GROUNDWATER RECHARGE QUANTIFICATION FROM RAINFALL IN PESHAWAR DISTRICT-KHYBER PAKHTUNKHWA

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ABSTRACT

Water is an unlimited and exquisite gift which has been given by nature. However, its increasing demand and current pattern of usage are threats to human welfare, livelihood, development, and for the life itself, in the coming years. The main objective of this study was to quantify the ground water recharge due to rainfall on yearly basis of Peshawar district Khyber Pakhtunkhwa Province of Pakistan. Groundwater recharge was estimated by subtracting runoff from the rainfall. The Soil Conservation Service Curve Number (SCS-CN) method was used to estimate the runoff produced from rainfall events. As per the data provided by Pakistan Metrological Department, Peshawar, average annual rainfall in district Peshawar during 2002-2011 was 486.1 mm. The weighted curve number (CN) was found to be 82.0. Mean annual runoff produced was estimated to be 217.0 mm where as mean annual recharge to the groundwater was calculated and found to be 269.1 mm. Different water conservation techniques are recommended to increase water recharge in the study area.

KEY WORDS: *Weighted CN, Groundwater recharge, Rainfall, SCS-CN, Runoff*

INTRODUCTION

Water is an essential component for the survival of all living organismsand is considered the backbone of agriculture and ecological balance. However, the speedy industrialization, population growth, and agricultural practices leads to overexploitation of ground water resources (Ibrahim, 2009).The hydrosphere of the earth contain 1,386 million cubic kilometer. However its 97.5% is salineand 2.5% is fresh. Out of the total mass of fresh water,68.70% is present in glaciers and ice caps,29.9% is stored as underground deposits, and 0.26% is found in the form of lakes, reservoir and river systems (Shiklomanov, 2000).

Groundwater is the water which is found below the earth surface in soil pores and in the fractures of geological rock formations. Being one of the largest sources of water supply, groundwater has numerous advantages upon the surface water i.e. it is of higher quality, free from pollution including infection, less subject to seasonal and perennial variations, and considerably more uniformly spread over vast regions than surface water. Globally groundwater as a largest accessible deposit of fresh water constitute 36% drinking water and 42% of irrigation water (Doll et al., 2012). In majority of the semi-arid and arid regions where surface waters are seasonally or perennially absent, groundwater is the only reliable source of fresh water (Taylor et al., 2012). Taylor et al. (2012) reported that for many communities groundwater is the perennial source of drinking water and irrigated agriculture and its quantity is dependent on the sustainable groundwater recharge. Out of the total irrigated land in the United States of America (USA), 45% is irrigated by groundwater, 67% in Algeria, and 58% in Iran, while in Libya irrigated farming is wholly based on groundwater (Zektser & Everett, 2004).

In Pakistan, per capita surface water availability was 5260 m3/year in 1955, which has reduced to 1036 m3/year in 2012. The situation is worsening and with the increasing population, and industrialization may further reduce to about 860 m3/year by 2025 representing acute water scares condition. While, the minimum water requirement to evade food and health limitations due to being a “water short country” is 1000 m3/year (WAPDA, 2014). The average annual rainfall in Pakistan is 290 mm and only 18.26 million ha-m appears as average annual potential flow in rivers while the total ground water resources of the country are 6.91million ha-m(PILDAT, 2003).

In Peshawar district, groundwater is used for domestic, industrial, commercial and irrigation purposes. Sources of groundwater reservoir in Peshawar areseepage from unlined canals, infiltration, precipitation, water applied

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for irrigation and water stored in depressions.

Study Area

Peshawar is the provincial capital of Khyber Pakhtunkhwa. Geographically it is located between 33.73° to 34.25° N and 71.37° to 71.70° E. Its total area is 1,257 km2 and is approximately 358 m above the sea level. In 1998, the total population of Peshawar district was estimated to be 2.019 million. It is surrounded by Charsadda district and Mohmand Agency in the north, FR Kohat and FR Peshawar in the south, Khyber Agency in the west, and Nowshera district in the east. The central part of the district contains fine alluvial deposits. The cultivated territories consist of a rich, light and porous soil, composed of a mixture of clay, silt and sand which is suitable for cultivation of tobacco, wheat, and sugar-cane (Population Census Organisation, 1998). Location map of the study area is shown in Fig. 1.

