Effective Rainfall for Irrigated Agriculture Plains of Pakistan

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Abstract

Rainwater is essential source for agriculture, human beings and animals that falls on the surface of earth. Agriculture production in Pakistan is highly dependent upon precipitation, which either fall in the form of rain or snow. Not all that is useful rather a part of it is effective. This study deals with "effective rainfall", i.e. useful rainfall. Agriculturists consider the portion of rainfall effective that directly satisfies crop water requirements. In this study, four different methods have been used to estimate effective rainfall using data from 58 meteorological stations covering irrigated plains of Pakistan. The effective rainfall have been estimated for two crop growing seasons, i.e. Rabi(October to April) and Kharif(May to September). It has been observed that effective rainfall values for Rabi and Kharif season varies widely from 13.03% and 21.31% at humid zone of northeastern Punjab to 100% at several stations by Renfro Equation method, 43% and 30% at humid zone of northeastern Punjab, 99.86% to 100% is at central Sindh by U.S Bureau of Reclamation Method. 17.57% at humid zone of northwestern NWFP, 98.98% and 99.93% at arid zone of southwestern Sindh and Balochistan by Potential Evapotranspiration /Precipitation Ratio method and 54.40% and 60% at arid zone of southern Balochistan to 100 % at several stations by U.S.D.A, SCS method respectively. Murree has the lowest amount of effective rainfall. It has been observed effective rainfall is directly proportional to consumptive use, water storage capacity and irrigation application. Renfro equation is not suitable for short term planning. U.SBR recommended for regions of heavy amount and high intensities of rainfall. PET/ Precipitation Ratio method is most effective for preliminary planning than the rest and U.S.D.A, SCS method is for areas, which receive low intensity of rainfall like southern parts of Pakistan. It has been observed as the distance from the sea increases the value of effective rainfall decreases except northern areas. While designing an irrigation project, effective rainfall can be the most advantageous for utilization of irrigation water.

Keywords: Effective rainfall, Agriculture, Agriculturists, Climate, Pakistan

Introduction

Rainwater is highly important for agriculture as well as human beings and animals that fall on the earth surface. Pakistan is a land where rainfall not only falls in summer but also in winter. During the summer monsoon period (July to September) easterly systems/depressions form in the Arabian Sea and the Bay of Bengal, produce rainfall over low elevation plains of Pakistan. August is the peak month of that season. Nearly 60% of annual rainfall over most parts of Pakistan is received during summer (June to September). Rainfall occurs primarily due to differential heating of the land and sea [3]. Kharif crop largely depends upon the amount and distribution of rain especially during monsoon season. [1]

In Pakistan, winter precipitation occurs due to the western disturbances which are generally the off-shores of mid latitude frontal systems. These disturbances move in the northeasterly direction. These disturbances pick up the moisture from Persian Gulf as well as from the Arabian Sea and not only enhance the winter rainfall but also cause rainfall over the most parts of the Pakistan during winter [12]. These rains are very important for Rabi crops in rainfed areas.

The primary source of water supply for agriculture in most parts of the world is rainfall. The characteristics of rainfall vary from place to place, day to day, month to month and also year to year. In spite of voluminous data on weather, all is not yet known about rainfall variability over temporal and spatial scale. Certain simple entities have baffled planners right up to present. One of these is "effective rainfall". In its simplest sense, effective rainfall means useful or utilizable rainfall. Rainfall is not necessarily useful or desirable at the time, rate or amount in which it is received. Some of it may be unavoidably wasted while some may even be destructive. Just as total rainfall varies, so does the amount of effective rainfall [6]. The useful portion of rainfall is stored while the rest unwanted parts need to be detached or pass on speedily.

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The term effective rainfall has been interpreted differently not only by specialists in different fields but also by different workers in the same field. To an irrigation engineer, the rain which reaches the storage reservoir directly and by surface runoff from the surrounding area indirectly is the effective portion. Agriculturists consider that portion of the total rainfall as effective which directly satisfies crop water needs and also the surface runoff which can be used for crop production on their farms by being pumped from ponds or wells. Most rain water is used in agriculture for crop production. But some part of rainfall is lost. These losses includes water intercepted by living or dry vegetation, that lost by evapotranspiration during growth of crops, that lost by evaporation from the soil surface, that fraction which contribute to leaching and percolation. Meteorologists can neither solve nor evaluate the problem of effective rainfall merely from the tables of frequency, amount and intensity of rainfall or from physical phenomena in the atmosphere [7]. It is a task in which several disciplines and sub disciplines overlap. For example, in the field of agriculture, soil types, cropping patterns and social, economical and management factors all have a direct impact on the extent of effective and ineffective rainfall [5]. In view of these facts the study was conducted to review the various methods of determining effective rainfall; to calculate the effective rainfall for Pakistan at different meteorological stations for Rabi and Kharif crop season, using selected methods and to compare the different methods of estimating effective rainfall.

