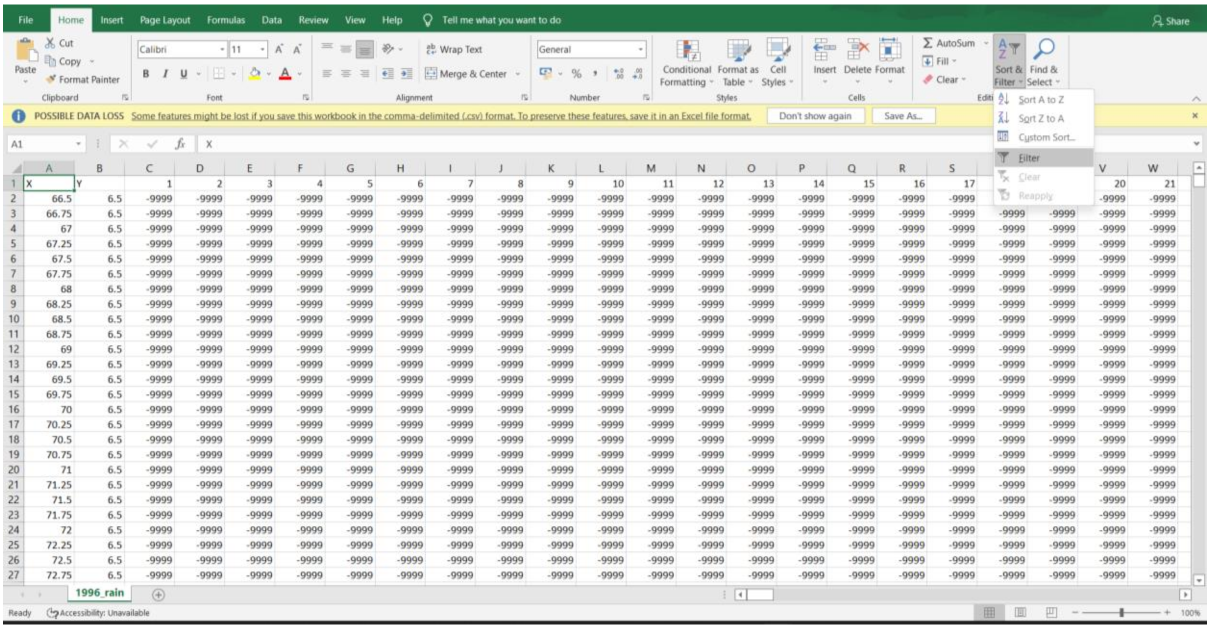
Filtering enormous of data according to our specifications is “Data Cleaning”. From the converted data, we need to filter rainfall data of our required location because the data is obtained for entire India. Data cleaning can be done in MS Excel in 3 ways to get the required results.

3.3.1 Manual Method:

This method is the most time-consuming method out of these 3 methods because in this method, filters for longitudinal and latitudinal values are manually applied and this process should be done for each years excel sheet.

- Step 1:

Select the sort and filter button in the ribbon

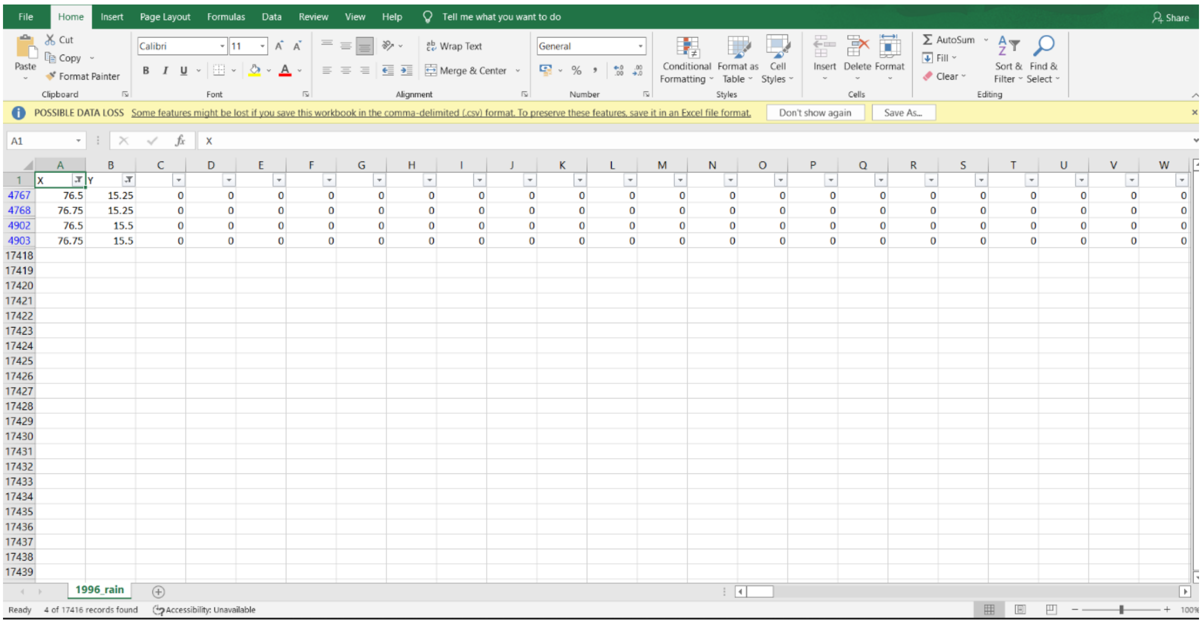


	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W
1	X	Y	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17			20	21
2	66.5	6.5	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999			-9999	-9999
3	66.75	6.5	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999
4	67	6.5	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999
5	67.25	6.5	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999
6	67.5	6.5	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999
7	67.75	6.5	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999
8	68	6.5	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999
9	68.25	6.5	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999
10	68.5	6.5	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999
11	68.75	6.5	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999
12	69	6.5	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999
13	69.25	6.5	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999
14	69.5	6.5	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999
15	69.75	6.5	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999
16	70	6.5	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999
17	70.25	6.5	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999
18	70.5	6.5	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999
19	70.75	6.5	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999
20	71	6.5	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999
21	71.25	6.5	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999
22	71.5	6.5	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999
23	71.75	6.5	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999
24	72	6.5	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999
25	72.25	6.5	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999
26	72.5	6.5	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999
27	72.75	6.5	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999

Figure 3. 5. csv file of rainfall data obtained

- Step 2:

Only select the required latitudes and longitude values and filter the data



	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W
1	X	Y																					
4767	76.5	15.25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4768	76.75	15.25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4902	76.5	15.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4903	76.75	15.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Figure 3. 6. Manual filtering

- Step 3:

We had obtained the filtered data as shown below

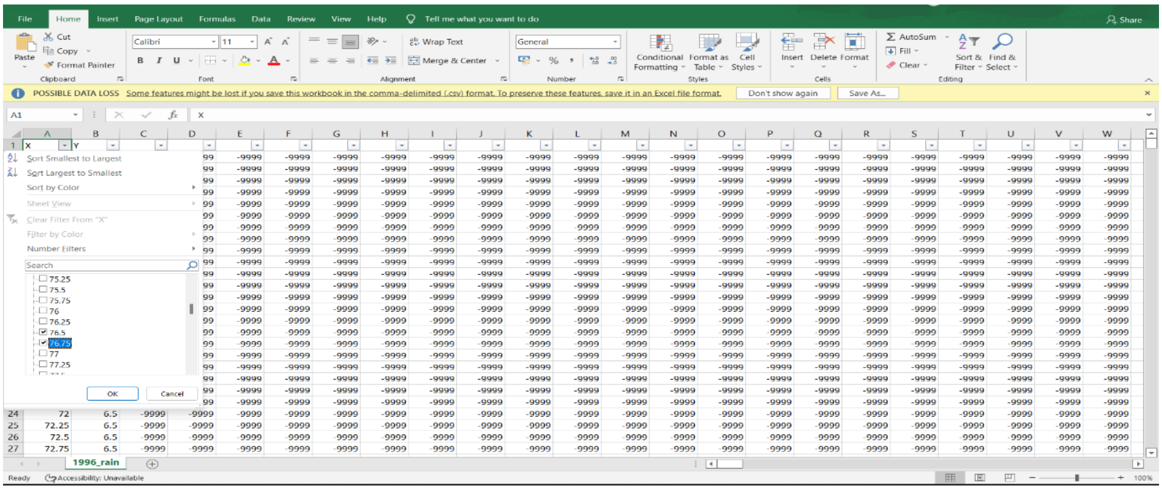


Figure 3. 7. Filtered to our location

- Step 4:

Now, as we are using Arithmetic method to for mean precipitation, take average for every day i.e., column in our excel sheet and apply function "Average" in formula bar and select the cells that have are present in each column and for every column in entire sheet.

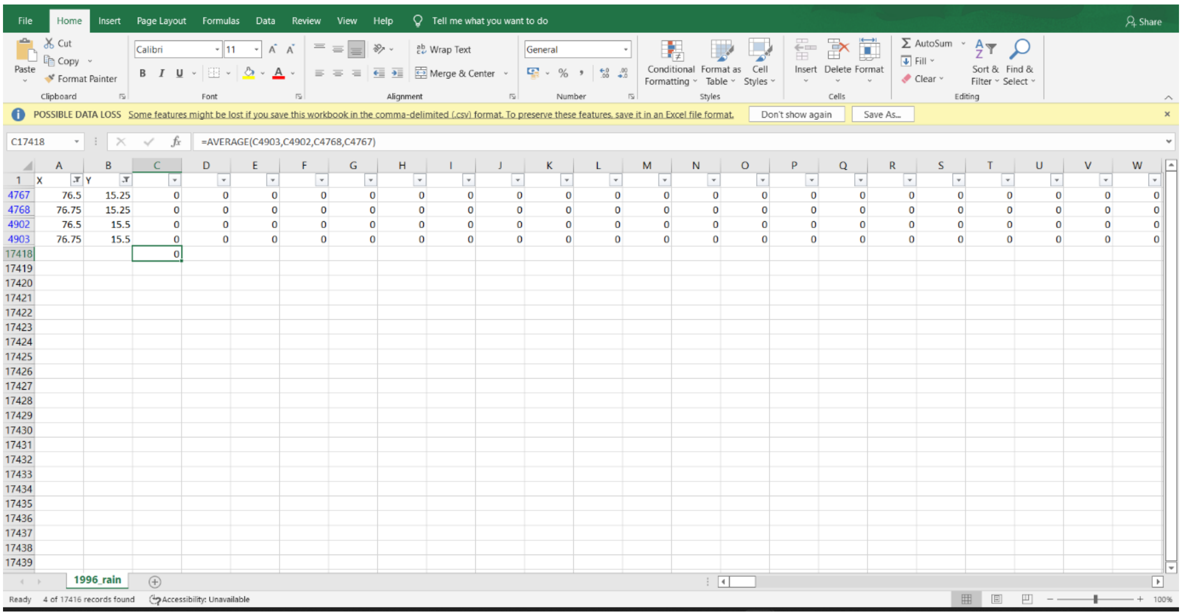


Figure 3. 8.Mean precipitation calculation using formula

- Step 5:

The above 4 steps have to be carried out for every year excel sheet from 1995 to 2020 and create a new excel sheet where all the mean precipitation values for 365 days and 366 days in case of leap year from 25 excel sheets are copy pasted.

3.3.2 Using Macros:

In this method, the manual filtration process is avoided by writing a code to let excel do our filtration of behalf of us and time which is used for manual filtrations have been saved in this method.

- Step 1:

Select 'developer' option present on the ribbon and select 'visual basic' in that tab.

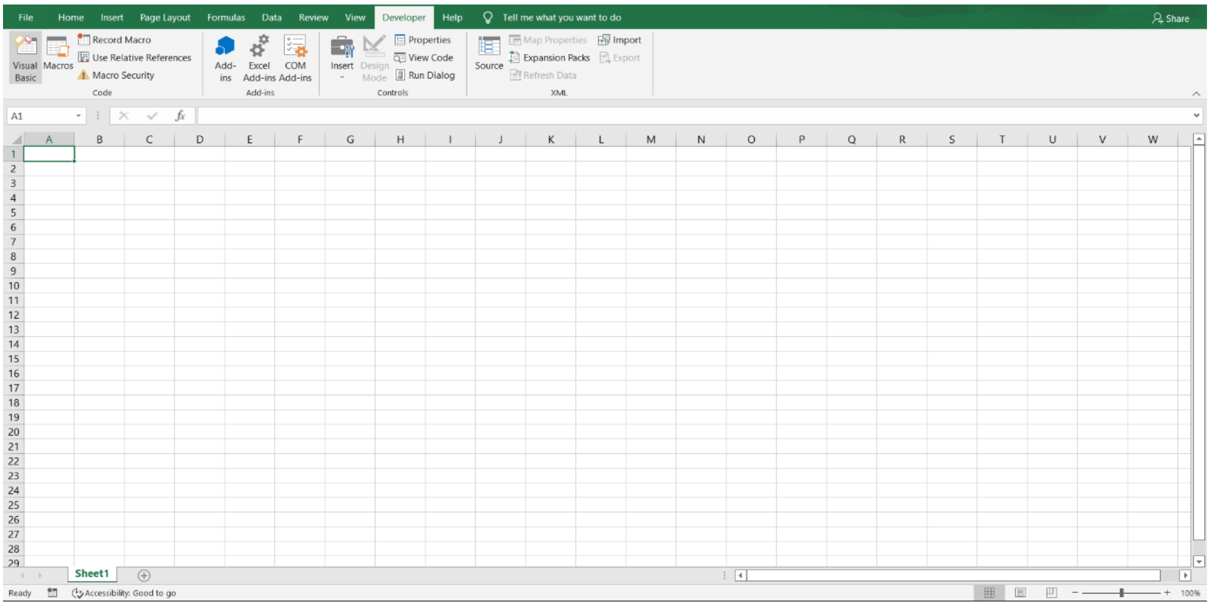


Figure 3. 9. Selecting Visual basic

- Step 2:

Now, we get a window in which we can write a code to perform our required filtration on our data. The code was named 'Macros 2' in our sheet. The entire window can be seen in fig.3.10.