Figure 1: Location map of district Peshawar

DATA AND METHODOLOGY

Recharge from Rainfall to the Ground Water

This study was conducted out to quantify ground water recharge from rainfall of Peshawar district of Khyber Pakhtunkhwa for the years 2002 to 2011. To calculate the amount of groundwater recharge, the surface runoff is subtracted from rainfall. The widely used simple and semi empirical conceptual model of surface runoff estimation which is supported by empirical data and wide experience is the Soil Conservation Service Curve Number (SCS-CN) model presently known as the Natural Resources Conservation Services Curve Number (NRCS-CN) (Ajmal et al., 2015; Ajmal et al., 2016; Mishra et al., 2006). Its simplicity, less number of parameters requirement, and flexibility makes it the most popular method among engineers and practitioners for field applications (Ajmal et al., 2015;Ponce and Hawkins, 1996).

In the SCS-CN model, the runoff depth (Q) is generally estimated from the rainfall depth (P) and the initial abstraction (I_a) as follows: (Ajmal et al., 2015b; Ponce, 1989;Ponce and Hawkins, 1996) and is given as:

$$Q = \frac{(P - I_a)^2}{P - I_a + S} = Q = \frac{(P - \lambda S)^2}{P + (1-\lambda)S} \qquad P > I_a(\lambda S), \quad \text{else} \quad Q = 0 \tag{1}$$

Where the terms Q, P, λ, and S arethe direct runoff, total rainfall occurred, initial abstraction coefficient, and potential maximum retention respectively. In Eq. (1), the initial abstraction (I_a) accounts for canopy interception, infiltration into the land during early parts of the storm and surface depression storage (Ajmal et al., 2015c;Wang et al., 2012). In the USA, the NRCS (2004) evaluated data from numerous small agricultural watersheds and recommended λ=0.2 for the general field applications. Eq. (1) can be simplified after inserting λ=0.2 as;

$$Q = \frac{(P - 0.2S)^2}{P + 0.8S} \qquad P > 0.2S, \quad \text{else} \quad Q = 0 \tag{2}$$

Here S is a transformed value for the dimensionless curve number (CN) obtained from watershed characteristics as:

$$S = 2.54\left(\frac{100}{CN} - 1\right) \tag{3}$$

In view of the popular SCS-CN model, the CN is obtained from combination of the watershed characteristics and climatic factors (Ajmal, Moon, et al., 2015). In other words, the CN is a function of land use/land cover, hydrologic conditions, hydrologic soil group, and antecedent moisture conditions (AMC) (Jain et al., 2006; Mishra et al., 2008). The CN value can be selected from the NRCS (2004) documented tables for various soil types and hydro-climatological conditions, but it is preferable to estimate the CN value from observed rainfall-runoff relationship if available (Soulis & Valiantzas, 2012).

Hydrologic Soil Group (HSG)

Based on the Hydrologic Soil Groups, all types of soils are categorized into four groups i.e. A, B, C, and D. Each group has different runoff producing properties. Details of each type of soil are given in Table 1, while the soil types were distinguished using hydrometer analysis.

Land Use Data

The effect of the watershed surface condition was assessed through the land use data. The land use denotes the watershed cover, which includes vegetation, litter and mulch, fallow (bare soil), water surfaces, impervious sections, and urban areas. Peshawar district wasdivided into eleven land use classes such as: agriculture (66.88%), settlements (16.54%), barren land (6.53%), range land (4.46%), river beds (3.31%), forest (0.65%), roads (0.57%), shrubs and bushes (0.41%), fruit orchards (0.32%), canal (0.3%), and water bodies (0.03%).

Antecedent Moisture Condition

Based on the total rainfall in five days period preceding a storm, the antecedent moisture conditions were classified into three levels i.e. AMC I, AMC II, AMC III and are shown in Table 2. In this study average antecedent moisture condition (AMC II) was assumed.

RESULTS AND DISCUSSION

Rainfall data

The rainfall data during 2002-2011 was collected from metrological department Peshawar and is shown in Table 3. Average annual rainfall in the study area comes out to be486.1 mm. The year 2002 shows significant increase from the mean value while rest of the years are less fluctuated. In addition,it is indicated that extreme rainfall event of 294.10 mm occur in the month of June, 2010 which causes devastating flood in Peshawar.

