Estimating Precipitation and its Abstractions Using Web Application: A Fundamental Approach

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Abstract— **Runoff due to storm event was often the major subject of study. All abstractions from precipitation like evaporation, evapotranspiration, interception, infiltration, surface detention and storage were considered as losses in the production of runoff. Depending upon the catchment characteristics and factors affecting it, several empirical formulae had been suggested from time to time for estimating these parameters. But the parameters calibrated manually using the data obtained from the field into the empirical relations were found to be time consuming, tedious and demand experience. Obtaining the data from the field and analysing the same in the laboratory delayed the work. Hence, the general idea was to standardize the above parameters in a single program using software programming methodologies.**

The program using this approach was able to estimate the values of the parameters involved in the rainfall-runoff process. The purpose of this paper was to develop computer-based programming for estimating the precipitation in the given catchment along with the abstractions of the precipitation in the same catchment. The approach was to assemble fundamental equations and empirical relations of rainfall-runoff process for estimating the values into one program. The program had considered all those parameters affecting the catchment hydrology. It was going to be a productive methodology for site engineers as instead of collecting data from the field and analysing it in the laboratory, the same can be achieved on the field itself if this program would be brought in practice. The overall idea of the paper was to avoid manual calculation, instead to provide a computer-based program in order to simplify the conception of basic hydrological events in the given catchment. The future scope of this paper would be to transmute this software programming methodology into an android application for improved use of this contemporary program.

Keywords— **Rainfall-runoff process, Software, Program, Precipitation, Hydrology, Infiltration, Evaporation, Evapotranspiration**

I. INTRODUCTION

The term precipitation denotes all forms of water that reached the earth from the atmosphere. Some of the common forms of precipitation were rain, snow, drizzle, glaze, sleet, hail etc. of all these, only the first two contributed significant amount of water. For precipitation to form: (i) the atmosphere must have moisture, (ii) there must be sufficient nuclei present to aid condensation, (iii) weather conditions must be good for condensation of water vapour to takes place, and (iv) the product of condensation must reach to the earth. Precipitation resulted when the water droplets came together and coalesce to form large drops that could be drop down. The net precipitation depends on the number of meteorological factors, such as weather elements like wind, temperature, humidity and pressure in the volume region enclosing the clouds and the ground surface at the given catchment as shown in Fig. 1. Precipitation was expressed in terms of depths to which the rainfall water would stand on that area if all the rain is collected on it. Runoff due to storm event was often the major subject of study [1].

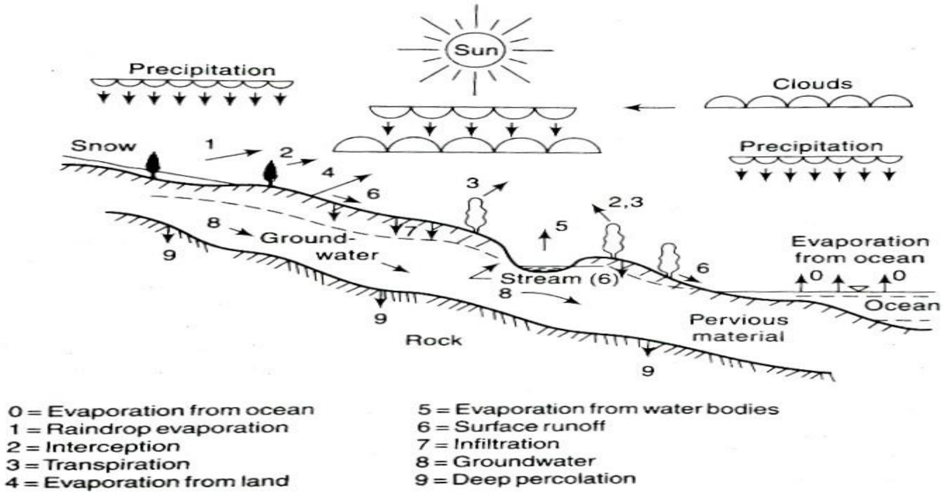

Fig 1: Rainfall- Runoff Process

All abstractions from precipitation like evaporation, evapotranspiration, interception, infiltration, surface detention and storage were considered as losses in the production of runoff. The intensity of the various types of the rains are given in Table I as shown below:

TABLE I
CLASSIFICATION OF RAIN ON BASIS OF INTENSITY

Type	Intensity
Light rain	Trace to 2.5 mm/h
Moderate rain	2.5 mm/h to 7.5 mm/h
Heavy rain	>7.5 mm/h

Depending upon the catchment characteristics and factors affecting it, several empirical formulae had been suggested from time to time for estimating these parameters. Chief components of abstractions from precipitation, knowledge of which were necessary in the analysis of various hydrological situations were described below:

A. Evaporation

Evaporation was the process in which a liquid changed to gaseous state at the free surface, below the boiling point through the transfer of heat energy. The molecules of the water were in constant motion with a wide range of instantaneous velocities. An addition of heat causes this range and speed to increase. When some molecules possessed sufficient kinetic energy, they might cross over the water surface. Similarly, the atmosphere in the immediate neighbourhood of the water surface contained water molecules within the water vapour and some of them penetrated the water surface. The net escape of the water molecules from the liquid state to the gaseous state constituted evaporation. Evaporation of the cooling process in that the latent heat of vaporisation might been provided by the water body.