- Step 3:

After writing code, go back to our sheet and select macros in the same developer tab as shown in fig.3.11. Press run on Macros2 and the filtration of data is done.

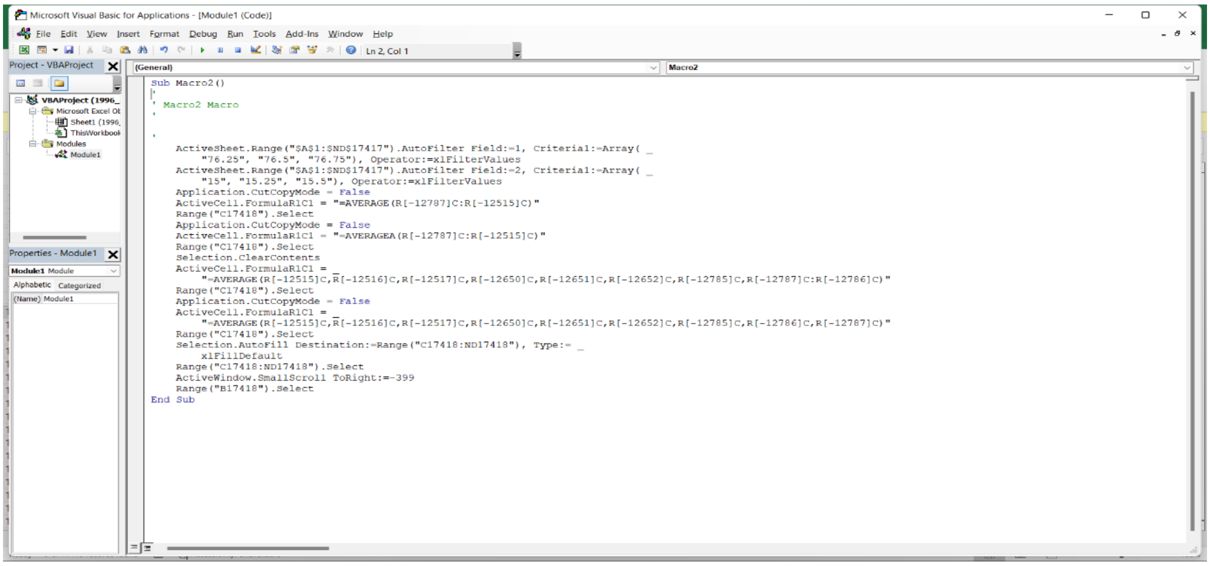


Figure 3. 10. Macros code for filtration of location in our data

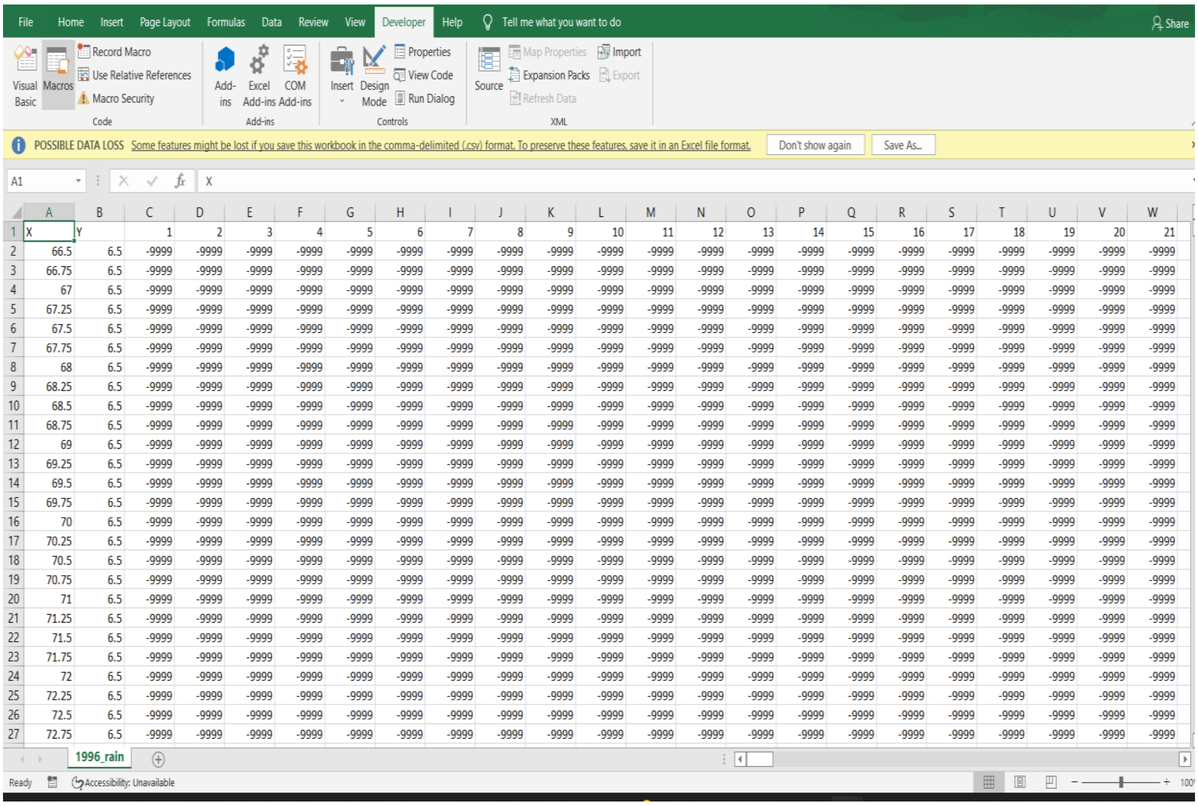


Figure 3. 11. Applying code

- Step 4:

  Now, for every 25 excel sheets, the same code can be used. Open the sheet and apply step 3 and the data will be filtered and step 5 in manual method is to be done as the last step in this method.

<u>3.3.3 using Power query:</u>

In this method, there is no requirement of writing code or doing manually for 25 times i.e., for every sheet. This is the best method in all the three methods which can be done in less time and with no requirement of any code. Filtration of our required location in all 25 excel sheets can be done in one excel sheet.

- Step 1:

  Create a folder consisting of all 25 excel sheets. Create a new excel sheet and select 'Get Data' in 'Data' tab.

- Step 2:

  Now select 'from file' and 'from folder' in drop down options of 'Get data'. Both step 1 and 2 can be seen in fig.3.12.

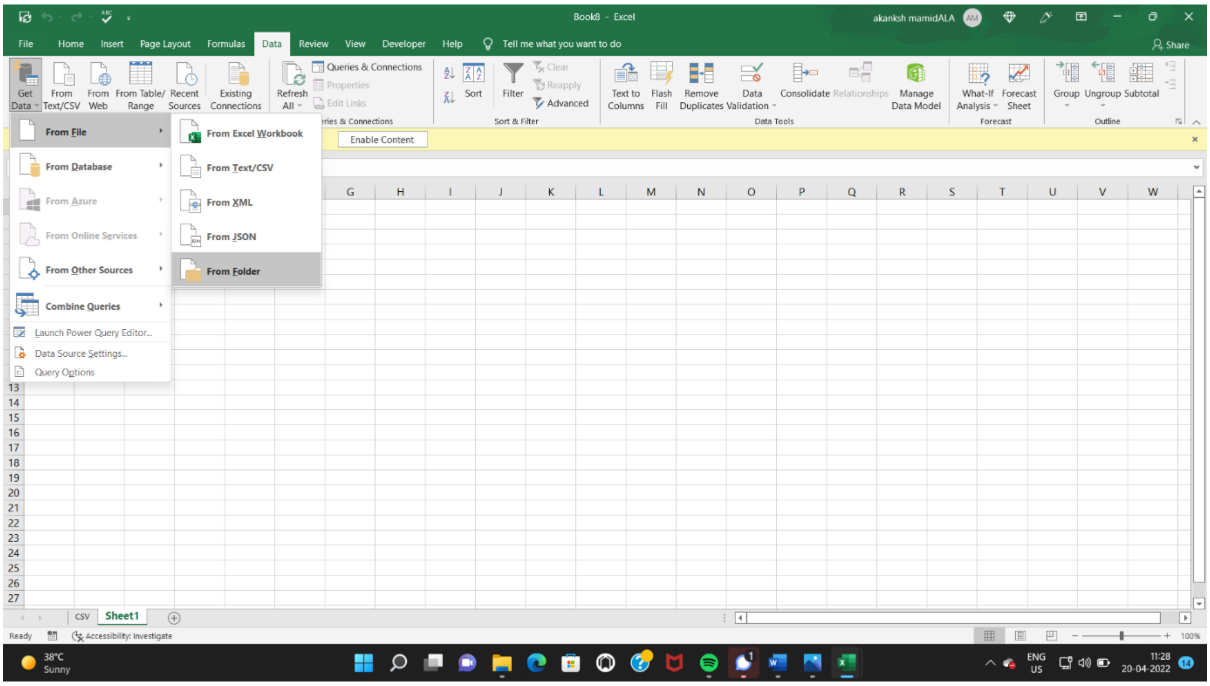


Figure 3. 12. Getting data from folder

- Step 3:

Select the folder which is containing all the 25 excel sheets. After selecting the folder, we get a window as shown in fig.3.13. and select 'combine and transform' option.

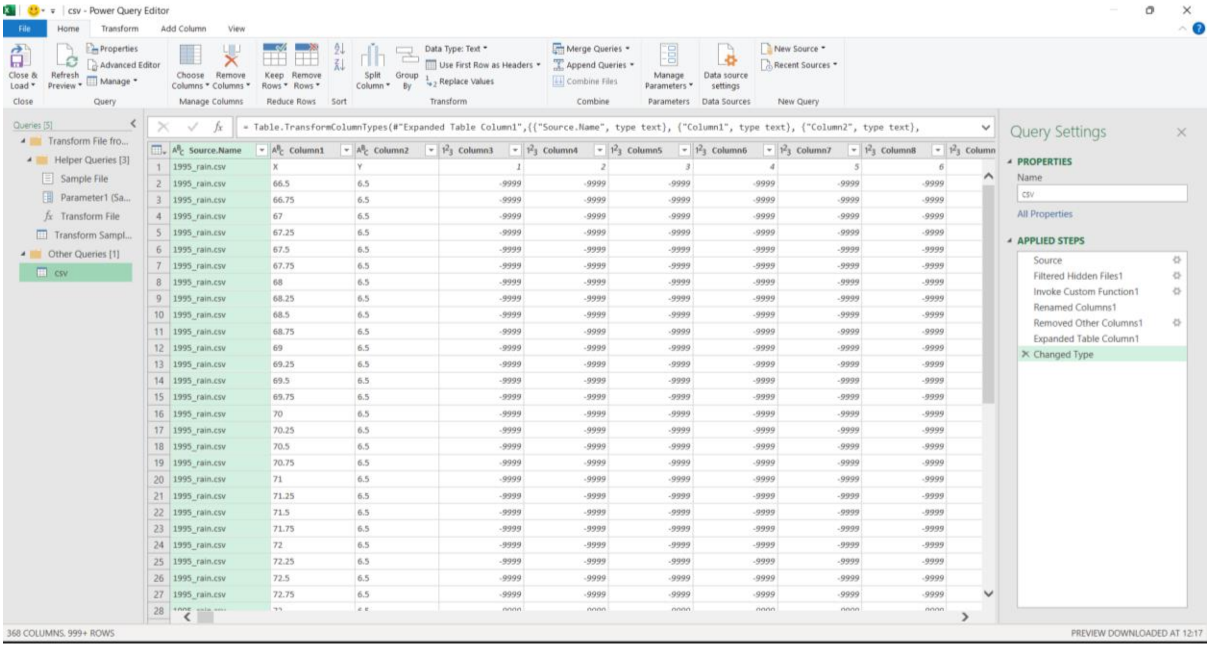


Figure 3. 13.Getting data into power query window

- Step 4:

Power query editor window is opened automatically with all the data from 25 excel sheets.