Materials and Methods

This study was conducted in different climatic zones (extremely arid to very humid) during 2009 to analyse what kind of methodology should be used to measure effective rainfall and how much amount of rainfall is effective for irrigated agriculture plains of Pakistan. The rainfall was recorded (1971-2000) at different meteorological stations of those regions as per WMO standard maintained by Pakistan Meteorological Department. Following four methods described by Dastane, [5] have been used to calculate effective rainfall for the fifty-eight meteorological stations of Pakistan covering the entire country:

- Renfro Equation method
- U.S. Bureau of Reclamation method
- Potential Evapotranspiration/Precipitation Ratio method
- U.S.D.A, SCS method.

Renfro Equation.

Renfro used following mathematical equation, as quoted by chow [4] for estimating effective rainfall.

$$ER = E.R_g + A$$

Where

ER	=	Effective Rainfall
R_g	=	Growing Season Rainfall
A	=	Average Irrigation Application
E	=	Ratio of Consumptive Use of water (CU) to rainfall during the Growing season (Table-1)

Table-1: Ratio E for Use in Estimating Effective Rainfall in Renfro Equation

CU/ R_g	E	CU/ R_g	E	CU/ R_g	E
0	0.00	1.60	0.57	3.5	0.84
0.2	0.10	1.80	0.61	4.0	0.88
0.4	0.19	2.00	0.65	4.5	0.91
0.6	0.27	2.20	0.69	5.0	0.93
0.8	0.35	2.40	0.72	6.0	0.96
1.0	0.41	2.60	0.75	7.0	0.98
1.2	0.47	2.80	0.77	9.0	0.99
1.4	0.52	3.00	0.80	/	/

U.S. Bureau of Reclamation method

A method described by Stamm [14], is recommended for arid and semi arid regions and uses mean seasonal precipitation of the five driest consecutive years. Percentage marks are given to increments of monthly rainfall ranging from greater than 90% for the first 25mm or fraction thereof, to 0 percent precipitation increment above some 150mm as shown in table2.

Table-2: Effective Precipitation based on increments of monthly rainfall (U.S. Bureau of Reclamation Method)

Precipitation Increment Range	Percent	Effective Precipitation Accumulated – Range
mm		mm
0.0 – 25.4	90-100	22.9 – 25.4
25.4 – 50.8	85 – 95	44.4 – 49.5
50.8 – 76.2	75 – 90	63.5 – 72.4
76.2 – 101.6	50-80	76.2 – 92.7
101.6 – 127.0	30-60	83.8 – 107.9
127.0 – 152.4	10 to 40	86.4 – 118.1
Over 152.4	0-10	86.4 – 120.6

Potential Evapotranspiration/Precipitation Ratio

The value of effective rainfall can be calculated for a certain group of days during the growing season by taking a ratio of potential evapotranspiration (PET), taken as 0.8 of the U.S class A pan data, to the total rainfall. Rainless period are eliminated from the calculations. The ratio is expressed in percentage for each period. So, the maximum ratio cannot exceed 100. The monthly means are then computed and from these grand mean ratios are obtained for the entire growing season. Precise knowledge on soil properties or aridity is not essential. Due to the distribution of rainfall over an area, results may be under or over estimated, but the error is small. This method is rapid and economical. The soil texture and its water holding capacity along with mean monthly Evapotranspiration is as shown in table-3

Table 3: Number of Days in a Group for Different Soil Types and Climatic Conditions.

Crop	Mean monthly ETp (mm/day)	Soil texture and water storage capacity (mm/m).			
		Light (below 40)	Medium (40 to 80)	Heavy (80 to 120)	Very heavy (over 120)
Rice	3 to 12	2	3	4	7
Other	Over 6	4	7	10	15
crops	Below 6	7	10	15	30

U.S.D.A, SCS method.

The U.S.Department of Agriculture's Soil Conservation Service has developed a procedure for estimating effective rainfall by processing long climatic and soil moisture data. To avoid high degree of complexity, neither the soil intake rate nor rainfall intensities are considered in this method. From total rainfall and monthly consumptive use, effective rainfall values were computed (Table-4). The values were based on a 3 inches or 75mm net irrigation application which is equal to the available storage capacity in the root zone at the time of irrigation application. To convert this data to other net depts., factors were worked out which are shown in Table-5.

The monthly effective rainfall cannot exceed the rate of consumptive use or ETcrop. If it does, the lower value of the two is taken.

Table 4 Average monthly effective rainfall as related to mean monthly rainfall and mean monthly consumptive use (USDA, SCS)

Mean Monthly Consumptive Use (mm)	Monthly Mean Rainfall															
	12.5	25	37.5	50	62.5	75	87.5	100	112.5	125	138	150	163	175	187.5	200
	Average Monthly Effective Rainfall in mm															
25	8	16	24													
50	8	16	25	32	39	46										
75	9	18	27	34	41	48	56	62	69							
100	9	19	28	35	43	52	59	66	73	80	87	94	100			
125	10	20	30	37	46	54	62	70	76	85	92	98	107	116	120	
150	10	21	31	39	49	57	66	74	81	89	97	104	112	119	127	133
175	11	23	32	42	52	61	69	78	86	95	103	111	118	126	134	141
200	11	24	33	44	54	64	73	82	91	100	109	117	125	134	142	150
225	12	25	35	47	57	68	78	87	96	106	115	124	132	141	150	159
250	13	25	38	50	61	72	84	92	102	112	121	132	140	150	158	167

Table 5 Multiplication factors to related monthly effective rainfall values obtained from table-4 to net dept of irrigation application (d) in mm.