The rate of evaporation was dependent on (i) the vapour pressure at the water surface and air above, (ii) air and water temperature, (iii) wind speed, (iv) atmospheric pressure, (v) quality of water, and (vi) size of the water body. The amount of the water evaporated could be estimated by using evaporation data, empirical evaporation equations, and analytical methods.

B. Evapotranspiration

While transpiration took place, the land area in which plant stand also loose moisture by the evaporation of water from soil and water bodies. In hydrology and irrigation practices, it was found that evaporation and transpiration process could be considered advantageously under one head as *evapotranspiration*.

For the given set of atmospheric conditions, evapotranspiration depended on the availability of water. If sufficient moisture was always available to completely meet the needs of vegetation fully covering the area, the resulting evapotranspiration was called *potential evapotranspiration (PET)*. This was no longer critically depended on soil and plant factors but essentially on the climatic factors. The real evapotranspiration occurred in a specific situation was called as a*ctual evapotranspiration (AET)*. The measurement of the given evapotranspiration for a given vegetation type could be carried out using *lysimeter* or by the field plots [2].

C. Infiltration

Infiltration was the flow of water into the ground through the soil surface. The distribution of the soil moisture within the soil profile during the infiltration process is shown in the Fig. 2.

The infiltration process could be easily understood through a simple analogy. Consider a small container covered with wire gauze as shown in Fig. 2, if water was poured into the container, a part of it would go into the container and the part overflown. Further, the container could hold the fixed quantity and when it was full, no more flow could take place. This underscored two important aspects: viz. (i) the maximum rate at which the ground could absorb water, i.e. the infiltration capacity, and (ii) the volume of water the ground could hold, i.e. the field capacity. Since the infiltered water could contribute to the groundwater infiltration in addition to the increase of soil moisture, the process could be schematically programmed [3].

Infiltration characteristics of a soil at a given location would been estimated by using flooding type infiltrometer, measurement of subsidence of free water in a large basin, rainfall simulator and hydrograph analysis etc.

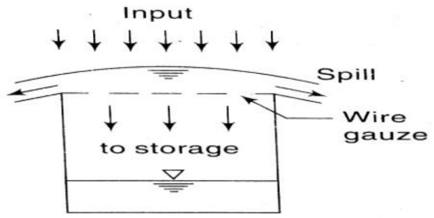

Fig 2: Infiltration Analogy

D. Runoff

Runoff mean the draining or flowing of precipitated water from a catchment area through a surface channel. It thus represented the output from the catchment in a given unit of time. For the given precipitation, the evapotranspiration, evaporation, infiltration and detention storage requirements would had been first satisfied before the commencement of runoff. When these were satisfied, the excess precipitation moves over the land surface to meet the smaller channels. This portion of the runoff was called overland flow. The flow in this mode, where it travelled all the time over the surface as overland flow and through the channels as open channel flow and reached the catchment outlet was called as surface runoff.

The measurement of the runoff volume was in the form of annual yield from the catchment as an end product of various processes such as precipitation, infiltration, evapotranspiration etc. operating in the catchment. Determination of runoff using hydrologic water-budget equation required enormous calculation efforts. With the availability of the digital computers, the use of water budgeting as above had become feasible. This technique of predicting the runoff (catchment response to the given rainfall) was termed as *deterministic watershed simulation.* Hence, calculation of natural runoff volume was of fundamental importance in all surface water resource development studies [4].

II. METHODOLOGY

The development of the software programming comprised of basic six operations viz. adequacy of rain gauge stations and precipitation measurement, the frequency of occurrence of precipitation, evaporation, evapotranspiration, infiltration and surface runoff. The fundamentals of these conceptions are discussed below [5]:

A. Adequacy of Rain Gauge Stations and Precipitation Measurement

Precipitation was expressed in terms of depths to which the rainfall water would stand on that area if all the rain was collected on it. The precipitation was collected and measured in a *rain gauge.* The ratio of the total area of the catchment to the number of the gauges in the given catchment was defined as the *rain gauge density* or *network density*. From practical consideration of the Indian conditions, the Indian Standard Code had recommended the following densities: (i) One gauge per 520km^2 in plane areas. (ii) one gauge per 260 to 390 km^{2}in regions with the average elevation of 1000m above mean sea level. (iii) One gauge per 130km^2 in predominantly hilly regions with heavy rainfall. It was also recommended that at least 10% of the gauges were of recording type. The network arrived on these recommendations might be located that all the gauges would have been more or less equal Thiessen weights.

