RESULTS AND DISCUSSIONS

1. <u>Land use evolution in the study area</u>

1.1 The land use change between 1980 and 2000

The land use change between 1980 and 2000 conducting by matrix operation are shown in Table 16 and Table 17 in the form of coincident matrix. An interaction of land use types is explained in Figure 18 by showing the land use change pattern. The land use change between 1980 and 2000 can be briefly described as follows:

Forest: About 188,475 ha (38%) forest area in 1980 were converted into agriculture in 2000, while about 1,625 ha (0.3%) into urban land, 825 ha (0.16%) into water bodies and 290,100 ha (59%) were remained as forests.

Agriculture: About 93,500 ha (8%) of agricultural area were converted into forests area, while 7,250 ha (0.6%) into urban, 19,250 ha (1.8%) into water bodies and 906,400 ha (87%) were remained as agricultural land.

Urban: About 1,600 ha (71%) of urban land area in 1980 were changed to agriculture in 2000 and another 75 ha (3%) of it were converted to water bodies as because the people moved to other places after the construction of Pasak Jolasid dam. Only its 25% of land area were remained as urban area in 2000.

Water: About 275 ha (30%) of water bodies in 1980 became forest in 2000 and equal amount converted to agriculture. It was because these areas (once wider channel) became narrowed by the expansion of adjacent agricultural areas and some areas became dried up and converted to reforestation activities. Only 350 ha (38%) were remained as water bodies.

Miscellaneous: About 40,950 ha (75%) of miscellaneous land including bare land, grass land in 1980 were converted to agriculture and 13,075 ha (23%) were changed to reforested areas in 2000.

Table 16 Coincident matrix of areal land use change (in ha) between 1980 and 2000, Pasak watershed

Unit: ha

1980\2000	Forest	Agriculture	Urban	Water	Misc.*	Total 1980	(%)
Forest	290,100	188,475	1,625	825	10,525	491,550	(30.89)
Agriculture	93,500	906,400	7,250	19,250	14,075	1,040,475	(65.49)
Urban	000	1,600	575	075	000	2,250	(0.14)
Water	275	275	000	350	000	900	(0.05)
Misc.	13,075	40,950	050	075	575	54,725	(3.43)
Total 2000	396,950	1,137,700	9,500	20,575	25,175	1,589,900	(100.00)
(%)	(25.01)	(71.51)	(0.61)	(1.27)	(1.60)	(100.00)	

Table 17 Probability coincident matrix of land use change between 1980 and 2000, Pasak watershed

1980\2000	Forest	Agriculture	Urban	Water	Misc.	Total
Forest	**0.5901**	0.3834	0.0033	0.0016	0.0214	1.0000
Agriculture	0.0898	**0.8711**	0.0069	0.0185	0.0135	1.0000
Urban	0.0000	0.7111	**0.2555**	0.0333	0.0000	1.0000
Water	0.3055	0.3055	0.0000	**0.3889**	0.0000	1.0000
Misc.	0.2389	0.7482	0.0009	0.0014	**0.0105**	1.0000

Remarks: Numbers in the table are the fraction (probability) of the particular area which converted. In each case, row probabilities total 100 percent. Numbers in bold size indicate the remaining percent area of each land use types.