Effective Storage	20	25	37.5	50	62.5	75	100	125	150	175	200
Storage Factor	0.73	0.77	0.86	0.93	0.97	1.00	1.02	1.04	1.06	1.07	1.08

Effective rainfall have been calculated for two crop growing seasons, one is Rabi (October to April) and the other is Kharif (May to September). Four different values of net depth of irrigation water requirement have been assumed for estimating rainfall during the crop-growing season by Renfro equation method and USDA, SCS method. The values are 25, 50, 75 and 100mm.

For the estimation of effective rainfall by Potential Evapotranspiration/Precipitation ratio method, four different values soil texture and water storage capacity i.e. light(below 40),medium(40 to 80),heavy(80 to 120) and very heavy (over 120).

Results and Discussion

Using mean monthly consumptive use data of different meteorological stations, the effective rainfall values for both Kharif and Rabi season have been calculated. For expediency, effective rainfall values are plotted only for 25mm and 100mm depth of irrigation with soil texture and storage capacity, light (below 40) and very heavy (over 120) respectively (Fig-1). It is observed that percentage effectiveness is higher in those areas which have little amount of rainfall during the seasons. Southern and most of the central parts of Balochistan and Northern Areas have little amount of rainfall during Kharif than Rabi season, therefore rainfall effectiveness is higher. While rest of the country have more rainfall in Kharif than Rabi due to which effectiveness decreases especially in northeastern parts of Balochistan, lower Sindh, upper Punjab, upper NWFP and Azad Kashmir regions. A soil has a definite and limited water intake rate and moisture holding capacity. Hence greater intensities of rainfall normally reduce the effectiveness. Higher intensities increase the run-off and reduce the infiltration. Similarly, uneven distribution decreases the extent of effective rainfall while an even spread enhances it. A well distributed rainfall in frequent light showers is more conducive to crop growth than heavy downpours. Benjamin et al. [2] also observed similar results in china.

In Pakistan (especially Punjab, NWFP and Azad Kashmir regions), the intensity, frequency and amount of rainfall are higher in Kharif season than in northern areas and most of the areas of Balochistan. Due to low amount of rainfall, a little or almost no water is lost through surface runoff, deep percolation and seepage. As the temperature is low during the Rabi season the evaporation loss from the land is relatively low. The methods except Potential Evapotranspiration/ Precipitation Ratio method that have been used for estimation of effective rainfall, calculation neglect retention losses. During Kharif season, the temperatures are high due to which more evaporation increases and effectiveness decreases.

The Renfro Equation method gives the lowest values of effective rainfall, among the four methods which have been used. Another aspect of this method, the more the average depth of irrigation application the higher is the effective rainfall. With this method one can only calculate the total growing season (such as October to April, May to September) effective rainfall, but not for a short period (such as ten days period, monthly period). It does not serve the purpose while short term planning or irrigation scheduling is required.

The Renfro Equation method is too empirical. It may not suit in many situations. The “E” (a constant dependent upon the ratio of consumptive use of water (CU) to rainfall during the growing season) values, which have been used to work out the effective rainfall are given without considering the runoff and type of crop. It only considers aridity and makes assumption about the soil. So, it can be concluded that the accuracy of this method is too low. Greater the value of E higher will be the effective rainfall. Dastane [5] also concluded similar findings. Therefore, for quick determination of effective rainfall during Rabi season with the net depth of irrigation water application of 100mm, 22.11% at like Murree and the lowest value with the net depth of irrigation water application of 25mm is 13.03% at Murree (fig-1d). During Kharif season, with net depth of irrigation is 100mm and 25mm, effective rainfall is 28.25% and 21.31% at Murree respectively (fig-1i).

With the help of U.S.Bureau of Reclamation (U.S.B.R) method the seasonal effective rainfalls as well as monthly effective rainfall have been calculated. Quick estimation of effective rainfall is the principal features of this method. But the U.S.B.R. method is not considered satisfactory. Because this method does not take into account the type of soil, nature of the crop and frequency and distribution of rainfall. It also does not consider the aridity factor. This method has been developed only considering surface runoff. This method is recommended for arid and semi arid regions. Among the values of effective rainfall obtained for Kharif season, the highest value is 100% at southern Balochistan (fig-1q) and lowest value is

30% at northeastern Punjab (fig-1s). During Rabi season, the highest value is 99.86% at central Sindh regions (fig-1o) and lowest value is 43% at northeastern Punjab (fig-1n). The U.S.B.R method is not suitable for use under all sorts of conditions. Patwardhan et al. [10] also supported this method.