The optimum number of rain gauges required, *n* was given by: $n=\left\{\frac{C_v}{e}\right\}\left\{\frac{C_v}{e}\right\}$……………………………………………… (1)

Where, e = allowable degree of error in the measurement, in %; C_v = coefficient of variation of rainfall, in % = $\left\{\frac{100\sigma}{P_{avg}}\right\}$, where,

P_{avg} = average rainfall = $\frac{\sum P}{m}$, and σ = standard deviation = $\sqrt{\frac{\sum(P_i-P_{avg})^2}{m-1}}$.

Here rain gauges represented only the point sampling of the aerial distribution of a storm. In practice, however, hydrological analysis required a knowledge of rainfall over an area, such as an over a catchment. To convert the point rainfall at various station into an average value over a catchment, the following methods were used:

1) *Arithmetic-Mean Method-* The value of mean precipitation (P_a) over the catchment was given by:
   $P_a = \sum_{i=1}^{m} P_i$ ………………………………………………………………………………………………*(2)*
2) *Thiessen-Mean Method-* Rainfall recorded at each station as shown in Fig. 3 was given a weightage based on an area closest to the station as: $P_a = \frac{\sum P_i A_i}{\sum A_i}$ ……………………………………………………………………………… *(3)*

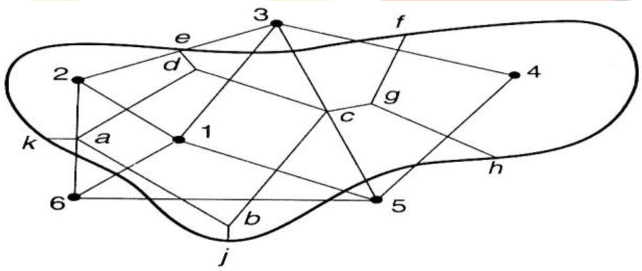

Fig 3: Thiessen's Method for Mean Precipitation

3) *Isohyetal Method-* Accurate method w.r.t. above two methods. Suitable for hilly regions. The average rainfall of the catchment was given by: $P_a = \frac{A_1\left(\frac{P_1+P_2}{2}\right)+A_2\left(\frac{P_2+P_3}{2}\right)\ldots\ldots}{A_1+A_2+\cdots\ldots}$. ……………………………………………………… *(4)*

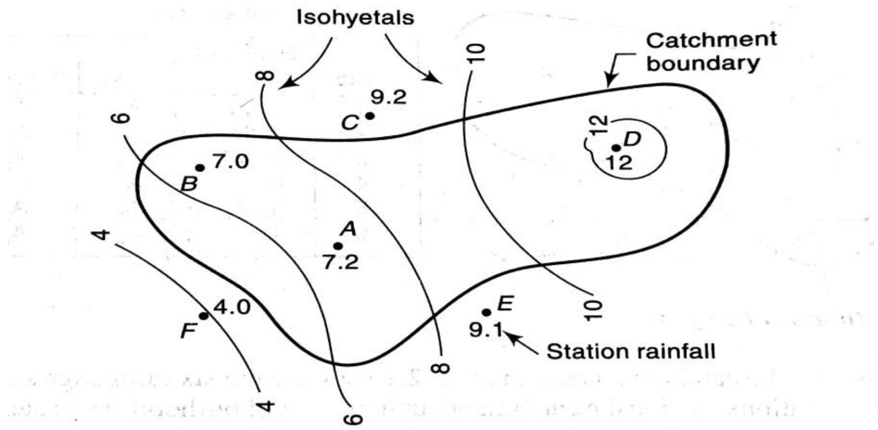

Fig 4: Isohyetal Method for Mean Precipitation

B. Frequency of Occurrence of Point Precipitation

The probability of rainfall which was equal to or more than specified magnitude (X) and had a recurrence interval T, occurred in each year, was given by: $p = (1/T)$……………………………………………………………………………...…… *(5)*

Then the probability of the event not occurred in each year, was: $q = 1 - p$. Also, the probability of occurrence of the event r times in n successive year was given by: $p_{r,n} = \frac{n!}{(n-r)!.r!} p^r q^{(n-r)}$. The probability of the event not occurring at all in n successive years was: $p_{o,n} = q^n$ and the probability of the event occurring at least once in n successive years was given by the equation called as *hydrological risk*: $p = 1 - q^n$ ……………………………………………………………………………………… .*(6)*

The value of p obtained by using plotting position formulae given in Table II.