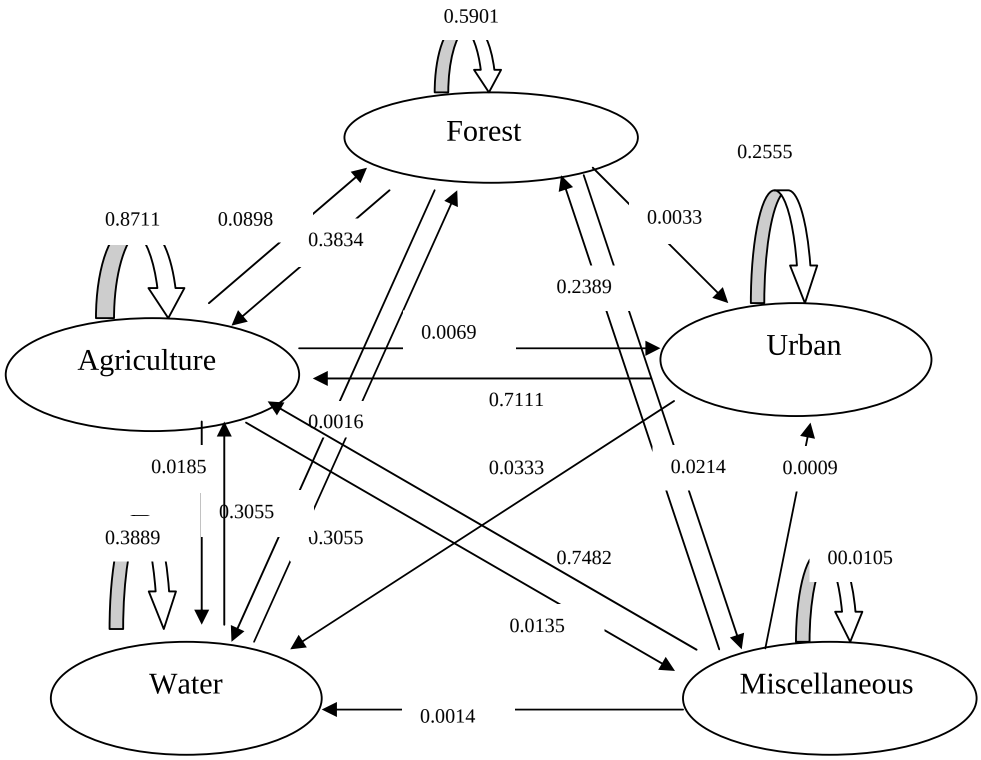


Figure 18 Land use change pattern between 1980 and 2000 in Pasak watershed

The result derived from land use transformation co-efficient in Table 16 and remaining land use in Table 17 implies that between 1980 and 2000 forest area was decreased about 94,600 ha or about 6% of the watershed area while the other land use classes were increased except miscellaneous category. The largest increased category was agriculture because due to increase in population during this period resulted in more upland cultivation as well as more paddy in the large plain land areas of lower Pasak. It was increased about 97,225 ha or 6% of the study area. While the smallest increased class was urban (7,250 ha or 0.45 % of the study area. The change of area of land use between 1980 and 2000 was also shown in Table 18 and Figure 19.

Table 18 The change of area of land use types in ha between 1980 and 2000 in Pasak watershed

Unit : ha

Land use types	In 1980	In 2000	Difference	% of total area
Forest	491,550	396,950	-94,600	-5.95
Agriculture	1,040,475	1,137,700	97,225	6.11
Urban	2,250	9,500	7,250	0.46
Water	900	20,575	19,675	1.24
Miscellaneous	54,725	25,175	-29,550	-1.86
Total	1,589,900	1,589,900	0	0.00

Note: Sign (-) indicate decreasing and sign (+) indicate increasing.

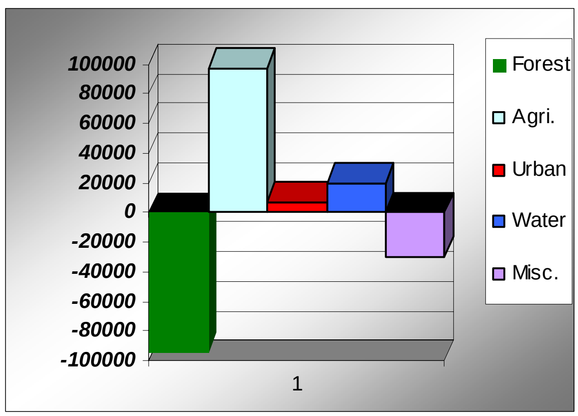


Figure 19 Comparison of land use change between 1980 and 2000 in Pasak watershed

1.2 The land use change between 2000 and 2004

The land use change between 2000 and 2004 was conducted by matrix operation as shown in Table 19 and 20. The interaction of land use types can be explained using the pattern of land use change as shown in Figure 20. The land use change between 2000 and 2004 can be briefly described as follows:

Forest: About 59,250 ha (15%) of forests in 2000 were converted into agriculture and 337,225 ha (85%) were remained as forests in 2004. Very negligible amounts were converted into urban, water and miscellaneous.