Potential Evapotranspiration/Precipitation Ratio method is a simple semi empirical method. With the help of this method the total growing season effective rainfall as well as the effective rainfall for a certain group of days can be computed. The number of days in a group is based on the soil type or soil moisture properties as well as general weather conditions or evapotranspiration rates. The maximum number of days in a group is 15 during warm weather and 30 during cool weather Dastane [5]. But in this study due to non availability of required data, one month has been used as a group for both the Kharif and Rabi seasons.

In the PET/Precipitation Ratio method, effective rainfall varies with the potential evapotranspiration, with the seepage and percolation losses and also the soil type or soil moisture properties. Higher the value of these losses, higher will be the value of effective rainfall. The lower the water holding capacity of the soil the higher will be the evapotranspiration rate. Greater the water holding capacity greater will be the value of effective rainfall. The value of PET remains almost below 6mm/day during Rabi season and for Kharif season, it remains greater than or equal to 6mm/day in Pakistan. Therefore, four different types of soil texture and water storage capacity were considered. In this method, water storage capacity is considered the part of effective rainfall. During Rabi, the highest value of effective rainfall is 98.83% at southeastern Sindh and lowest 17.57% at northwestern NWFP while in Kharif, the highest value of effective rainfall is 99.92% at southwestern Balochistan and lowest is 37.58% at northern NWFP. During Rabi, with the light texture, soil has water storage capacity of 7mm/m along with potential evapotranspiration below 6mm/day, the highest value is 98.87% at southeastern Sindh and lowest is 18.73% at northwestern NWFP (fig-1e&1c). For very heavy soil, which has water storage capacity of 30mm/m, highest value is 98.98% at southeastern Sindh and lowest 21.81% at northwestern NWFP (fig-1o&1m). During Kharif, with the light texture soil which has water storage capacity of 4mm/m along with potential evapotranspiration is equal to or above 6mm/day, the highest value is 99.92% at South western Balochistan and lowest at 34.52% at northern NWFP(fig-1,g-h). For very heavy soil which has water storage capacity of 15mm/m the highest value is 99.93% at Southwestern Balochistan and lowest at 36.95% at northern NWFP (fig-1,q-r). This method is most suitable among the four methods. In this method approximation have been made about the run off and soil properties. Aridity also has been considered. Dastane [5] suggests in the case of rice, instead of evapotranspiration, total water loss, which is evapotranspiration plus percolation a loss, is used for computation. This method is laborious but most accurate and inexpensive. Mohan et al. [8] also supported this result.

In the U.S.D.A, SCS method, the effective rainfall varies with the net depth of irrigation and consumptive use of crop. The greater the depth of irrigation water, consumptive use water, higher will be the value of effective rainfall. After comprehensive analysis of climatical and soil data at different experimental stations, this method has been developed. The accuracy of this method is high. Similar observations also found by Obreza and Pitts [9].

With the U.S.D.A, SCS method, the highest value of effective rainfall in Rabi season is 100% at southern parts of Pakistan when net depth of irrigation of water application of 100mm and the lowest is 54.40% at southern Balochistan when net depth of irrigation of water application of 25mm(fig-1b) . The highest value of effective rainfall during Kharif season is 100% at southern Balochistan and central Sindh regions(fig-1,q&t); when net depth of irrigation of water application of 100mm and lowest value is 60% at southwestern Balochistan when net depth of irrigation of water application of 25mm.

The highest values of effective rainfall by using four methods are calculated in different meteorological stations. During Rabi, upper NWFP, Northern Areas (except Gilgit and Gupis) and west to northwestern parts of Balochistan have high amount of rainfall than other regions while in Kharif season the rest of the country has high amount of rainfall. Only those stations have highest value of effective rainfall, which has

low amount of growing season rainfall, and high values of consumptive use than the other stations of the country either it is Rabi or Kharif season. With the combination of these two factors, higher values of effective rainfall will be observed in these regions. Simmers et al. [13], Rahman et al. [11] and Patwardhan et al. [10] also observed similar findings.

Murree has the lowest value of effective rainfall in both seasons. While Dir has lowest value of effective rainfall during Rabi. The growing season rainfall for Murree is 825mm and 1082mm during Rabi and Kharif respectively while at Dir is 924mm during Rabi season. The rainfall intensity at both these stations is very high. So, water lost through the surface runoff is high. Because of these reason both stations have lowest value of effective rainfall among all the meteorological stations.