TABLE II
PLOTTING-POSITION FORMULAE

Name of the Method	Equation for P
California	$P = \frac{m}{N}$
Hazen	$P = \frac{(m - 0.5)}{N}$
Weibull	$P = \frac{m}{(N + 1)}$
Chegodayev	$P = \frac{(m - 0.3)}{(N + 0.4)}$
Blom	$P = \frac{(m - 0.44)}{(N + 0.12)}$
Gringorten	$P = \frac{(m - 0.375)}{(N + 0.25)}$

C. Evaporation

Evaporation was usually measured by either *atmometers* or by the evaporation pan also called *evaporimeters*. Various types of evaporimeters and their pan coefficient are given in Table III. The depth of evaporation *(E)* in the reservoir was given by the equation: $= E_p \times C_p$……………………… …………………..……………………………………………………………………… *(7)*
Where, E_p: depth of pan evaporation loss; C_p: pan coefficient. The values of various types of pan are given in Table III.

The rate of evaporation (E_p) was given by: $E_p = R/(L \times \rho)$………………………………………………………………………. *(8)*
Where, R: radiation in W/m^2; L: latent heat of vaporisation in J/Kg; ρ: mass density of water in Kg/m^3.

TABLE III
VALUES OF PAN COEFFICIENTS C_P

Sr. No.	Types of pan	Average of Value	Range
1	Class A Land Pan	0.7	0.6 – 0.8
2	ISI Pan (Modified Class A)	0.8	0.65 – 1.10
3	Colorado Sunken Pan	0.78	0.75 – 0.86
4	USGS Floating Pan	0.8	0.7 – 0.820

D. Evapotranspiration

Evapotranspiration was measured using *Blaney-Criddle* formula. This purely empirical formula was based on data from the data of western United States. This formula assumed that the PET was related to hours of sunshine and temperature, which were taken as measure of the total solar radiation at an area. The potential evapotranspiration (E_t) in a crop-growing season in metres was given by: $E_t = 2.54 \times K \times P_h \times T_f$……………………………………………………………………………………… (9)

Where, K: an empirical constant, depended upon the type of crop and stage of growth as shown in Table IV; P_h: monthly % of annual day-time hours, depended upon the latitude of the place as shown in Table IV; T_f : mean monthly temperature in degree-Fahrenheit.

TABLE IV
VALUES OF K FOR SELECTED CROPS

Crop	**Average value of K**	**Range of Monthly values**
Rice	1.1	0.85 – 1.3
Wheat	0.65	0.5 – 0.75
Maize	0.65	0.5 – 0.8
Sugarcane	0.9	0.75 – 1
Cotton	0.65	0.5 – 0.9
Potatoes	0.70	0.65 – 0.75
Natural Vegetation		
(a) Very dense	1.3	-
(b) Dense	1.2	-
(c) Medium	1	-
(d) Light	0.8	-

E. Infiltration

In this paper, the *Horton's equation* had been used to express the decay of infiltration capacity with time (f_t). It was given as: $f_t = f_c + (f_o - f_c) \times e^{-kt}$……………………………………………………………………………………… (10)

where, f_o: initial rate of infiltration capacity; f_c: final constant rate of infiltration at saturation; k: a constant depending primarily upon soil and vegetation given as $(f_o - f_c)/A$ where, A: was the shaded area in the *Horton's curve*; t: time from the beginning of the storm.

F. Surface Runoff

The calculation of the surface runoff (R) from the catchment area was based in the *water-budget or hydrological equation* given by: $R = P – E - E_t – I - \Delta S – V_O + V_i$……………………………………………………………………………… (11)

Where, P: precipitation depth in metres; I: infiltration depth; V_o: volume outflow from the reservoir; V_i: volume inflow into the reservoir; ΔS: change in the storage. Either the values of some of the parameters which were already obtained had substituted into the Eqn. 11 or the program asked to enter the fresh values of the concerned parameters.

III. Software Development

The methodology required for the working of the program is discussed here. All the steps mentioned in the sequence in the previous section was assembled together to obtain the pathway of the development of the program. The various abstractions from the precipitation affecting the rainfall-runoff process is illustrated in Fig. 5. The objective was to obtain the magnitude of any process of hydrological phenomena without manual calculation but to make the use of the water budget equation in the development of the software program. The standard symbols were used in the flowchart was already explained in the section II.