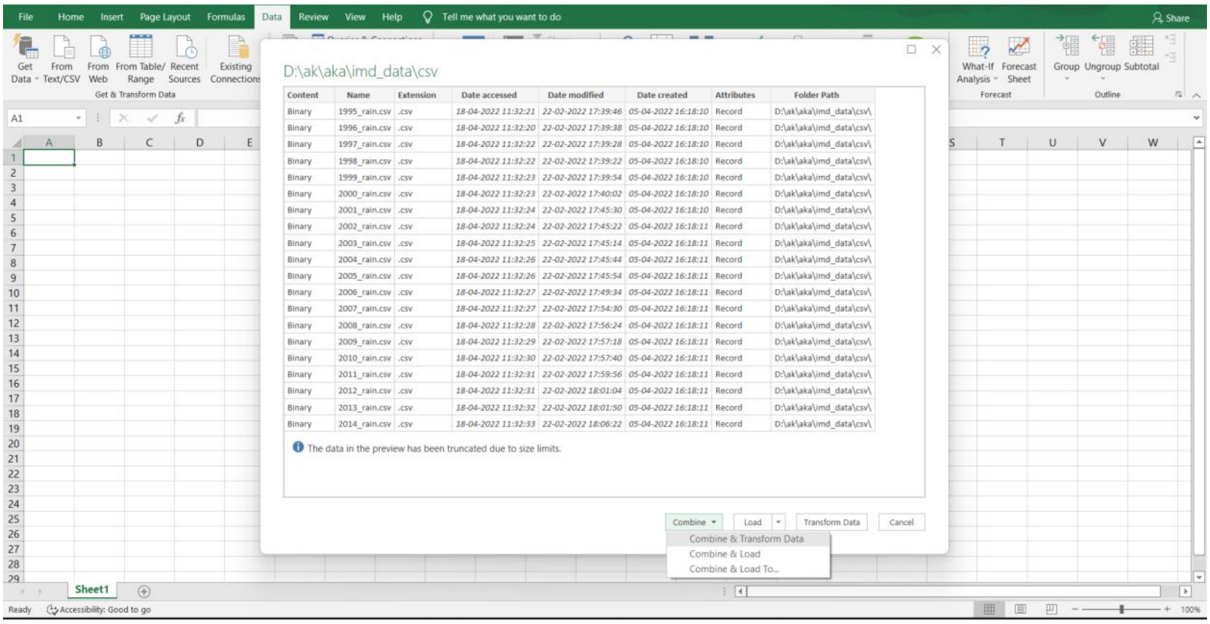


Figure 3. 14. power query editor window

- Step 5:

  The required filtration of our location can be done manually on one sample data in 'Transform Sample File' in Queries section.

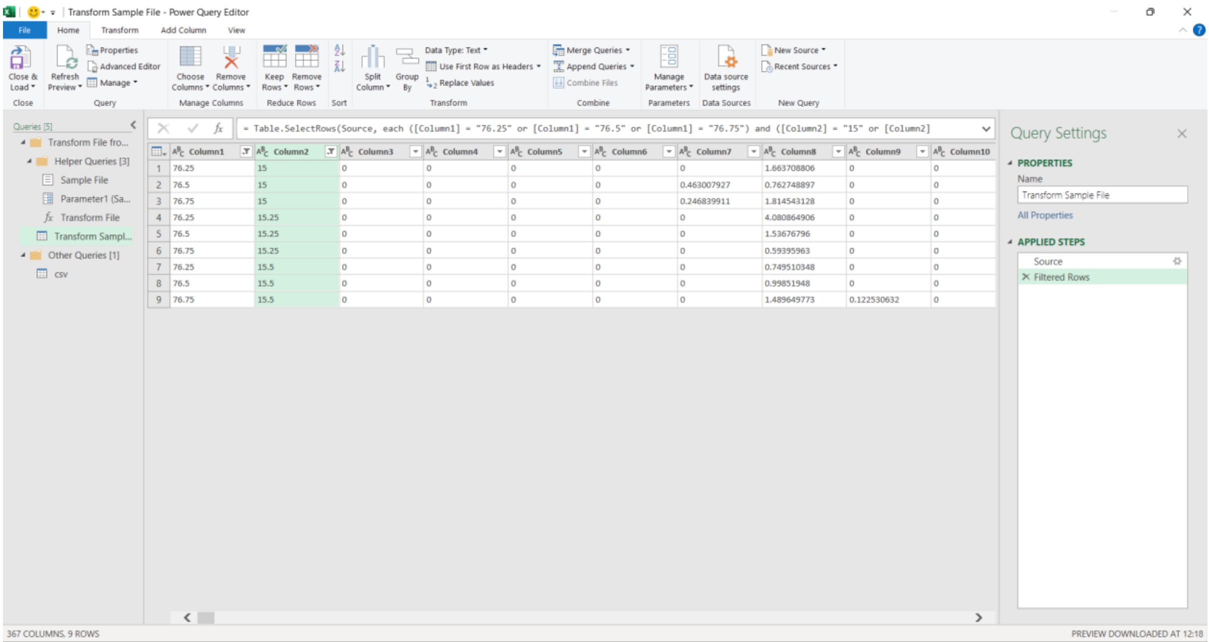


Figure 3. 15.Filtering of our location in sample file

- Step 6:

  Now, when we open csv file in Queries section, we will get the filtration we did for sample file done for all other 24 excel sheets. This step can be seen in fig.3.16

- Step 7:

  As the required filtration is done, we can select 'Close & Load' option in the power query editor and the filtered data will be loaded to our Excel sheet. This step can be seen in fig.3.16. and fig.3.17

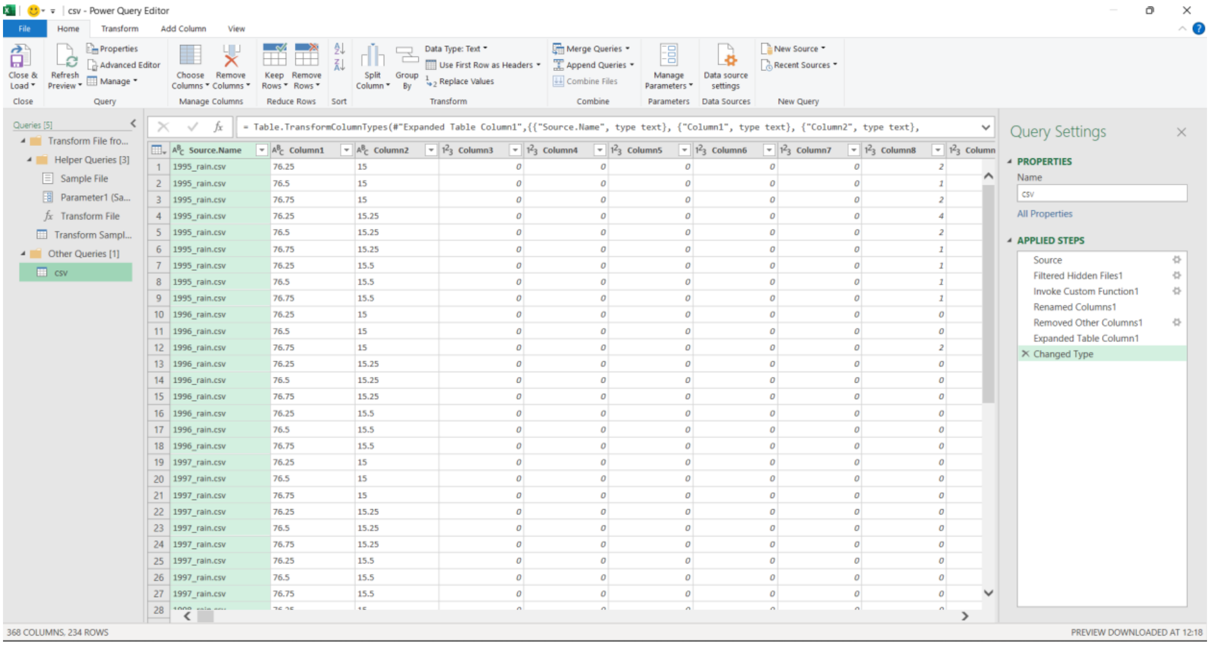


Figure 3. 16. Filtered data of 25 sheets in power query editor

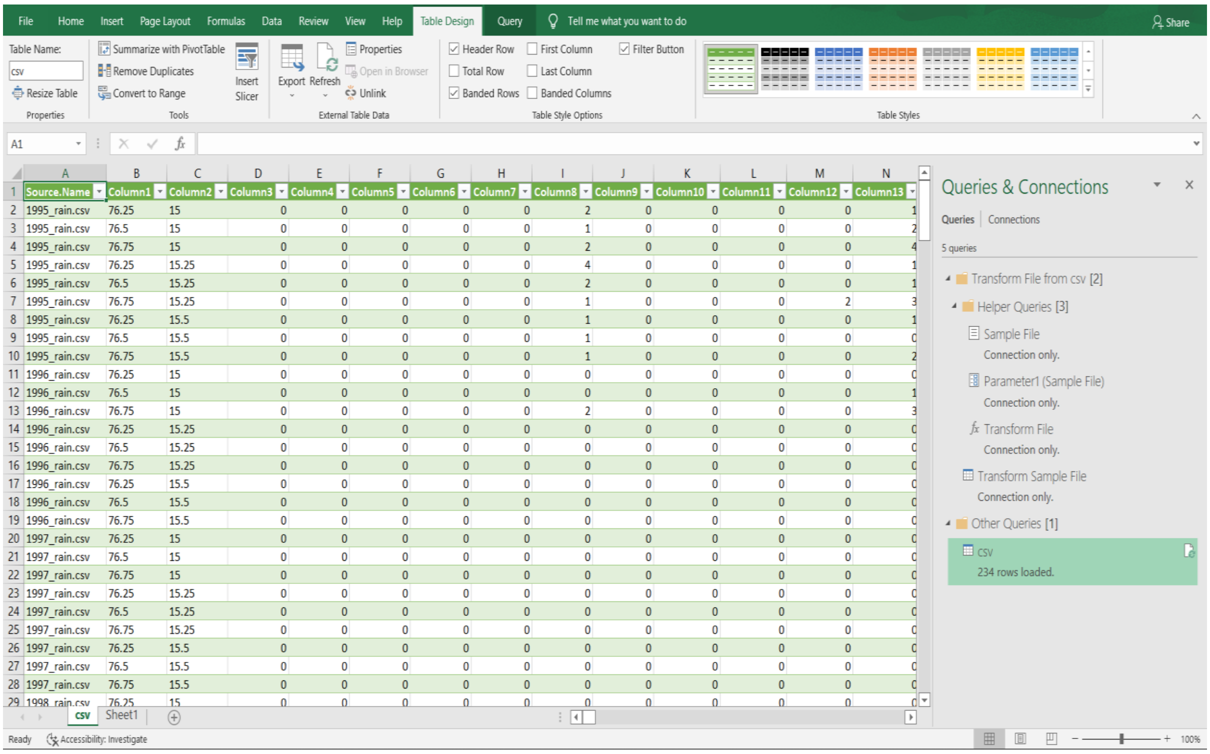
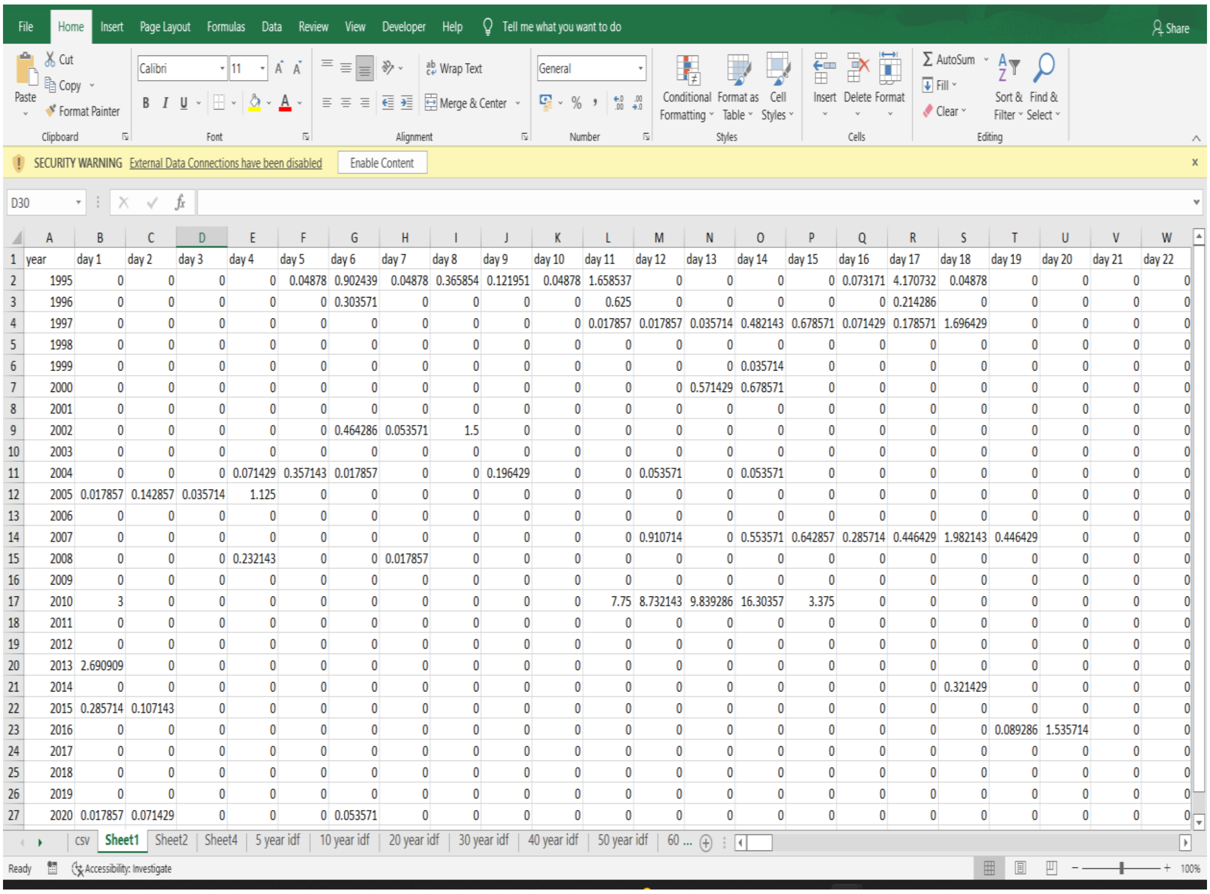