Table 1: Hydrologic Soil Group (USDA SCS, 1986)

S. No.	Soil Group	Type of Soil	Runoff Potential
1	A	sand, loamy sand or sandy loam	Low
2	B	silt loam or loam	Moderate
3	C	sandy clay loam	High
4	D	clay loam, silty clay loam, sandy clay, silty clay or clay	Very High

Table 2: Rainfall limits for three levels of AMCs (USDA SCS, 1985)

AMC Class	5-day cumulative rainfall preceding a storm (cm)	
	Dormant Season	Growing Season
I (dry soil)	< 1.25	< 3.50
II (average condition of soil)	1.25−2.75	3.50−5.25
III (wet soil)	> 2.75	> 5.25

Determination of Hydrologic Soil Group and weighted CN

To determine the hydrologic soil group of each land cover, hydrometer analysis of soil samples collected from agricultural, settlements, barren land, range land, shrubs and bushes, fruit orchards, and forest were executed. The roads, river beds, canals, and water bodies were discountedas it has the same CN for all types of hydrologic condition(USDA SCS, 1986).The soil samples locations along with soil type, determined by hydrometer analysis, are given in Tables 4. A clay loam and silty clay loam soil were found in the urban sections while the rest of the land covers samples shows the silt and silt loam conditions. The hydrologic soil groups of each land cover were assumed based on the result of hydrometer analysis of the collected samples. The settlement portion hydrologic soil group comes out to be highly runoff producing i.e. D and the remaining classes shows B condition which has the moderate runoff potential. Further detailed are mentioned in Table 5.

The Peshawar district were sorted out to eleven land use classes and each class was assigned runoff CN according USDA SCS TR-55 Manual (1986). The CN of each land cover was multiplied by their occupied percent area. The products were summed, then divide

Table 3: District Peshawar monthly rainfall (Pakistan Meteorological Department, 2014)

Year	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
January	2.00	33.00	109.00	131.00	55.30	0.00	63.50	30.10	20.60	0.60
February	76.00	131.50	93.00	112.20	17.50	159.10	8.90	35.30	94.70	80.00
March	73.00	66.00	0.00	139.20	27.40	81.00	10.60	48.50	10.00	19.40
April	21.00	129.00	60.00	29.80	15.30	14.60	107.10	96.10	20.10	26.30
May	8.00	23.00	0.00	37.00	5.00	21.80	2.70	42.60	13.90	17.90
Jun	53.00	10.00	0.00	0.00	24.80	54.10	9.60	2.60	29.20	2.80
July	0.00	156.00	7.00	31.00	56.60	50.80	63.30	22.50	294.10	33.80
August	87.00	114.00	57.00	11.60	8.00	18.20	136.30	43.50	95.40	167.40
Septem-ber	20.00	111.00	35.00	71.30	5.80	13.20	12.00	14.60	8.30	45.00
October	2.00	70.00	24.60	4.00	15.00	0.00	0.00	0.00	0.00	31.30
Novem-ber	8.00	42.00	15.60	12.30	21.00	7.00	1.60	16.00	0.00	19.60
Decem-ber	38.00	19.00	34.40	0.00	60.00	0.00	13.80	0.60	9.20	0.00

Table 4: Soil sampling locations and basic information

Soil Sample No.	Soil Class	Sample Locations	Latitude (o)	Longitude (o)	Soil Type
PR-01	Forest	RegiLalma	34.05 N	71.45 E	Silt Loam
PR-02	Agricultural Land	RegiLalma	34.04 N	71.45 E	Silt
PR-03	Agricultural Land	NasirPurPatik	34.02 N	71.67 E	Silt
PR-04	Agricultural Land	BudniNala, Charsadda Road	34.06 N	71.61 E	Silt Loam
PR-05	Agricultural Land	Charpariza, Pajjagai	34.08 N	71.53 E	Silt Loam
PR-06	Barren Land	RegiLalma Town	34.03 N	71.41 E	Silt Loam
PR-07	Forest	RegiLalma Grave Yard	34.04 N	71.47 E	Silt Loam
PR-08	Range Land	ShafaKhanyKhwar, Adezai	33.81 N	71.64 E	Silt
PR-09	Range Land	UchNeher	33.86 N	71.68 E	Silt Loam
PR-10	Range Land	Tela Band	33.86 N	71.67 E	Silt
PR-11	Barren Land	AdezaiAzakhel	33.78 N	71.60 E	Silt
PR-12	Barren Land	Matanni	33.81 N	71.56 E	Silt Loam
PR-13	Barren Land	Badbher	33.90 N	71.53 E	Silt Loam
PR-14	Agricultural Land	Badbher	33.90 N	71.54 E	Silt Loam
PR-15	Settlement	Faqir Abad	34.02 N	71.58 E	Silty Clay Loam
PR-16	Settlement	Small Industrial town	33.98 N	71.56 E	Silty Clay Loam
PR-17	Settlement	Hayat Abad	33.98 N	71.44 E	Clay Loam
PR-18	Forest	Haryana Payan	34.08 N	71.57 E	Silt

the sum by 100 to determine the weighted CN which comes out to be 82.0.