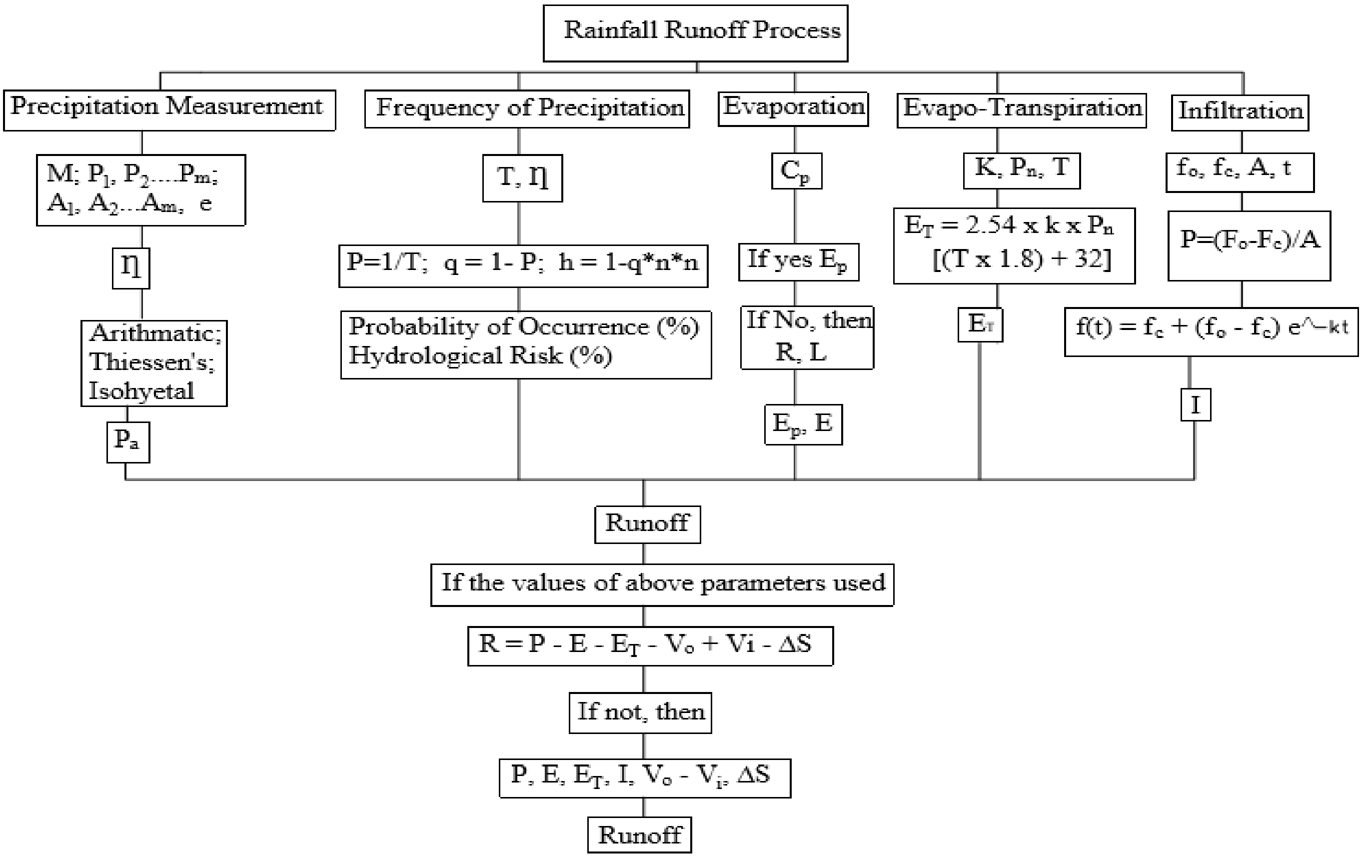

Fig. 5: Pathway of the Working Software Model of Rainfall-Runoff Process

IV. Problem Statement

In this section, the problem was solved on rainfall-runoff process. The objective was to determine whether the results so obtained manually were consistent with the result that was executed by the program developed in this study.

A catchment area had 7 rain gauge stations, the rainfall in cm recorded by the stations are 130, 142.1, 118.2, 108.5, 165.2, 102.5, 146.9 and their corresponding areas in km^2 are 8, 12, 7, 13, 8, 8,14 respectively, having 5% of error in estimation of mean rainfall. The return period for annual maximum storm was 8 years. The evaporation was measured from the ISI standard pan having evaporation rate 0.79 cm/day. The evapotranspiration for month having mean temperature of 25 ^{o}C and having average day time of 8.60% of the year and the consumptive use by crop was 0.6. If the infiltration during the storm can be represented by Horton's Equation with f_0=6.5 mm/hr, f_c= 1.5mm/hr, k=0.151/hr for a storm lasting for 24 hours. Initial water surface elevation 103.2m in that month the average inflow was $6m^3/s$ from surface runoff and outflow is 6.5 m^3/s, the water surface elevation of the lake at end of the month was 102.58 m.

Determine the following parameters:

1. No. of rain gauges required
2. Average precipitation
3. Probability of Occurrence of rainfall once in 5 years
4. Hydrological risk involved
5. Depth of water evaporated
6. Potential evapotranspiration
7. Rate of infiltration
8. Runoff

V. Result

The above stated problem was solved as per the standard manual calculation and the results so obtained from the calculations is shown in Table V. The equations and the formulae mentioned in the section II had been used in solving the above numerical.