Figure 3. 17. Loading of filtered data to excel sheet

- Step 8:

  The mean precipitation is calculated as same as in manual method and step 5 of manual method is to be performed as the last step in this method.

Due to requirement of less time and no requirement of any code applying in 25 different excel sheets, power query method is selected and the output of every method will be same which is a excel sheet of mean precipitation values of our location for 365 days in a normal year and 366 days in a leap year for every year from 1995 to 2020. The output can be seen in fig.3.18.



	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W
1	year	day 1	day 2	day 3	day 4	day 5	day 6	day 7	day 8	day 9	day 10	day 11	day 12	day 13	day 14	day 15	day 16	day 17	day 18	day 19	day 20	day 21	day 22
2	1995	0	0	0	0	0.04878	0.902439	0.04878	0.365854	0.121951	0.04878	1.658537	0	0	0	0	0.073171	4.170732	0.04878	0	0	0	0
3	1996	0	0	0	0	0	0.303571	0	0	0	0	0.625	0	0	0	0	0	0.214286	0	0	0	0	0
4	1997	0	0	0	0	0	0	0	0	0	0	0.017857	0.017857	0.035714	0.482143	0.678571	0.071429	0.178571	1.696429	0	0	0	0
5	1998	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6	1999	0	0	0	0	0	0	0	0	0	0	0	0	0	0.035714	0	0	0	0	0	0	0	0
7	2000	0	0	0	0	0	0	0	0	0	0	0	0	0.571429	0.678571	0	0	0	0	0	0	0	0
8	2001	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9	2002	0	0	0	0	0	0.464286	0.053571	1.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10	2003	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11	2004	0	0	0	0.071429	0.357143	0.017857	0	0	0.196429	0	0	0.053571	0	0.053571	0	0	0	0	0	0	0	0
12	2005	0.017857	0.142857	0.035714	1.125	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
13	2006	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
14	2007	0	0	0	0	0	0	0	0	0	0	0	0.910714	0	0.553571	0.642857	0.285714	0.446429	1.982143	0.446429	0	0	0
15	2008	0	0	0	0.232143	0	0	0.017857	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
16	2009	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
17	2010	3	0	0	0	0	0	0	0	0	0	7.75	8.732143	9.839286	16.30357	3.375	0	0	0	0	0	0	0
18	2011	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
19	2012	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
20	2013	2.690909	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
21	2014	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.321429	0	0	0	0
22	2015	0.285714	0.107143	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
23	2016	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.089286	1.535714	0	0
24	2017	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
25	2018	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
26	2019	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
27	2020	0.017857	0.071429	0	0	0	0.053571	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Figure 3. 18. Mean precipitation values of our location for 25 years

3.4. Analysing data:

Now, for analysis, we need to create a annual maximus series rainfall that means we need to find the maximum 24 hours rainfall data from 366 days for each year and as we are constructing IDF curves for 0.25 hr, 0.5 hr, 1 hr,2 hr, 3 hr, 4 hr, 5 hr, 6 hr, 7 hr, 8 hr , 9 hr, 10 hr, 11 hr, 12 hr,13 hr,14 hr, 15 hr, 16 hr, 17 hr, 18 hr, 19 hr, 20 hr, 21 hr,22 hr, 23 hr maximum series is obtained by using IMD reduction formula and then Gumbel's probability distribution is fitted to each of the maximum series dataset of different durations and rainfall intensities are calculated.

3.4.1 Creating maximum data series and calculating rainfall intensities for all durations and return periods:

- Step 1:

  Find maximum rainfall value for 366 days for each year from 1995 to 2020 by using 'MAX' function in excel sheet.

- Step 2:

  We are ready with annual maximum 24 hours rainfall data for every year and in this step, annual maximum series of 0.25 hr, 0.5 hr, 1 hr,2 hr, 3 hr, 4 hr, 5 hr, 6 hr, 7 hr, 8 hr, 9 hr, 10 hr, 11 hr, 12 hr,13 hr,14 hr, 15 hr, 16 hr, 17 hr, 18 hr, 19 hr, 20 hr, 21 hr,22 hr, 23 hr duration rainfall data is created using IMD reduction formula which is

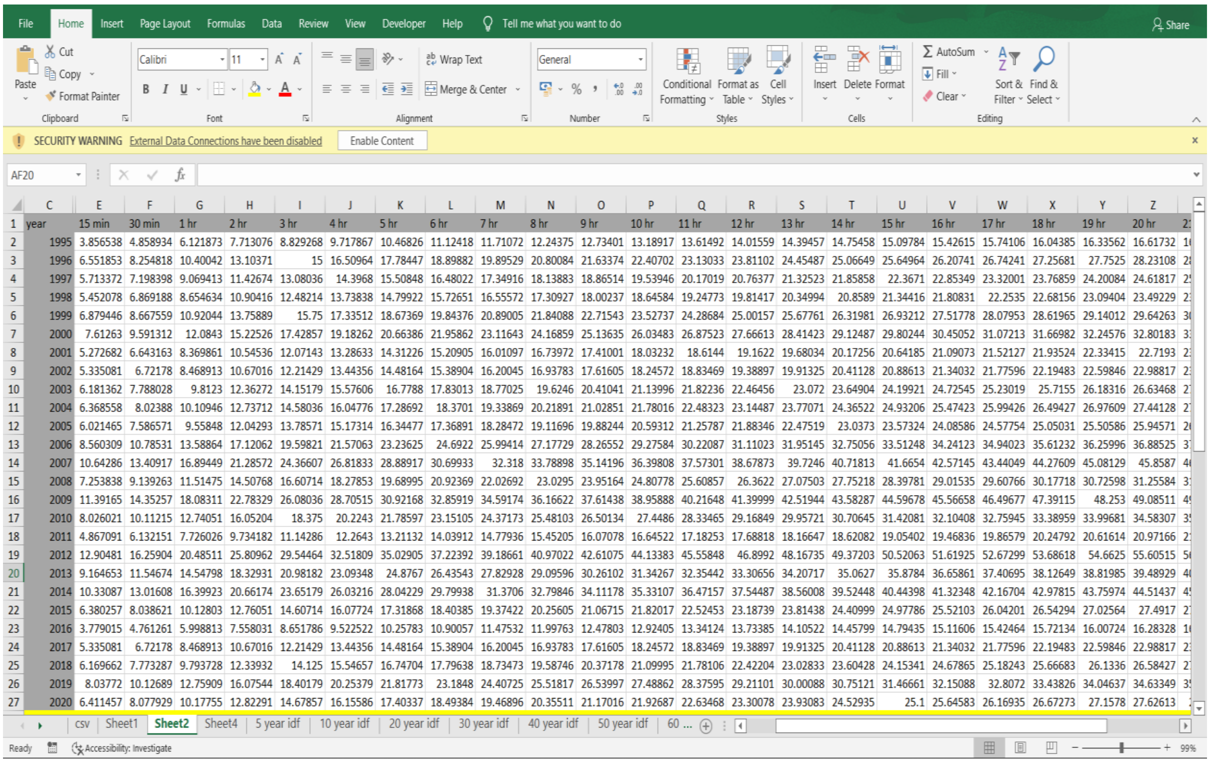
$$Pt = P24 \times \sqrt[3]{\left(\frac{t}{24}\right)}. \tag{3.1}$$

Where Pt = Rainfall for t hr duration in mm,

P24 = max 24 hr rainfall in mm,

t = Duration in hrs.

After applying of the above formula, we are ready with annual maximum series of 0.25 hr, 0.5 hr, 1 hr,2 hr, 3 hr, 4 hr, 5 hr, 6 hr, 7 hr, 8 hr, 9 hr, 10 hr, 11 hr, 12 hr,13 hr,14 hr, 15 hr, 16 hr, 17 hr, 18 hr, 19 hr, 20 hr, 21 hr,22 hr, 23 hr, 24 hr rainfall data as shown in fig.3.19.