Agriculture: About 25,875 ha (2.3%) of agricultural land were converted into forest area in 2004 where upland agricultural crops were replaced by plantation. About 1084,550 ha (95%) were remained as agricultural area in 2004. The rest 27,275 ha (2.7 %) of agricultural areas were converted into urban, water and miscellaneous area.

Urban: About 4,300 ha (45%) of urban area in 2000 were converted to agricultural area and 100 ha (1%) were changed to forest area in 2004. It is due to movement of village people to outside for dam construction in Pasak River and the area left by them were changed to forest and agricultural area. About 3,875 ha (45%) were remained as urban areas.

Water: About 1,675 ha (8%) of water areas in 2000 were converted into agricultural area in 2004 and 1,8750 ha (91%) were remained as water bodies.

Misc.: About 14,775 ha (58%) of miscellaneous land were converted to agriculture and 7,950 ha (31%) to forest areas.

Table 19 Coincident matrix of areal land use change in ha between 2000 and 2004, Pasak watershed

2004\2000	Forest	Agricul-ture	Urban	Water	Misc.	Total 2000	(%)
Forest	**337,225**	59,250	75	50	350	396,950	(24.97)
Agriculture	25,875	**1,084,550**	8,675	2,300	16,300	1,137,700	(71.56)
Urban	100	4,300	**3,875**	75	1,150	9,500	(0.60)
Water	125	1,675	25	**18,750**	0	7,500	(1.29)
Misc.	7,950	14,775	150	25	**2,275**	25,175	(1.58)
Total 2004	371,275	1,164,550	12,800	21,200	20,075	1,589,900	(100)
(%)	(23.35)	(73.25)	(0.81)	(1.33)	(1.26)	(100)	

Table 20 Probability coincident matrix of land use change between 2000 and 2004, Pasak watershed

2004\2000	Forest	Agriculture	Urban	Water	Misc.	Total
Forest	**0.84954**	0.149263	0.000189	0.000126	0.000882	1
Agriculture	0.022743	**0.953283**	0.007625	0.002022	0.014327	1
Urban	0.010526	0.452632	**0.407895**	0.007895	0.121053	1
Water	0.006075	0.081409	0.001215	**0.9113**	0.00000	1
Misc.	0.315789	0.586892	0.005958	0.000993	**0.090367**	1

Remarks: Numbers in the table are the fraction (probability) of the particular area which converted. In each case, row probabilities total 100 percent. Numbers in bold size indicate the remaining percent area of each land use types.