TABLE V
RESULTS OBTAINED FROM MANUAL CALCUATION

Parameter	Results
Number of rain gauge required	12
Mean Precipitation	130.5 cm

Mean Precipitation by Thiessen's Method	131.16 cm
Probability of occurrence of rainfall	12.5%
Hydrological Risk	48.709%
Depth of water evaporated	0.00632 m
Potential Evapotranspiration	10.09 m
Rate of Infiltration	1.63333 mm/hr
Runoff	119.5175 m

The various data given in the problem was used as input to the web application program and then was solved. The objective was to confirm the validity of the methodology that had been used for program development. The results obtained from the web application is shown in the screenshots (Fig. 6):

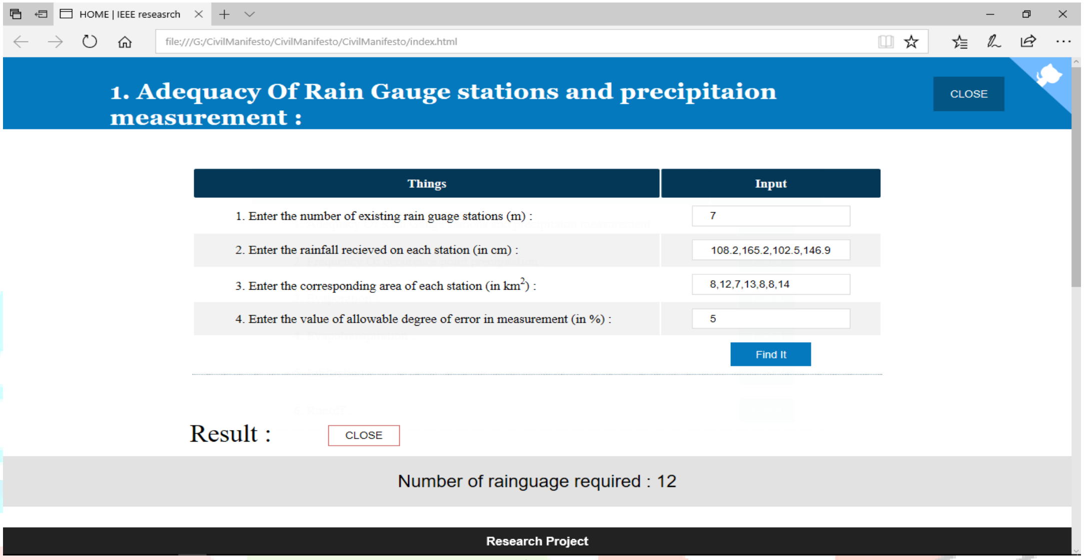

Fig 6(a): Adequacy of Rain Gauges Stations

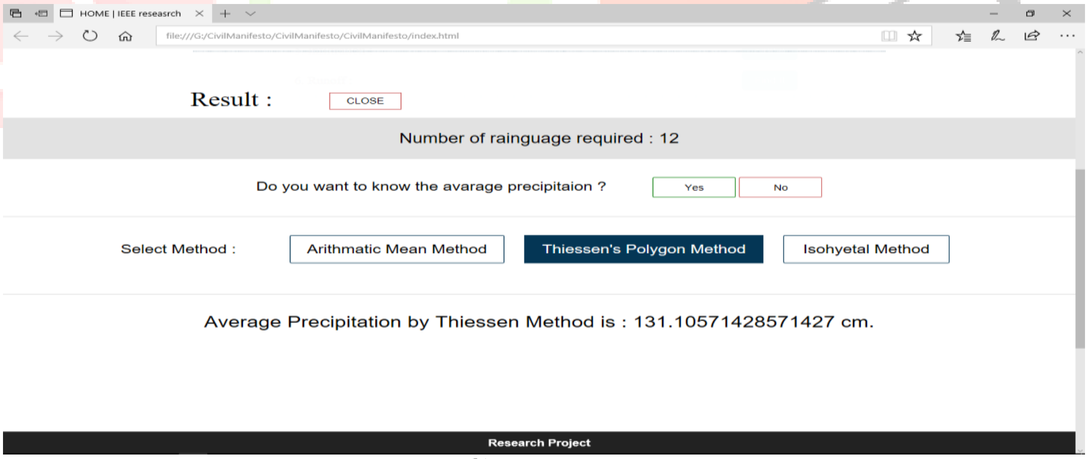

Fig 6(b): Mean Precipitation

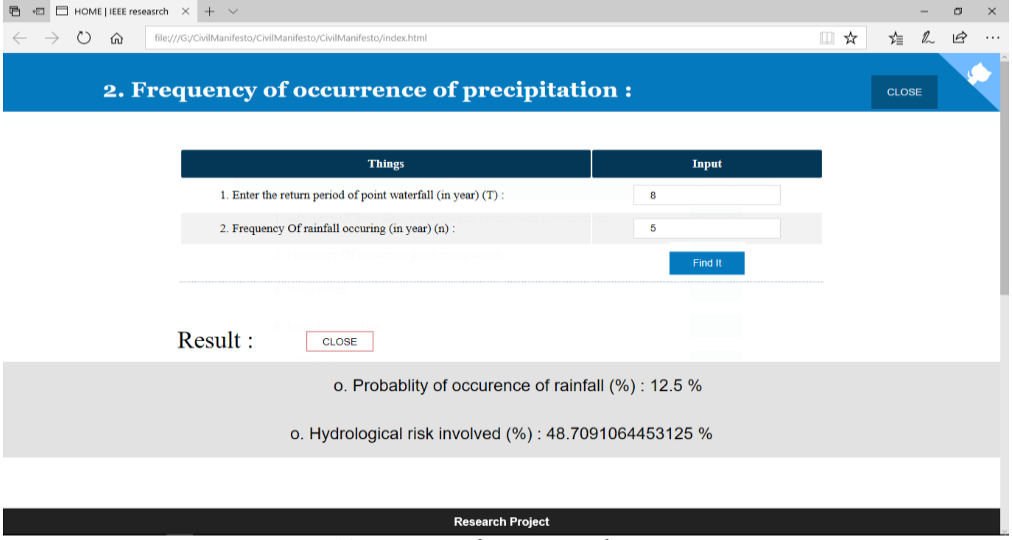

Fig 6(c): Frequency of Occurrence of Precipitation

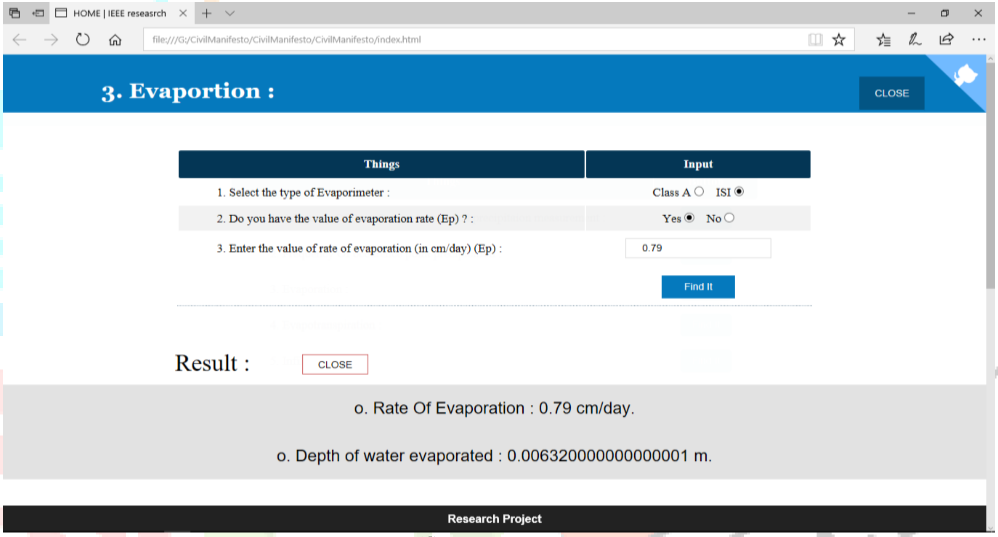

Fig 6(d): Evaporation Process

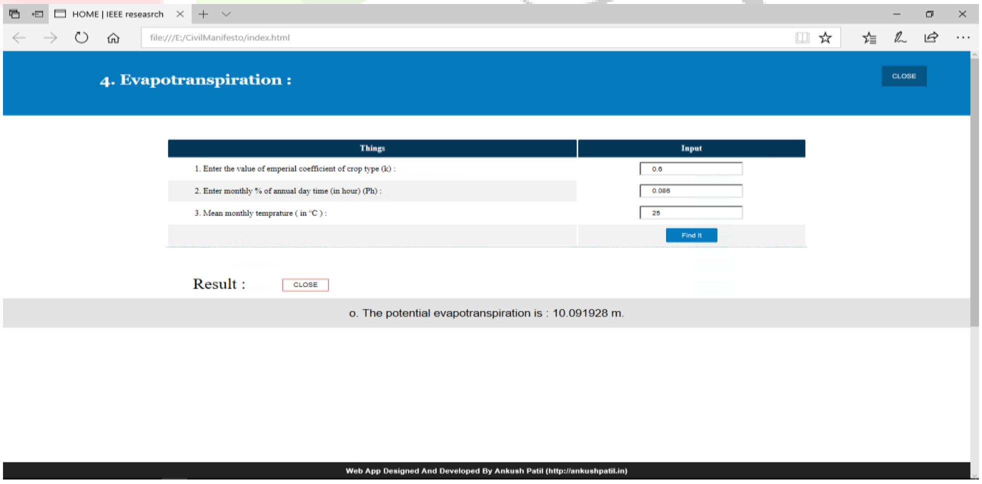

Fig 6(e): Evapotranspiration Process

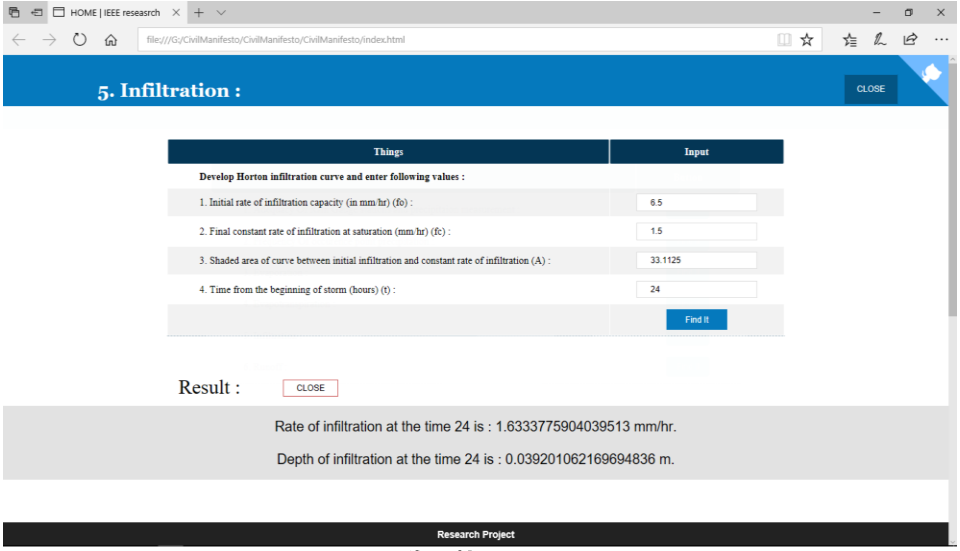

Fig 6(f): Infiltration Process

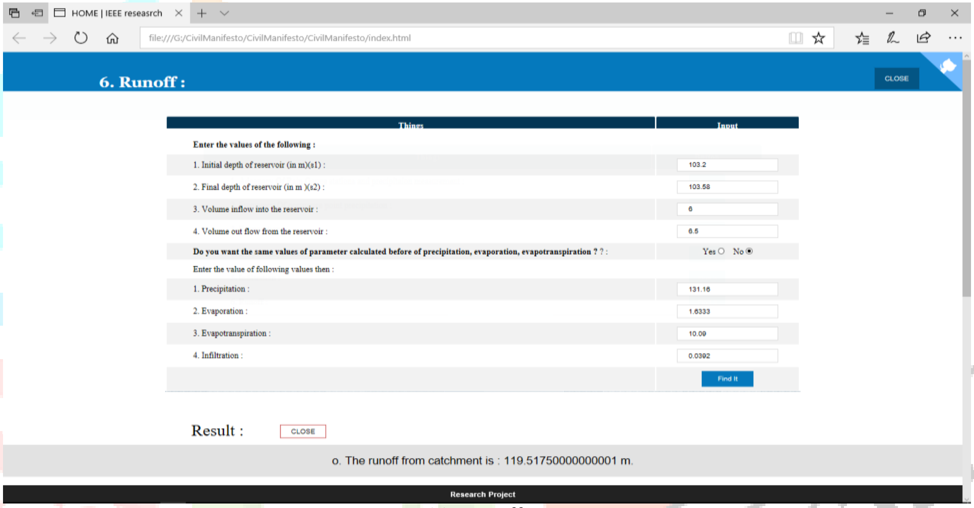

Fig 6(g): Runoff Process