year	15 min	30 min	1 hr	2 hr	3 hr	4 hr	5 hr	6 hr	7 hr	8 hr	9 hr	10 hr	11 hr	12 hr	13 hr	14 hr	15 hr	16 hr	17 hr	18 hr	19 hr	20 hr
1995	3.856538	4.858934	6.121873	7.713076	8.829268	9.717867	10.46826	11.12418	11.71072	12.24375	12.73401	13.18917	13.61492	14.01559	14.39457	14.75458	15.09784	15.42615	15.74106	16.04385	16.33562	16.61732
1996	6.551853	8.254818	10.40042	13.10371	15	16.50964	17.78447	18.89882	19.89529	20.80084	21.63374	22.40702	23.13033	23.81102	24.45487	25.06649	25.64964	26.20741	26.74241	27.25681	27.7525	28.23108
1997	5.713372	7.198398	9.069413	11.42674	13.08036	14.3968	15.50848	16.48022	17.34916	18.13883	18.86514	19.53946	20.17019	20.76377	21.32523	21.85858	22.3671	22.85349	23.32001	23.76859	24.20084	24.61817
1998	5.452078	6.869188	8.654634	10.90416	12.48214	13.73838	14.79922	15.72651	16.55572	17.30927	18.00237	18.64584	19.24773	19.81417	20.34994	20.8589	21.34416	21.80831	22.2535	22.68156	23.09404	23.49229
1999	6.879446	8.667559	10.92044	13.75889	15.75	17.33512	18.67369	19.84376	20.89005	21.84088	22.71543	23.52737	24.28684	25.00157	25.67761	26.31981	26.93212	27.51778	28.07953	28.61965	29.14012	29.64263
2000	7.61263	9.591312	12.0843	15.22526	17.42857	19.18262	20.66386	21.95862	23.11643	24.16859	25.13635	26.03483	26.87523	27.66613	28.41423	29.12487	29.80244	30.45052	31.07213	31.66982	32.24576	32.80183
2001	5.272682	6.643163	8.369861	10.54536	12.07143	13.28633	14.31226	15.20905	16.01097	16.73972	17.41001	18.03232	18.6144	19.1622	19.68034	20.17256	20.64185	21.09073	21.52127	21.93524	22.33415	22.7193
2002	5.335081	6.72178	8.468913	10.67016	12.21429	13.44356	14.48164	15.38904	16.20045	16.93783	17.61605	18.24572	18.83469	19.38897	19.91325	20.41128	20.88613	21.34032	21.77596	22.19483	22.59846	22.98817
2003	6.181362	7.788028	9.8123	12.36272	14.15179	15.57606	16.7788	17.83013	18.77025	19.6246	20.41041	21.13996	21.82236	22.46456	23.072	23.64904	24.19921	24.72545	25.23019	25.7155	26.18316	26.63468
2004	6.368558	8.02388	10.10946	12.73712	14.58036	16.04776	17.28692	18.3701	19.33869	20.21891	21.02851	21.78016	22.48323	23.14487	23.77071	24.36522	24.93206	25.47423	25.99426	26.49427	26.97609	27.44128
2005	6.021465	7.586571	9.55848	12.04293	13.78571	15.17314	16.34477	17.36891	18.28472	19.11696	19.88244	20.59312	21.25787	21.88346	22.47519	23.0373	23.57324	24.08586	24.57754	25.05031	25.50586	25.94571
2006	8.560309	10.78531	13.58864	17.12062	19.59821	21.57063	23.23625	24.6922	25.99414	27.17729	28.26552	29.27584	30.22087	31.11023	31.95145	32.75056	33.51248	34.24123	34.94023	35.61232	36.25996	36.88525
2007	10.64286	13.40917	16.89449	21.28572	24.36607	26.81833	28.88917	30.69933	32.318	33.78898	35.14196	36.39808	37.57301	38.67873	39.7246	40.71813	41.6654	42.57145	43.44049	44.27609	45.08129	45.8587
2008	7.253838	9.139263	11.51475	14.50768	16.60714	18.27853	19.68995	20.92369	22.02692	23.0295	23.95164	24.80778	25.60857	26.3622	27.07503	27.75218	28.39781	29.01535	29.60766	30.17718	30.72598	31.25584
2009	11.39165	14.35257	18.08311	22.78329	26.08036	28.70515	30.92168	32.85919	34.59174	36.16622	37.61438	38.95888	40.21648	41.39999	42.51944	43.58287	44.59678	45.56658	46.49677	47.39115	48.253	49.08511
2010	8.026021	10.11215	12.74051	16.05204	18.375	20.2243	21.78597	23.15105	24.37173	25.48103	26.50134	27.4486	28.33465	29.16849	29.95721	30.70645	31.42081	32.10408	32.75945	33.38959	33.99681	34.58307
2011	4.867091	6.132151	7.726026	9.734182	11.14286	12.2643	13.21132	14.03912	14.77936	15.45205	16.07078	16.64522	17.18253	17.68818	18.16647	18.62082	19.05402	19.46836	19.86579	20.24792	20.61614	20.97166
2012	12.90481	16.25904	20.48511	25.80962	29.54464	32.51809	35.02905	37.22392	39.18661	40.97022	42.61075	44.13383	45.55848	46.8992	48.16735	49.37203	50.52063	51.61925	52.67299	53.68618	54.6625	55.60515
2013	9.164653	11.54674	14.54798	18.32931	20.98182	23.09348	24.8767	26.43543	27.82928	29.09596	30.26102	31.34267	32.35442	33.30656	34.20717	35.0627	35.8784	36.65861	37.40695	38.12649	38.81985	39.48929
2014	10.33087	13.01608	16.39923	20.66174	23.65179	26.03216	28.04229	29.79938	31.3706	32.79846	34.11178	35.33107	36.47157	37.54487	38.56008	39.52448	40.44398	41.32348	42.16704	42.97815	43.75974	44.51437
2015	6.380257	8.038621	10.12803	12.76051	14.60714	16.07724	17.31868	18.40385	19.37422	20.25605	21.06715	21.82017	22.52453	23.18739	23.81438	24.40999	24.97786	25.52103	26.04201	26.54294	27.02564	27.4917
2016	3.779015	4.761261	5.998813	7.558031	8.651786	9.522522	10.25783	10.90057	11.47532	11.99763	12.47803	12.92405	13.34124	13.73385	14.10522	14.45799	14.79435	15.11606	15.42464	15.72134	16.00724	16.28328
2017	5.335081	6.72178	8.468913	10.67016	12.21429	13.44356	14.48164	15.38904	16.20045	16.93783	17.61605	18.24572	18.83469	19.38897	19.91325	20.41128	20.88613	21.34032	21.77596	22.19483	22.59846	22.98817
2018	6.169662	7.773287	9.793728	12.33932	14.125	15.54657	16.74704	17.79638	18.73473	19.58746	20.37178	21.09995	21.78106	22.42204	23.02833	23.60428	24.15341	24.67865	25.18243	25.66683	26.1336	26.58427
2019	8.03772	10.12689	12.75909	16.07544	18.40179	20.25379	21.81773	23.1848	24.40725	25.51817	26.53997	27.48862	28.37595	29.21101	30.00088	30.75121	31.46661	32.15088	32.8072	33.43826	34.04637	34.63349
2020	6.411457	8.077929	10.17755	12.82291	14.67857	16.15586	17.40337	18.49384	19.46896	20.35511	21.17016	21.92687	22.63468	23.30078	23.93083	24.52935	25.1	25.64583	26.16935	26.67273	27.1578	27.62613

Figure 3. 19.Annual maximum data series of rainfall data.

- Step 3:

Now, Gumbel's probability distribution is fitted to all annual maximum data sets. For that, Gumbel's constants are to be found out.

a. Mode of distribution (u):

This is based on mean and standard deviations of the datasets.

$$u = \text{mean} - 0.5772\alpha \quad (3.2)$$

Where mean is statistical mean of given dataset

α is mode of sample moments of given dataset.

b. Mode of sample moments(α):

This is based on only the standard deviation of given dataset.

$$\alpha = \left(\frac{\sqrt{6}}{\pi}\right)\sigma \quad (3.3)$$

Where σ is standard deviation of given dataset.

c. Reduced variate(y_T):

This depends on return period.

$$y_T = -\ln(\ln(\frac{T}{T-1})) \quad (3.4)$$

Where T is return period or frequency.

d. Rainfall (X_t):

Using above three constants, rainfall is obtained in millimetres.

$$X_t = u + \alpha y_T \quad (3.5)$$

Where X_t is rainfall in mm,

u is mode of distribution,

α is mode of sample moments,

y_T is reduced variate.

e. Rainfall intensity(i):

It is obtained by dividing rainfall with duration of rainfall.

$$i = \frac{X_t}{t} \quad (3.6)$$

Where X_t is rainfall in mm,

i is rainfall intensity in mm/hr,

t is duration in hours.

y_T values are calculated for every return period 5, 10, 20, 30, 40, 50, 60, 70, 80, 90 and 100 years.

Table.3.1 y_T values for every return period.

Return period	5	10	20	30	40	50	60	70	80	90	100
y_T values	1.500	2.250	2.970	3.384	3.676	3.902	4.086	4.241	4.376	4.494	4.600

As u and α depends on mean and standard deviation of dataset, u and α values will be different for each annual maximum series data and is shown below

Table 3. 1. Statistical values of Gumbel's distribution part 1

year	15 min	30 min	1 hr	2 hr	3 hr	4 hr	5 hr	6 hr
1995	3.857	4.859	6.122	7.713	8.829	9.718	10.468	11.124
1996	6.552	8.255	10.400	13.104	15.000	16.510	17.784	18.899
1997	5.713	7.198	9.069	11.427	13.080	14.397	15.508	16.480
1998	5.452	6.869	8.655	10.904	12.482	13.738	14.799	15.727
1999	6.879	8.668	10.920	13.759	15.750	17.335	18.674	19.844
2000	7.613	9.591	12.084	15.225	17.429	19.183	20.664	21.959
2001	5.273	6.643	8.370	10.545	12.071	13.286	14.312	15.209
2002	5.335	6.722	8.469	10.670	12.214	13.444	14.482	15.389
2003	6.181	7.788	9.812	12.363	14.152	15.576	16.779	17.830
2004	6.369	8.024	10.109	12.737	14.580	16.048	17.287	18.370
2005	6.021	7.587	9.558	12.043	13.786	15.173	16.345	17.369
2006	8.560	10.785	13.589	17.121	19.598	21.571	23.236	24.692
2007	10.643	13.409	16.894	21.286	24.366	26.818	28.889	30.699
2008	7.254	9.139	11.515	14.508	16.607	18.279	19.690	20.924
2009	11.392	14.353	18.083	22.783	26.080	28.705	30.922	32.859
2010	8.026	10.112	12.741	16.052	18.375	20.224	21.786	23.151
2011	4.867	6.132	7.726	9.734	11.143	12.264	13.211	14.039
2012	12.905	16.259	20.485	25.810	29.545	32.518	35.029	37.224
2013	9.165	11.547	14.548	18.329	20.982	23.093	24.877	26.435
2014	10.331	13.016	16.399	20.662	23.652	26.032	28.042	29.799
2015	6.380	8.039	10.128	12.761	14.607	16.077	17.319	18.404
2016	3.779	4.761	5.999	7.558	8.652	9.523	10.258	10.901
2017	5.335	6.722	8.469	10.670	12.214	13.444	14.482	15.389
2018	6.170	7.773	9.794	12.339	14.125	15.547	16.747	17.796
2019	8.038	10.127	12.759	16.075	18.402	20.254	21.818	23.185
2020	6.411	8.078	10.178	12.823	14.679	16.156	17.403	18.494
mean	7.096	8.941	11.264	14.192	16.246	17.881	19.262	20.469
std dev	2.272	2.862	3.606	4.543	5.201	5.724	6.166	6.553
α	1.772	2.232	2.813	3.544	4.0571	4.465	4.8102	5.111
u	6.073	7.651	9.640	12.146	13.904	15.303	16.485	17.518

Table 3.2. Statistical values of Gumbel's distribution part 2

Year	7 hr	8 hr	9 hr	10 hr	11 hr	12 hr	13 hr	14 hr
1995	11.711	12.244	12.734	13.189	13.615	14.016	14.395	14.755
1996	19.895	20.801	21.634	22.407	23.130	23.811	24.455	25.066
1997	17.349	18.139	18.865	19.539	20.170	20.764	21.325	21.859
1998	16.556	17.309	18.002	18.646	19.248	19.814	20.350	20.859
1999	20.890	21.841	22.715	23.527	24.287	25.002	25.678	26.320
2000	23.116	24.169	25.136	26.035	26.875	27.666	28.414	29.125
2001	16.011	16.740	17.410	18.032	18.614	19.162	19.680	20.173
2002	16.200	16.938	17.616	18.246	18.835	19.389	19.913	20.411
2003	18.770	19.625	20.410	21.140	21.822	22.465	23.072	23.649
2004	19.339	20.219	21.029	21.780	22.483	23.145	23.771	24.365
2005	18.285	19.117	19.882	20.593	21.258	21.883	22.475	23.037
2006	25.994	27.177	28.266	29.276	30.221	31.110	31.951	32.751
2007	32.318	33.789	35.142	36.398	37.573	38.679	39.725	40.718
2008	22.027	23.029	23.952	24.808	25.609	26.362	27.075	27.752
2009	34.592	36.166	37.614	38.959	40.216	41.400	42.519	43.583
2010	24.372	25.481	26.501	27.449	28.335	29.168	29.957	30.706
2011	14.779	15.452	16.071	16.645	17.183	17.688	18.166	18.621
2012	39.187	40.970	42.611	44.134	45.558	46.899	48.167	49.372
2013	27.829	29.096	30.261	31.343	32.354	33.307	34.207	35.063
2014	31.371	32.798	34.112	35.331	36.472	37.545	38.560	39.524
2015	19.374	20.256	21.067	21.820	22.525	23.187	23.814	24.410
2016	11.475	11.998	12.478	12.924	13.341	13.734	14.105	14.458
2017	16.200	16.938	17.616	18.246	18.835	19.389	19.913	20.411
2018	18.735	19.587	20.372	21.100	21.781	22.422	23.028	23.604
2019	24.407	25.518	26.540	27.489	28.376	29.211	30.001	30.751
2020	19.469	20.355	21.170	21.927	22.635	23.301	23.931	24.529
Mean	21.548	22.529	23.431	24.269	25.052	25.789	26.487	27.149
std dev	6.898	7.212	7.501	7.769	8.020	8.256	8.479	8.691
A	5.381	5.626	5.851	6.061	6.256	6.440	6.614	6.780
U	18.442	19.282	20.054	20.770	21.441	22.072	22.669	23.236