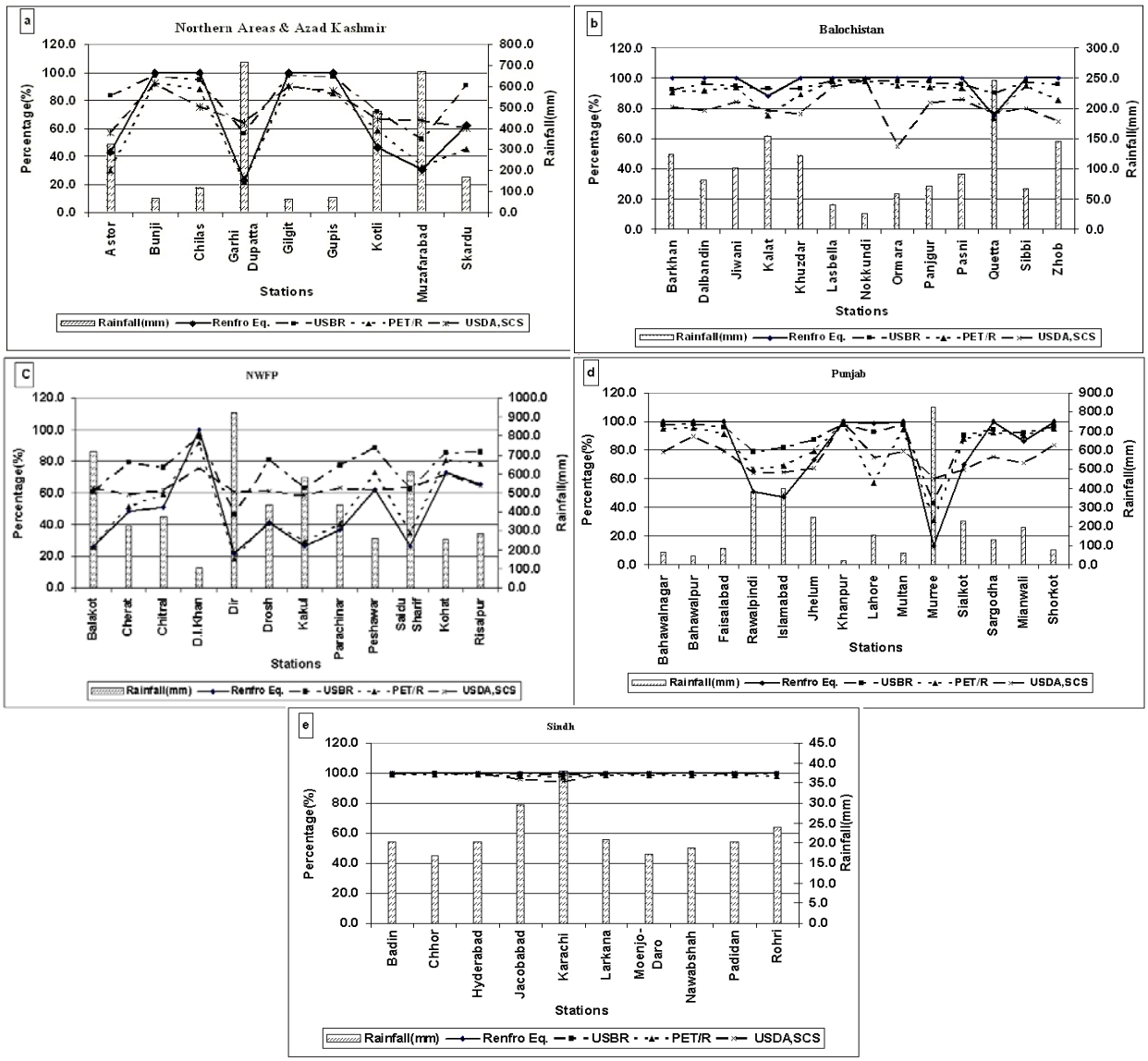

Fig-1(a-e).Percentage of Effective Rainfall during Rabi Season of Pakistan when depth of irrigation water application 25mm, Soil Texture & Storage Capacity, Light (below 40) mm/m

The effective rainfall depends upon various factors, like land characteristics and soil characteristics, soil water characteristics, ground water characteristics etc Dastane [5]. These factors are different for the fifty eight meteorological station of Pakistan. Some characteristics of soil have been considered in this study along with consumptive use and rainfall. So we can not expect a high degree of accuracy from this study. Uribe et al. [15] and Zimmermann [16] observed similar result.