By comparing the measured values so obtained using manual calculation with the values so obtained from the execution of the web application, the paper concluded that there was no variation in the result of these two approaches. Hence, the program developed in this study was found consistent with the methodology so adopted with respect to the hydrological equation of the rainfall-runoff process.

VI. CONCLUSIONS

The software programming developed in this study afforded a fundamental approach of analytical cum mathematical approach using computer-based programming. The empirical relations and the different formulae of rainfall-runoff process cast-off in this paper were already in existence and were attained for study from the standard reference books. This had been referred for developing the software of the process using computer programming in order to minimize time consuming tedious manual calculations. The study tried to associate the fundamental notion of the concept of the *Rainfall-Runoff Process* with the computer-based programming.

The mathematical interdependencies between the parameters involved had been resulting into formula by numerous researchers which was incorporated in this paper for developing software programming for the concerned hydrological phenomenon. When the parameters of the delinquent area (input) was applied over the program, the program construed the data (processing) and relieved the information into the obligatory formula already defined in the program which produced one of the result (output) for which the data was processed. The output was compared with observed data (*software validation*) provided by the standard specification or by solving one problem manually and compared the same by solving the problem using the program. The comparative analysis of the result obtained from these two approaches was found to be the same. As this was an empirical cum numerical approach of estimating the abstractions from the precipitation, hence the output obtained from this program will vary if the characteristics considered here had another formula (empirical or numerical) w.r.t. some other field conditions. Therefore, the software application was limited to give result of only those conditions for which the corresponding formula had been considered.

Hence, the study concluded that this methodology of understanding the conceptions of rainfall-runoff process provided a preliminary approach to the undergraduates to link the practical on hydrological phenomena with computer programming to develop their interdisciplinary approach towards learning. The future scope of this paper would be to transmute this software programming into an android application for improved use of this contemporary program.

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