Table 3. 3.Statistical values of Gumbel's distribution part 3

year	15 hr	16 hr	17 hr	18 hr	19 hr	20 hr	21 hr	22 hr	23 hr	24 hr
1995	15.098	15.426	15.741	16.044	16.336	16.617	16.890	17.154	17.410	17.659
1996	25.650	26.207	26.742	27.257	27.752	28.231	28.694	29.142	29.577	30.000
1997	22.367	22.853	23.320	23.769	24.201	24.618	25.022	25.413	25.792	26.161
1998	21.344	21.808	22.254	22.682	23.094	23.492	23.877	24.251	24.613	24.964
1999	26.932	27.518	28.080	28.620	29.140	29.643	30.129	30.600	31.056	31.500
2000	29.802	30.451	31.072	31.670	32.246	32.802	33.340	33.861	34.366	34.857
2001	20.642	21.091	21.521	21.935	22.334	22.719	23.092	23.453	23.803	24.143
2002	20.886	21.340	21.776	22.195	22.598	22.988	23.365	23.730	24.084	24.429
2003	24.199	24.725	25.230	25.716	26.183	26.635	27.071	27.494	27.905	28.304
2004	24.932	25.474	25.994	26.494	26.976	27.441	27.891	28.327	28.750	29.161
2005	23.573	24.086	24.578	25.050	25.506	25.946	26.371	26.783	27.183	27.571
2006	33.512	34.241	34.940	35.612	36.260	36.885	37.490	38.076	38.644	39.196
2007	41.665	42.571	43.440	44.276	45.081	45.859	46.611	47.339	48.046	48.732
2008	28.398	29.015	29.608	30.177	30.726	31.256	31.768	32.265	32.746	33.214
2009	44.597	45.567	46.497	47.391	48.253	49.085	49.890	50.670	51.426	52.161
2010	31.421	32.104	32.759	33.390	33.997	34.583	35.150	35.699	36.232	36.750
2011	19.054	19.468	19.866	20.248	20.616	20.972	21.316	21.649	21.972	22.286
2012	50.521	51.619	52.673	53.686	54.663	55.605	56.517	57.400	58.257	59.089
2013	35.878	36.659	37.407	38.126	38.820	39.489	40.137	40.764	41.373	41.964
2014	40.444	41.323	42.167	42.978	43.760	44.514	45.244	45.951	46.637	47.304
2015	24.978	25.521	26.042	26.543	27.026	27.492	27.942	28.379	28.803	29.214
2016	14.794	15.116	15.425	15.721	16.007	16.283	16.550	16.809	17.060	17.304
2017	20.886	21.340	21.776	22.195	22.598	22.988	23.365	23.730	24.084	24.429
2018	24.153	24.679	25.182	25.667	26.134	26.584	27.020	27.442	27.852	28.250
2019	31.467	32.151	32.807	33.438	34.046	34.633	35.201	35.751	36.285	36.804
2020	25.100	25.646	26.169	26.673	27.158	27.626	28.079	28.518	28.944	29.357
mean	27.781	28.385	28.964	29.521	30.058	30.576	31.078	31.563	32.035	32.492
std dev	8.893	9.087	9.272	9.451	9.622	9.788	9.949	10.104	10.255	10.402
α	6.938	7.088	7.233	7.372	7.506	7.636	7.761	7.882	8.000	8.114
u	23.776	24.293	24.789	25.266	25.725	26.169	26.598	27.014	27.417	27.809

- Step 4:

  From Gumbel's constants, we can now calculate intensity values for respective annual maximum data series of different durations (0.25 hr, 0.5 hr, 1 hr,2 hr, 3 hr, 4 hr, 5 hr, 6 hr, 7 hr, 8 hr , 9 hr, 10 hr, 11 hr, 12 hr,13 hr,14 hr, 15 hr, 16 hr, 17 hr, 18 hr, 19 hr, 20 hr, 21 hr,22 hr, 23 hr, 24 hr) and for different return periods (5, 10, 20, 30, 40, 50, 60, 70, 80, 90 and 100 years).

3.4.2 Construction of IDF curve:

For every return period, rainfall intensities and duration of rainfall are plotted on Y-axis and X-axis respectively. These curves are 'IDF (Intensity-Duration-frequency) curves'. As we had selected 11 return periods (5, 10, 20, 30, 40, 50, 60, 70, 80, 90 and 100 years), we had generated 11 IDF curves which can be seen in Results & Discussions chapter (Chapter 4).

3.5 Calculating Discharge from intensity values of each return period:

Rational method is used to find the discharge that is getting to the hydropower plant for generating electricity.

$$Q = CiA \tag{3.7}$$

Where Q is discharge in m^3/sec,

C is coefficient of runoff,

i is rainfall intensity in mm/hr,

A is area of catchment in km^2.

a. Rainfall intensity(i):

   The rainfall intensity values are taken from the IDF curves constructed for each return period. For every return period, maximum intensity is used as we are calculating the maximum discharge that can be received by the hydropower plant.

b. Area(A):

   As Rational method is used to calculate the discharge, the area is to be less than 50 km^2 whereas our area is 232 km^2. So, they are was divided into 5 areas of 50, 50, 50, 50 and 32 km^2 separate catchment areas and discharge was calculated for each of the 5 areas and later all the discharges were combined to get the maximum discharge which is available for hydropower plant to generate electricity.

c. Coefficient of runoff (C):

Coefficient of runoff values of a catchment area depends on the texture of land, slope of the surface area and vegetative cover of that particular area. Coefficient of runoff values for different textures and vegetative covers can be seen in fig.3.20.

Sl. No	Vegetative cover and Slope (%)		Soil Texture		
			Sandy Loam	Clay and Silty Loam	Stiff Clay
1	Cultivated Land				
		0–5	0.30	0.50	0.60
		5–10	0.40	0.60	0.70
		10–30	0.52	0.72	0.82
2	Pasture Land				
		0–5	0.10	0.30	0.40
		5–10	0.16	0.36	0.55
		10–30	0.22	0.42	0.60
3	Forest Land				
		0–5	0.10	0.30	0.40
		5–10	0.25	0.35	0.50
		10–30	0.30	0.50	0.60

Figure 3. 20. Values of coefficient of runoff (Source: Engineering Hydrology)

3 Coefficient of runoff values are considered for 5 areas by assuming their soil texture and vegetative cover to be true for entire selected area.

For 82 km^2 area,

Soil texture – sandy loam

Slope (%) – 0-5

Vegetative cover – pasture land.

Coefficient of runoff – 0.1

For 100 km^2 area,

Soil texture – clay and silty loam

Slope (%) – 0-5

Vegetative cover – cultivated land

Coefficient of runoff – 0.3

For 50 km^2 area,

Soil texture – clay and silty loam

Slope (%) – 0-5

Vegetative cover – cultivated land

Coefficient of runoff – 0.5.

The total discharge that is available for the hydropower plant is calculated for each return period by using rational method and are given in table.

Return period in years	Discharge in m3/sec
100	948.355
90	935.842
80	921.844
70	905.961
60	887.607
50	865.868
40	839.204
30	804.712
20	755.790
10	670.748
5	582.092

Table 3. 4. discharge for each return period.

3.6. Hydropower Potential:

The hydropower potential of the Sugur hydropower plant is estimated for each return period by using

$$P = egQH \tag{3.8}$$

Where P is Power in KW,

e is Efficiency of turbine,

g is Gravity in m^2/sec,

Q is Discharge in m^3/sec,

H is Head of turbine.

Efficiency of the turbine is assumed as 65 %, the head is obtained from Bhoruka power corporation limited official website which is 6.2 m, gravity is taken as 9.8 m^2/sec and the discharge values are taken from table 3.5. for each return period

The hydropower potential of Sugur hydropower plant for different return periods are calculated and presented in table.4.12 in Results & Discussions chapter (chapter 4).

CHAPTER 4

RESULTS

i) The below graph and table show the rainfall intensities for 15 min, 30 min, 1 hr, 2 hr, 3 hr, upto 24 hr for a return period of **5 years** respectively.

Table 4. 1. Intensities for 5-year return period

duration	intensity
0.25 hr	34.93
0.5 hr	22.00
1 hr	13.86
2 hr	8.73
3 hr	6.66
4 hr	5.50
5 hr	4.74
6 hr	4.20
7 hr	3.79
8 hr	3.47
9 hr	3.20
10 hr	2.99
11 hr	2.80
12 hr	2.64
13 hr	2.51
14 hr	2.39
15 hr	2.28
16 hr	2.18
17 hr	2.10
18 hr	2.02
19 hr	1.95
20 hr	1.88
21 hr	1.82
22 hr	1.77
23 hr	1.71
24 hr	1.67

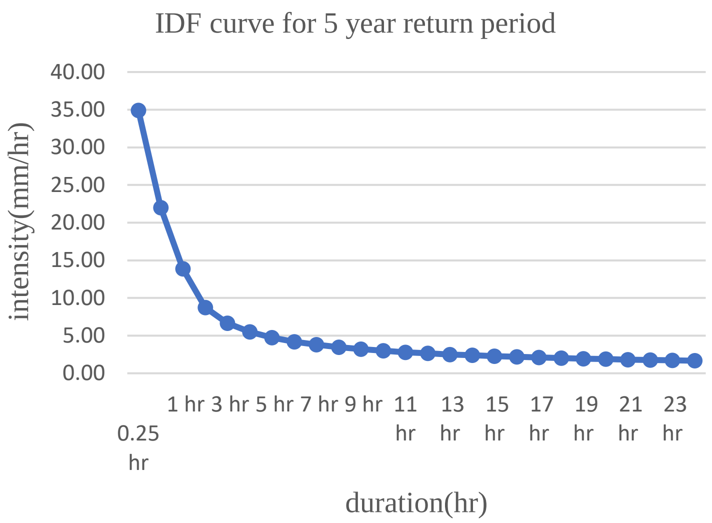


Figure 4. 1. IDF curve for 5-year return period

ii) The below graph and table show the rainfall intensities for 15 min, 30 min, 1 hr, 2 hr, 3 hr, 4 hr, 5 hr, 6 hr, 7 hr, 8 hr, 9 hr, 10 hr,11 hr, 12 hr, 13 hr, 14 hr, 15 hr, 16 hr, 17 hr, 18 hr, 19 hr, 20 hr, 21 hr, 22 hr, 23 hr, 24 hr for a return period of **10 years** respectively.

Table 4. 2. . Intensities for 10-year return period

duration	intensity
0.25 hr	40.24
0.5 hr	25.35
1 hr	15.97
2 hr	10.06
3 hr	7.68
4 hr	6.34
5 hr	5.46
6 hr	4.84
7 hr	4.36
8 hr	3.99
9 hr	3.69
10 hr	3.44
11 hr	3.23
12 hr	3.05
13 hr	2.89
14 hr	2.75
15 hr	2.63
16 hr	2.52
17 hr	2.42
18 hr	2.33
19 hr	2.24
20 hr	2.17
21 hr	2.10
22 hr	2.03
23 hr	1.97
24 hr	1.92

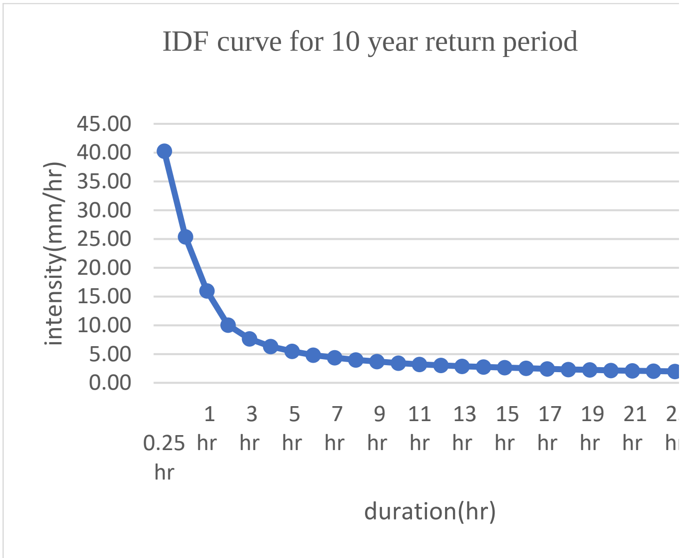


Figure 4. 2. IDF curve for 10-year return period

iii) The below graph and table show the rainfall intensities for 15 min, 30 min, 1 hr, 2 hr, 3 hr, 4 hr, 5 hr, 6 hr, 7 hr, 8 hr, 9 hr, 10 hr,11 hr, 12 hr, 13 hr, 14 hr, 15 hr, 16 hr, 17 hr, 18 hr, 19 hr, 20 hr, 21 hr, 22 hr, 23 hr, 24 hr for a return period of **20 years** respectively.

Table 4. 3. . Intensities for 20-year return period

duration	intensity
0.25 hr	45.35
0.5 hr	28.57
1 hr	18.00
2 hr	11.34
3 hr	8.65
4 hr	7.14
5 hr	6.15
6 hr	5.45
7 hr	4.92
8 hr	4.50
9 hr	4.16
10 hr	3.88
11 hr	3.64
12 hr	3.43
13 hr	3.25
14 hr	3.10
15 hr	2.96
16 hr	2.83
17 hr	2.72
18 hr	2.62
19 hr	2.53
20 hr	2.44
21 hr	2.36
22 hr	2.29
23 hr	2.23
24 hr	2.16

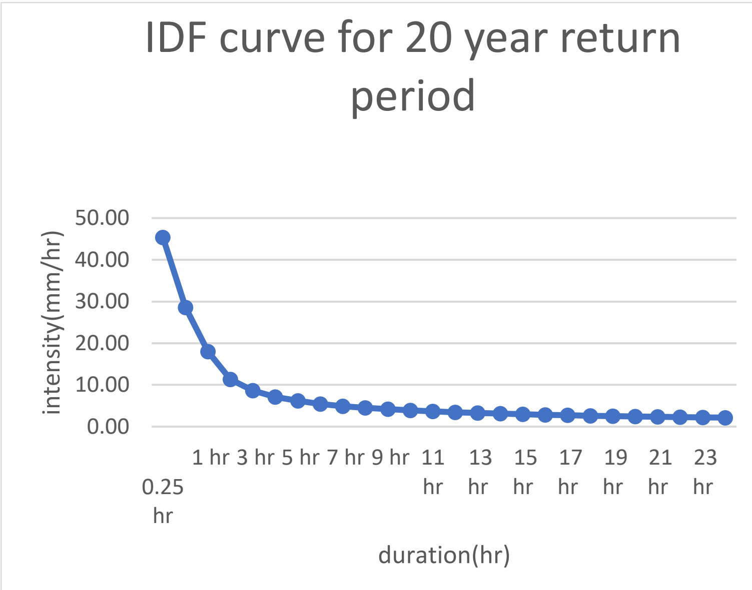


Figure 4. 3. IDF curve for 20-year return period

iv) The below graph and table show the rainfall intensities for 15 min, 30 min, 1 hr, 2 hr, 3 hr, 4 hr, 5 hr, 6 hr, 7 hr, 8 hr, 9 hr, 10 hr,11 hr, 12 hr, 13 hr, 14 hr, 15 hr, 16 hr, 17 hr, 18 hr, 19 hr, 20 hr, 21 hr, 22 hr, 23 hr, 24 hr for a return period of **30 years** respectively.