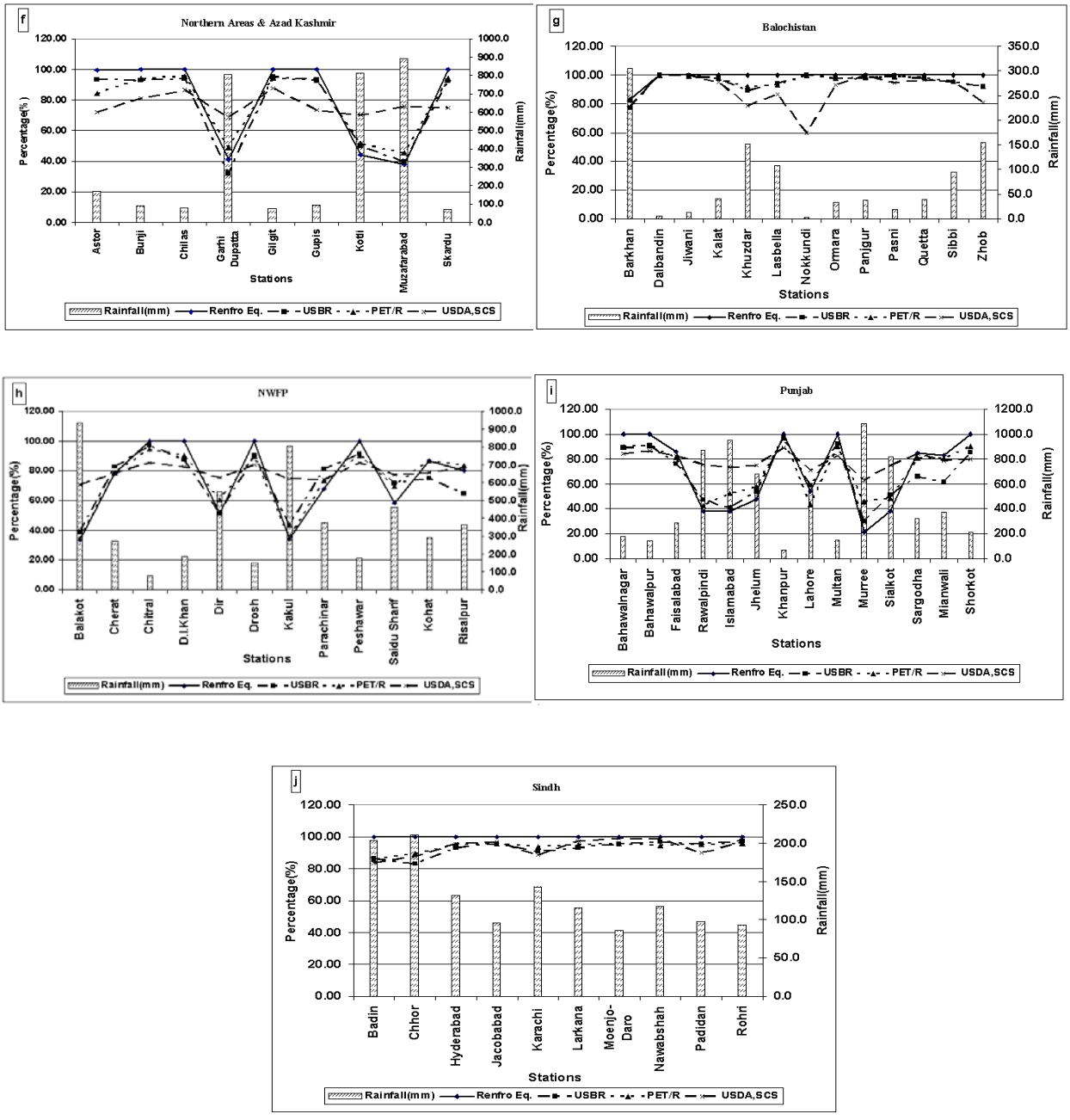

Fig-1(f-j). Percentage of Effective Rainfall during *Kharif* Season of Pakistan when depth of irrigation water application 25mm, Soil Texture & Storage Capacity, Light (below 40) mm/m.

Rainfall should satisfy not only the consumptive needs of crops but also leaching, land preparation needs, percolation needs etc. It is more suitable and precise to use the total water needs of the crops in calculating effective rainfall. The PET/Precipitation Ratio method gives effective rainfall considering the seepage and percolation losses along with soil texture and water storage capacity. More accurate values of Effective rainfall can be calculated by taking actual soil characteristics, seepage and percolation losses Uribe et al. [15].