Recharge to the groundwater

Annual recharge to the ground water reservoir for the period 2002-2011 was determined by excluding annual runoff produced from the rainfall and are shown in Tables 6. In addition,Fig 2 shows clear variation of the rainfall, runoff, and recharge for 2002-2011. In 2003 and 2010, the runoff concentration was higher than recharge because of significant rainfall; 2005 shows almost balance situation; and in the remaining years recharge was more than the runoff.Yousafzai et al(2008) reported that the ground water is the main source for irrigation, domestic, and industrial consumption in Peshawar district.The ratio between runoff produced and rainfall amount comes out to be 0.45. Itindicates thatample amount of rain water is wasting which isrequired to be reduced.

Table 5: CN from land cover, watershed characteristics, and HSG

Cover type	Cover condition	Percent area	HSG	CN
Agricultural Land	Straight row crops	66.88	B	78
Settlement	Commercial and business	16.54	D	94
Barren Land	-	6.53	B	86
Range Land	Mixture of grass, weeds and low-growing brush with poor hydrologic condition	4.46	B	80
Forest	Fair hydrologic condition	0.65	B	60
Roads	-	0.57	-	98
Shrubs and Bushes	Good hydrologic condition	0.41	B	98
Fruit Orchards	Good hydrologic condition	0.32	B	58
Rivers	-	3.31	-	97
Canal	-	0.03	-	100
Water Bodies	-	0.3	-	100
Weighted CN				82.0

Table 6: Yearly groundwater recharge from rainfall

Year	Rainfall (mm)	Weighted CN	S (mm)	Actual runoff (mm)	Annual groundwater recharge (mm)
2002	388.8	82.0	55.9	143.9	244.9
2003	904.5	82.0	55.9	474.8	429.7
2004	435.6	82.0	55.9	171.6	264.0
2005	579.4	82.0	55.9	286.2	293.2
2006	311.7	82.0	55.9	73.1	238.6
2007	419.8	82.0	55.9	184.4	235.4
2008	430.2	82.0	55.9	201.0	229.2
2009	351.81	82.0	55.9	105.5	246.3
2010	595.5	82.0	55.9	344.4	251.1
2011	443.5	82.0	55.9	185.3	258.2
Mean	486.1	-	-	217.0	269.1

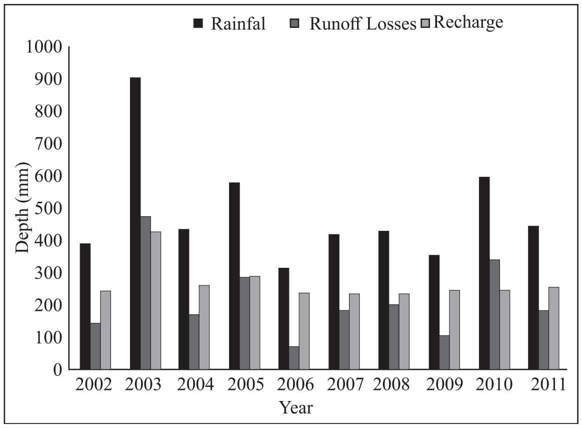

Figure 2: Yearly groundwater recharge from rainfall

CONCLUSIONS

From 2002-2011, mean annual rainfall occurred in district Peshawar was 486.1 mm. Out of which 217.0mm was lost as a runoff (45% of the total rainfall occurred) and total recharge to groundwater during this period was 269.1 mm(which is 55 % of the total rainfall occurred). This information is quite productive as a major portion of this precious water is lost as runoff which needs to be reduced and discouraged through some techniques like the construction of retention and detention ponds, improving infiltration capacity of the soil etc. This is because the ever expanding population of District Peshawar is going to disturb the balance of recharge and discharge of groundwater. Similar studies can be extended to other parts of the country. Groundwater recharge due to seepage from canal is required to be measured and by considering evapotranspiration and the calculation of outflow will make the results much more reliable and interesting.

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