Table 4. 4. Intensities for 30-year return period

duration	intensity
0.25 hr	48.28
0.5 hr	30.42
1 hr	19.16
2 hr	12.07
3 hr	9.21
4 hr	7.60
5 hr	6.55
6 hr	5.80
7 hr	5.24
8 hr	4.79
9 hr	4.43
10 hr	4.13
11 hr	3.87
12 hr	3.66
13 hr	3.47
14 hr	3.30
15 hr	3.15
16 hr	3.02
17 hr	2.90
18 hr	2.79
19 hr	2.69
20 hr	2.60
21 hr	2.52
22 hr	2.44
23 hr	2.37
24 hr	2.30

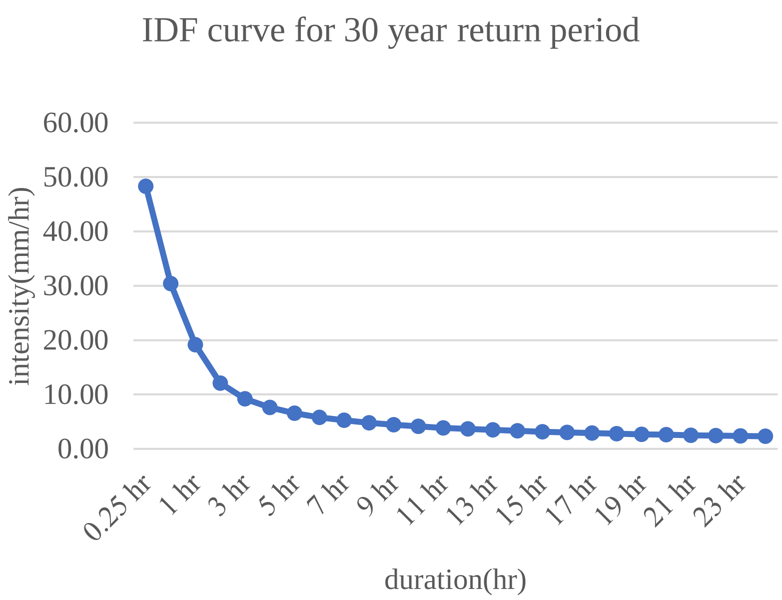


Figure 4. 4. IDF curve for 30-year return period

v) The below graph and table show the rainfall intensities for 15 min, 30 min, 1 hr, 2 hr, 3 hr, 4 hr, 5 hr, 6 hr, 7 hr, 8 hr, 9 hr, 10 hr,11 hr, 12 hr, 13 hr, 14 hr, 15 hr, 16 hr, 17 hr, 18 hr, 19 hr, 20 hr, 21 hr, 22 hr, 23 hr, 24 hr for a return period of **40 years** respectively.

Table 4. 5. Intensities for 40-year return period

duration	intensity
0.25 hr	50.35
0.5 hr	31.72
1 hr	19.98
2 hr	12.59
3 hr	9.61
4 hr	7.93
5 hr	6.83
6 hr	6.05
7 hr	5.46
8 hr	5.00
9 hr	4.62
10 hr	4.31
11 hr	4.04
12 hr	3.81
13 hr	3.61
14 hr	3.44
15 hr	3.29
16 hr	3.15
17 hr	3.02
18 hr	2.91
19 hr	2.81
20 hr	2.71
21 hr	2.63
22 hr	2.55
23 hr	2.47
24 hr	2.40

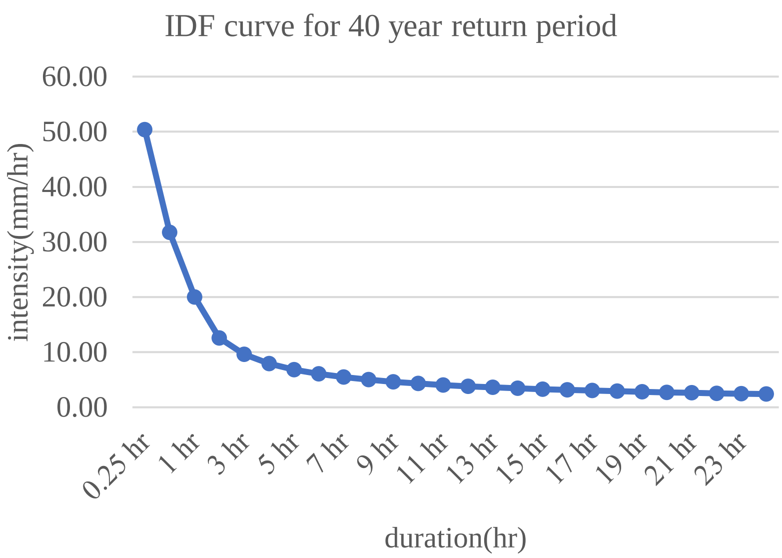


Figure 4. 5. IDF curve for 40-year return period

vi) The below graph and table show the rainfall intensities for 15 min, 30 min, 1 hr, 2 hr, 3 hr, 4 hr, 5 hr, 6 hr, 7 hr, 8 hr, 9 hr, 10 hr,11 hr, 12 hr, 13 hr, 14 hr, 15 hr, 16 hr, 17 hr, 18 hr, 19 hr, 20 hr, 21 hr, 22 hr, 23 hr, 24 hr for a return period of **50 years** respectively.

Table 4. 6. Intensities for 50-year return period

duration	intensity
0.25 hr	51.95
0.5 hr	32.73
1 hr	20.62
2 hr	12.99
3 hr	9.91
4 hr	8.18
5 hr	7.05
6 hr	6.24
7 hr	5.63
8 hr	5.15
9 hr	4.77
10 hr	4.44
11 hr	4.17
12 hr	3.93
13 hr	3.73
14 hr	3.55
15 hr	3.39
16 hr	3.25
17 hr	3.12
18 hr	3.00
19 hr	2.90
20 hr	2.80
21 hr	2.71
22 hr	2.63
23 hr	2.55
24 hr	2.48

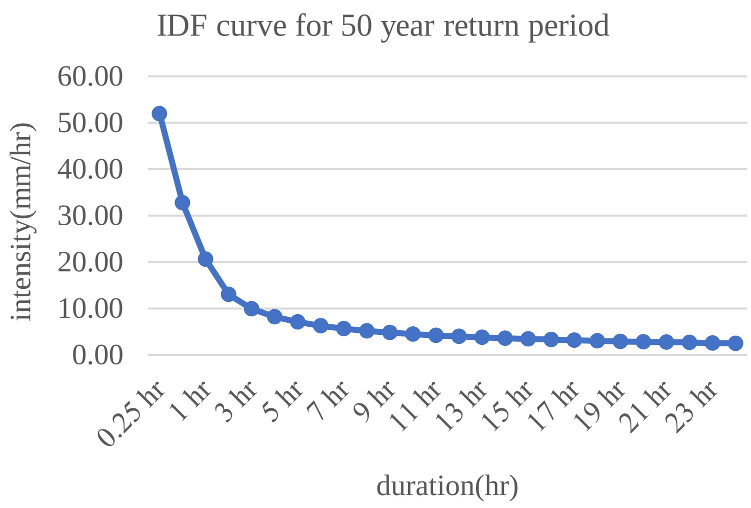


Figure 4. 6. IDF curve for 50-year return period

vii) The below graph and table show the rainfall intensities for 15 min, 30 min, 1 hr, 2 hr, 3 hr, 4 hr, 5 hr, 6 hr, 7 hr, 8 hr, 9 hr, 10 hr,11 hr, 12 hr, 13 hr, 14 hr, 15 hr, 16 hr, 17 hr, 18 hr, 19 hr, 20 hr, 21 hr, 22 hr, 23 hr, 24 hr for a return period of **60 years** respectively.

Table 4. 7. Intensities for 60-year return period

duration	intensity
0.25 hr	53.26
0.5 hr	33.55
1 hr	21.13
2 hr	13.31
3 hr	10.16
4 hr	8.39
5 hr	7.23
6 hr	6.40
7 hr	5.78
8 hr	5.28
9 hr	4.88
10 hr	4.55
11 hr	4.27
12 hr	4.03
13 hr	3.82
14 hr	3.64
15 hr	3.47
16 hr	3.33
17 hr	3.20
18 hr	3.08
19 hr	2.97
20 hr	2.87
21 hr	2.78
22 hr	2.69
23 hr	2.61
24 hr	2.54

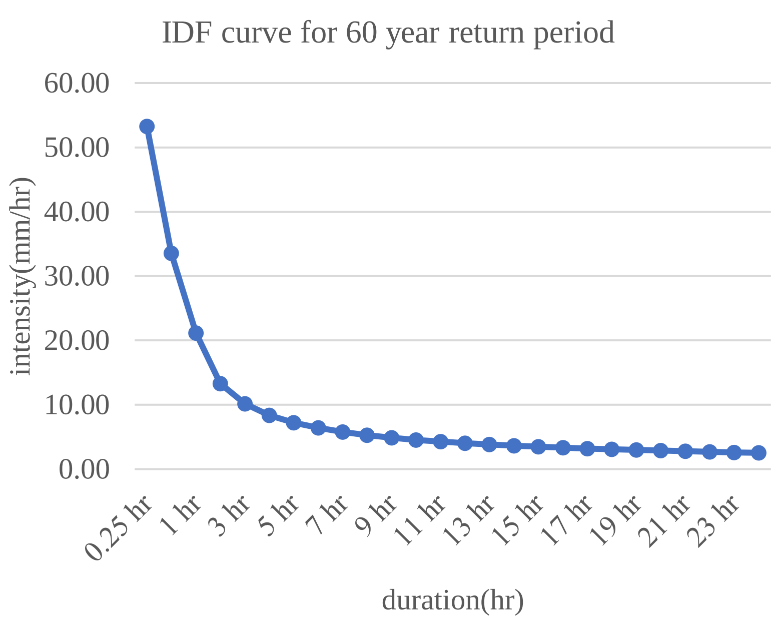


Figure 4. 7. IDF curve for 60-year return period

viii) The below graph and table show the rainfall intensities for 15 min, 30 min, 1 hr, 2 hr, 3 hr, 4 hr, 5 hr, 6 hr, 7 hr, 8 hr, 9 hr, 10 hr,11 hr, 12 hr, 13 hr, 14 hr, 15 hr, 16 hr, 17 hr, 18 hr, 19 hr, 20 hr, 21 hr, 22 hr, 23 hr, 24 hr for a return period of **70 years** respectively.

Table 4. 8. Intensities for 70-year return period

duration	intensity
0.25 hr	54.36
0.5 hr	34.24
1 hr	21.57
2 hr	13.59
3 hr	10.37
4 hr	8.56
5 hr	7.38
6 hr	6.53
7 hr	5.90
8 hr	5.39
9 hr	4.99
10 hr	4.65
11 hr	4.36
12 hr	4.12
13 hr	3.90
14 hr	3.71
15 hr	3.55
16 hr	3.40
17 hr	3.26
18 hr	3.14
19 hr	3.03
20 hr	2.93
21 hr	2.83
22 hr	2.75
23 hr	2.67
24 hr	2.59

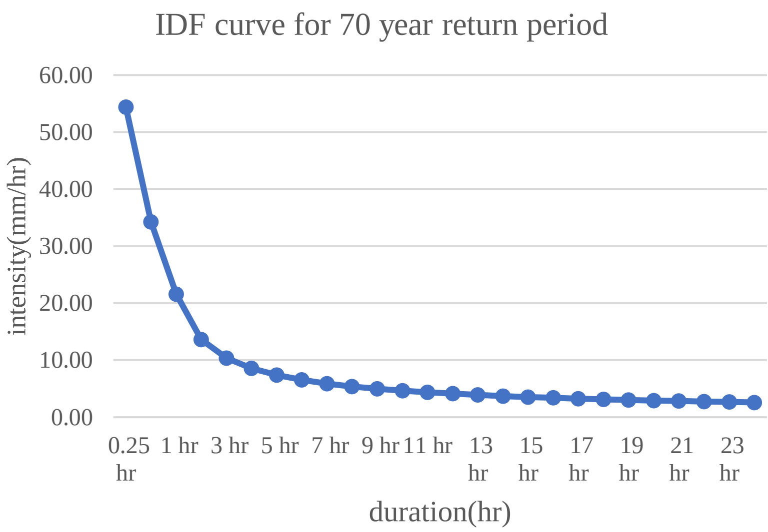


Figure 4. 8. IDF curve for 70-year return period

ix) The below graph and table show the rainfall intensities for 15 min, 30 min, 1 hr, 2 hr, 3 hr, 4 hr, 5 hr, 6 hr, 7 hr, 8 hr, 9 hr, 10 hr,11 hr, 12 hr, 13 hr, 14 hr, 15 hr, 16 hr, 17 hr, 18 hr, 19 hr, 20 hr, 21 hr, 22 hr, 23 hr, 24 hr for a return period of **80 years** respectively.