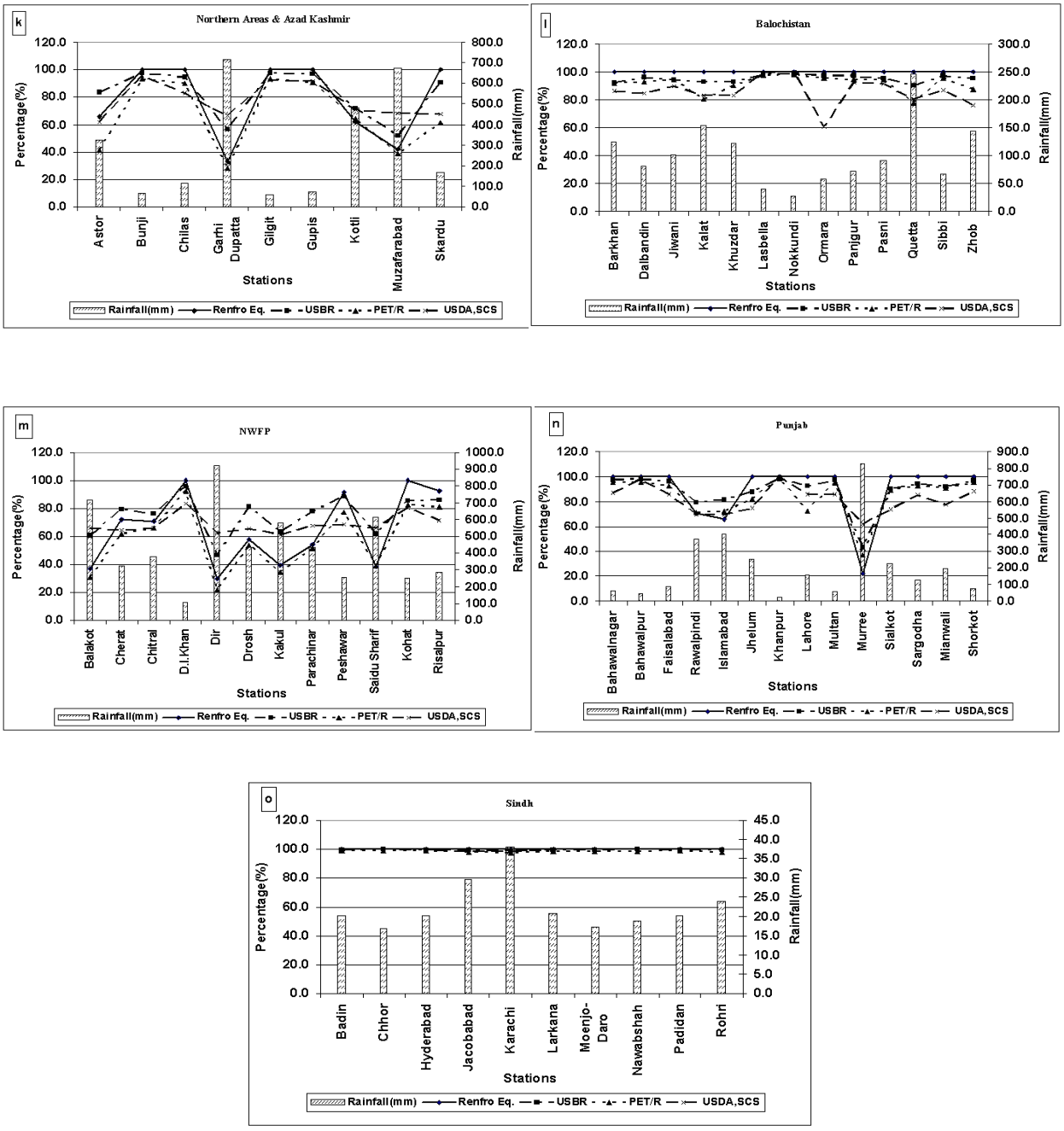

Fig-1(k-o).Percentage of Effective Rainfall during Rabi Season of Pakistan when depth of irrigation water application 100mm, Soil Texture & Storage Capacity, very heavy (over 120) mm/m.

Renfro Equation method first approximation is soil along with aridity factor. The accuracy of this method is low and it is too empirical. USBR method considers only the runoff. It may be used those regions of the country which has heavy amount of rainfall along with high intensities. The accuracy of this method is low and not suitable for wide use. In PET/Precipitation Ratio method takes first approximation is run off, soil and aridity factor. This method is suitable for very preliminary planning and most effective than the rest methods almost through out the country. USDA, SCS method takes first approximation of soil and crop along with aridity factor. This method is good for those areas which have low intensity of rainfall and high infiltration rate. This method is recommended especially in most parts of Balochistan, southern Punjab and Sindh regions. The accuracy of these above two mention method is medium. It has been observed as the distance from the sea increases the value of percentage effective rainfall decreases.