Table 4. 9. Intensities for 80-year return period

duration	intensity
0.25 hr	55.31
0.5 hr	34.84
1 hr	21.95
2 hr	13.83
3 hr	10.55
4 hr	8.71
5 hr	7.51
6 hr	6.65
7 hr	6.00
8 hr	5.49
9 hr	5.07
10 hr	4.73
11 hr	4.44
12 hr	4.19
13 hr	3.97
14 hr	3.78
15 hr	3.61
16 hr	3.46
17 hr	3.32
18 hr	3.20
19 hr	3.08
20 hr	2.98
21 hr	2.88
22 hr	2.80
23 hr	2.71
24 hr	2.64

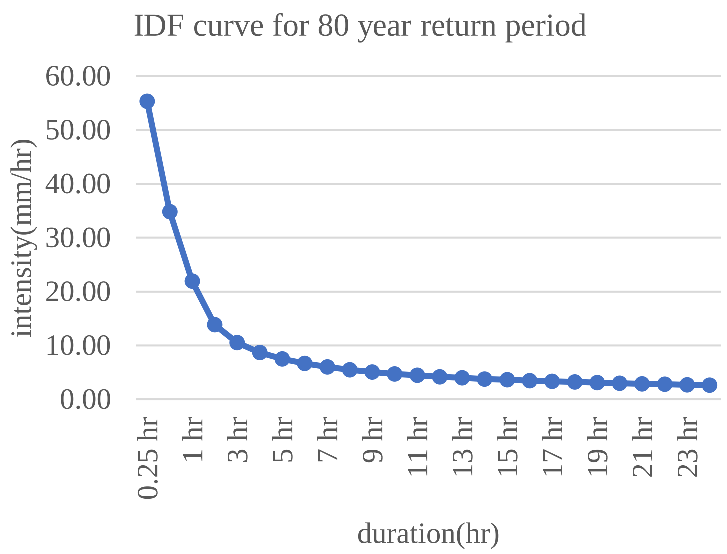


Figure 4. 9. IDF curve for 80-year return period

x) The below graph and table show the rainfall intensities for 15 min, 30 min, 1 hr, 2 hr, 3 hr, 4 hr, 5 hr, 6 hr, 7 hr, 8 hr, 9 hr, 10 hr,11 hr, 12 hr, 13 hr, 14 hr, 15 hr, 16 hr, 17 hr, 18 hr, 19 hr, 20 hr, 21 hr, 22 hr, 23 hr, 24 hr for a return period of **90 years** respectively.

Table 4. 10. Intensities for 90-year return period

duration	intensity
0.25 hr	56.15
0.5 hr	35.37
1 hr	22.28
2 hr	14.04
3 hr	10.71
4 hr	8.84
5 hr	7.62
6 hr	6.75
7 hr	6.09
8 hr	5.57
9 hr	5.15
10 hr	4.80
11 hr	4.51
12 hr	4.25
13 hr	4.03
14 hr	3.84
15 hr	3.66
16 hr	3.51
17 hr	3.37
18 hr	3.24
19 hr	3.13
20 hr	3.02
21 hr	2.93
22 hr	2.84
23 hr	2.76
24 hr	2.68

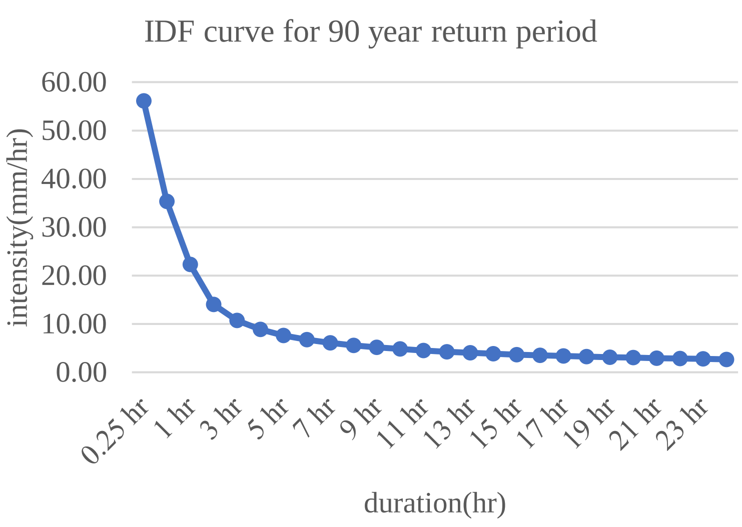


Figure 4. 10. IDF curve for 90-year return period

xi) The below graph and table show the rainfall intensities for 15 min, 30 min, 1 hr, 2 hr, 3 hr, 4 hr, 5 hr, 6 hr, 7 hr, 8 hr, 9 hr, 10 hr,11 hr, 12 hr, 13 hr, 14 hr, 15 hr, 16 hr, 17 hr, 18 hr, 19 hr, 20 hr, 21 hr, 22 hr, 23 hr, 24 hr for a return period of **100 years** respectively.

Table 4. 10. Intensities for 100-year return period

duration	intensity
0.25 hr	56.90
0.5 hr	35.85
1 hr	22.58
2 hr	14.23
3 hr	10.86
4 hr	8.96
5 hr	7.72
6 hr	6.84
7 hr	6.17
8 hr	5.65
9 hr	5.22
10 hr	4.86
11 hr	4.57
12 hr	4.31
13 hr	4.08
14 hr	3.89
15 hr	3.71
16 hr	3.56
17 hr	3.42
18 hr	3.29
19 hr	3.17
20 hr	3.06
21 hr	2.97
22 hr	2.88
23 hr	2.79
24 hr	2.71

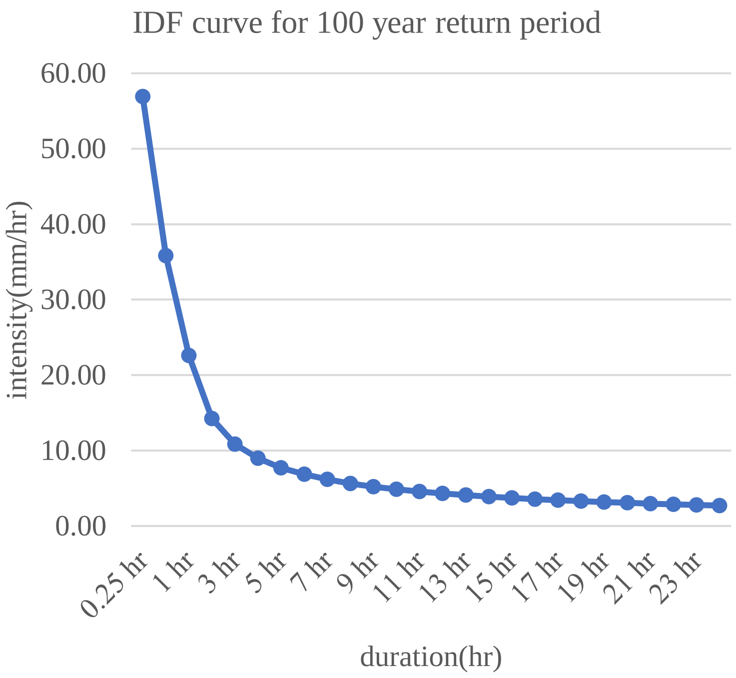


Figure 4. 11. IDF curve for 100-year return period

From above intensity values, we have obtained the discharge values which are then used to find the hydropower potential of the plant.

Return period in years	**Discharge in m3/sec**	**Hydropower potential in MW**
100	948.355	37.454
90	935.842	36.960
80	921.844	36.407
70	905.961	35.780
60	887.607	35.055
50	865.868	34.197
40	839.204	33.144
30	804.712	31.781
20	755.790	29.849
10	670.748	26.491
5	582.092	22.989

Table 4. 11. Hydro power potential and discharge values for different return periods

The discharge and hydro power potential values were plotted with respective return periods values in X -axis and discharge and hydropower potential values in Y-axis.

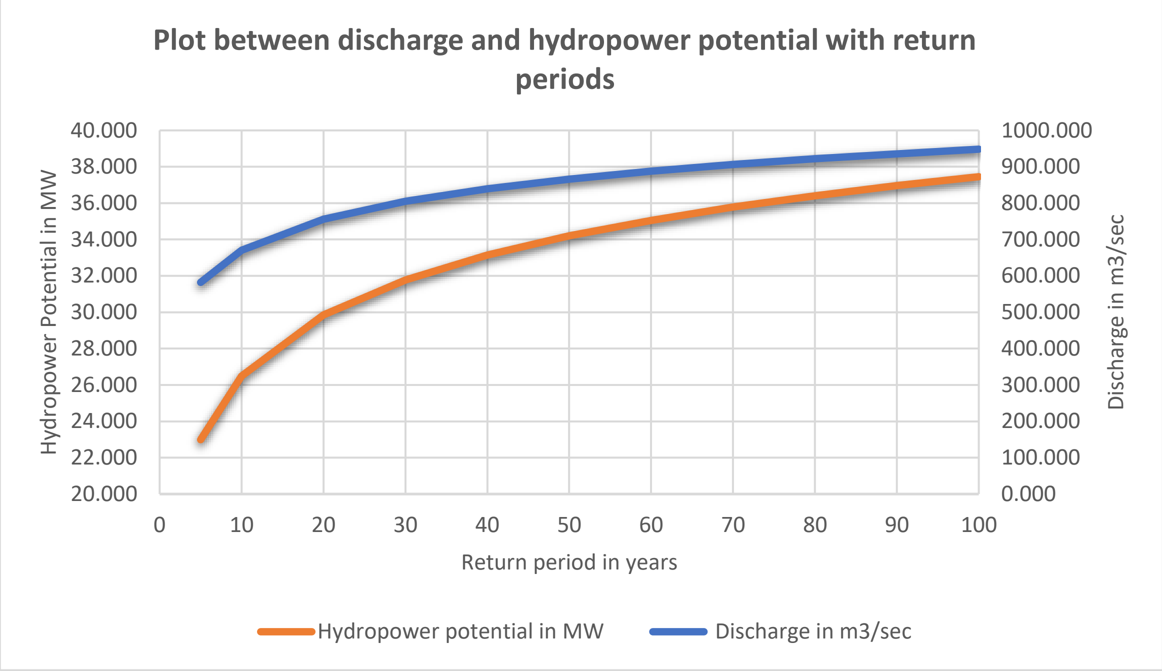


Figure 4. 12.Graph Plotted between discharge and hydropower potential with different return periods.

CHAPTER 5

CONCLUSIONS

In this study, after collecting rainfall data of past 25 years from 1995 to 2020 of Sugur hydropower plant, IDF (Intensity-Duration-Frequency) curves are generated for durations 0.25 hr, 0.5 hr, 1 hr,2 hr, 3 hr, 4 hr, 5 hr, 6 hr, 7 hr, 8 hr, 9 hr, 10 hr, 11 hr, 12 hr,13 hr,14 hr, 15 hr, 16 hr, 17 hr, 18 hr, 19 hr, 20 hr, 21 hr,22 hr, 23 hr and 24 hours of 5, 10, 20, 30, 40, 50, 60, 70, 80, 90 and 100 year return periods. 11 IDF curves are constructed and observed that

i. Rainfall intensity values had been decreasing as the duration increases in all 11 curves.

ii. Rainfall intensity values are increasing with increase in return period.

iii. Discharge available for hydropower plant also shows similar fashion with increasing trend with increase of return period.

iv. The maximum discharge is obtained for 100-year return period which is 948.355 m^3/sec.

v. Hydro power potential of the hydropower plant has also increased with increase in return period.

vi. The maximum hydropower potential is achieved for 100-year return period.

vii. Sugur small hydropower plant is capable of generating 37.454 MW of hydro power in future with the discharge of 948.355 m^3/sec coming to the plant.

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