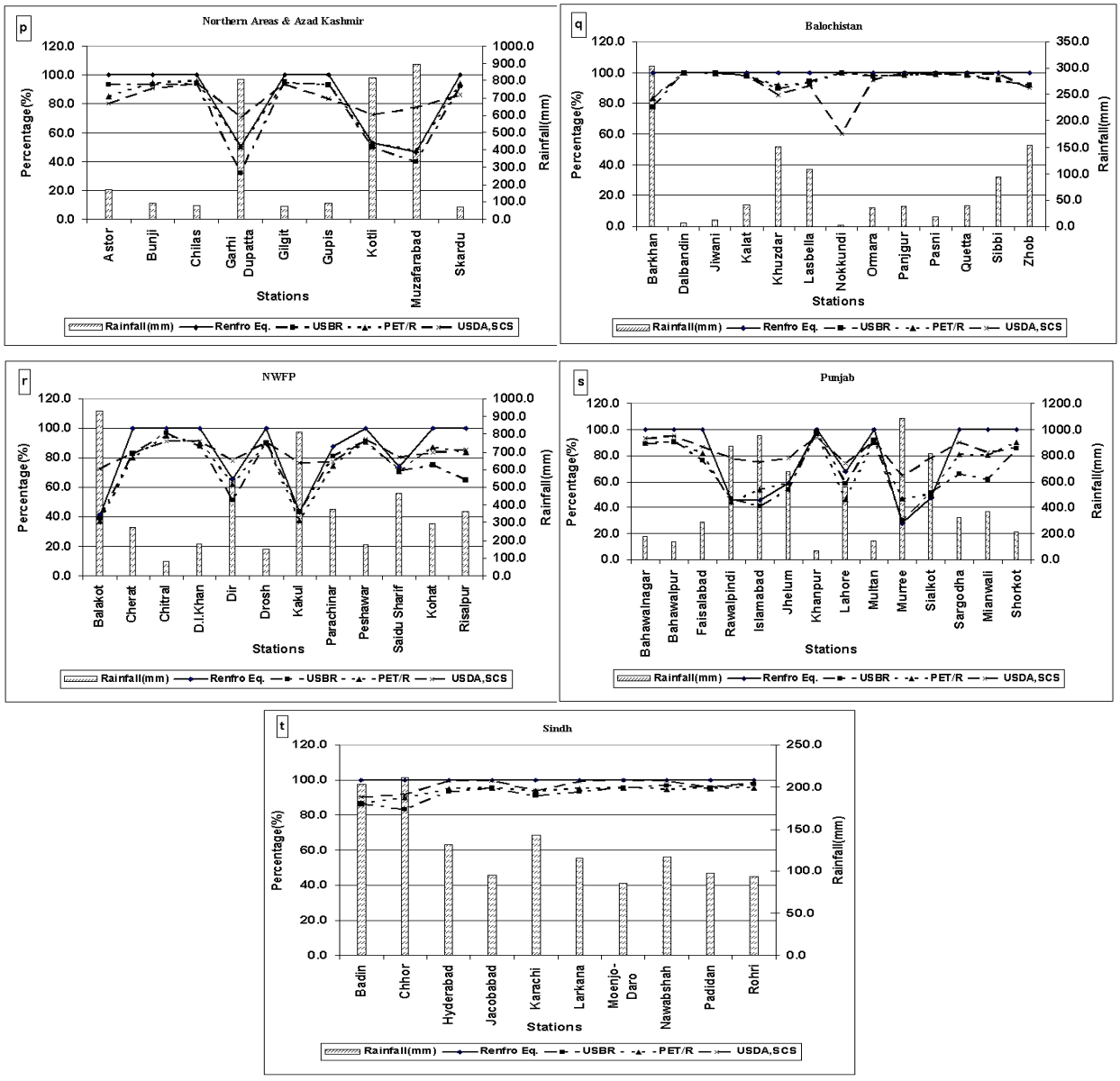

Fig-1(p-t).Percentage of Effective Rainfall during Kharif Season of Pakistan when depth of irrigation water application 100mm, Soil Texture & Storage Capacity, very heavy (over 120) mm/m.

A method used for estimating effective rainfall must include surface runoff, evapotranspiration and crop characteristics. For field use, the method should be simple, accurate, inexpensive and rapid. It should be useful for broad regional planning or precise irrigation scheduling under a given set of conditions. These methods used are relatively simple, rapid and inexpensive than the rest methods like Ramdas apparatus method, integrating gauge, drum technique. However, a high degree of precision can be attained with these methods by considering various influencing factors. The information on effective rainfall can be used for design of irrigation projects, design and operation of drainage systems, leaching of slats, rice cultivation, planning of irrigation systems using ground water and for rainfed agriculture. Dastane [5], Mohan et al. [8] and Rahman et al. [11] also have the similar results.

Conclusions

It may be concluded that effective rainfall is directly proportional to consumptive use, water storage capacity, irrigation application and seepage and percolation losses. In USDA, SCS method, greater the depth of irrigation water, greater will be the value of effective rainfall. Greater the storage capacity greater will be the effective rainfall as in case of PET/Precipitation ratio method. Effective rainfall is inversely proportional to the amount and intensity of rainfall. Effective rainfall for Rabi season (October to April) varies widely from 13.03% at northeastern Punjab to 100% at several stations through out Pakistan. During Kharif season (May to September) effective rainfall percentage varies widely from 21.31% at northeastern Punjab to 100% at most stations in the country. Murree has the lowest amount of effective rainfall than rest of the country while the southern parts of the country have high value of effective rainfall. For short term, (decadal or monthly) calculation of effective rainfall Renfro Equation method is not suitable in Pakistan. USBR method is suitable for areas of heavy amount and high intensities of rainfall. PET/Precipitation Ratio method is suitable for very preliminary planning and most effective than the rest methods almost through out the country. USDA, SCS method is recommended especially for southern parts of Pakistan because of low intensity of rainfall. It has been observed as the distance from the sea increases the value of effective rainfall percentage decreases except northern areas.

Recommendations

These methods are mainly developed for USA. So, these methods should be modified and improved of Pakistan if necessary by comparing the practical values. The experimental data may be collected by lysimeters in the field. This study is carried out form the irrigation point of view. The same study can be carried out for other purposes, such as flood control engineering, hydro-electric engineering, Geohydrology, etc.

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