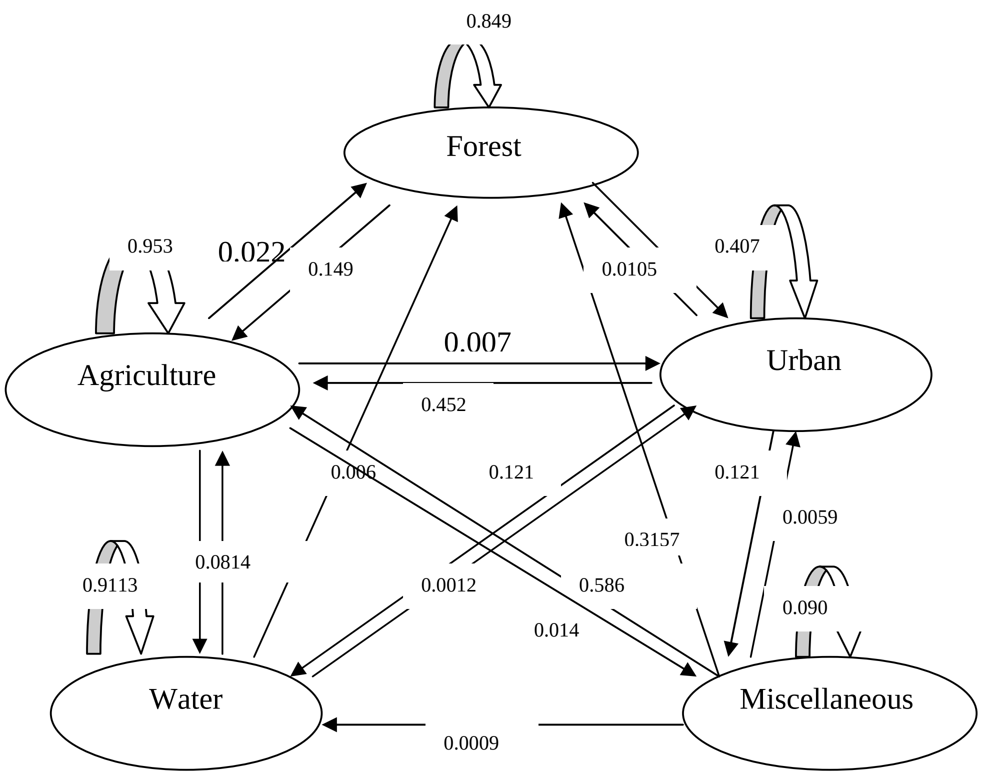


Figure 20 Land use change pattern between 2000 and 2004 in Pasak watershed

The result derived from land use transformation coefficient Table 18, Figure 20 and remaining land use in Table 19 show that forest lands were decreased about 25,675 ha or 1.6% of the study area between 2000 and 2004, while the agricultural, urban and water land use classes were increased about 26,850 ha (1.68%), 3,300 ha (21%) and 625 ha (4%) of the study area respectively. The largest increased category was agriculture. The miscellaneous land use type including bare land, grass lands etc were decreased about 5,100 ha (32%) of the study area. This scenario of land use change between 2000 and 2004 was also depicted in Table 21 and Figure 21.

Table 21 The change of area of land use types in ha between 2000 and 2004, Pasak watershed

Land use types	In 2000	In 2004	Difference	% of total area
Forest	396,950	3,71,275	-25,675	-1.61
Agriculture	1,137,700	1,164,550	26,850	1.69
Urban	9,500	12,800	3,300	0.21
Water	7,500	21,200	625	0.04
Miscellaneous	25,175	20,075	-5,100	-0.32
Total	1,589,900	1,589,900	0.00	0.00

Note: Sign (+) indicate increasing and (–) indicate decreasing.

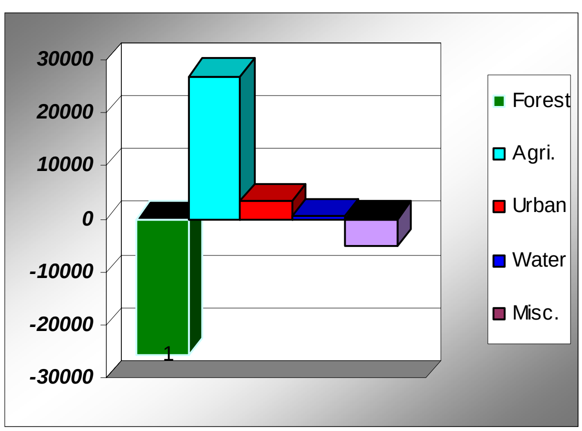


Figure 21 Comparison of change of land use types between 2000 and 2004, Pasak watershed

1.3 Trend of land use change in Pasak watershed from 1980 to 2004

The area of land use types between 1980 to 2004 as derived from land use transformation coefficient calculated by Markov Chain Model is shown in Table 22. The trend of land use change based on area of each land use type as depicted in Figure 22 indicate the increasing trend of agricultural land area and decreasing trend of forest land area. Water bodies has been increased due to construction of Pasak Cholasid dam in 1998. Miscellaneous land including bare land and grass land show decreasing trend as because these are being increasingly used for agricultural uses.

Table 22 Transformed area of different land uses of Pasak watershed (1980-2004) determined by Markov Chain Model

Year	Transformed area of different Land uses of Pasak watershed									
	Forest		Agriculture		Misc.		Urban		Water	
	ha	%	ha	%	ha	%	ha	%	ha	%
1980*	491099	30.89	1041238	65.49	54578	3.43	2166	0.14	872	0.05
1981	485944	30.56	1045830	65.78	52530	3.30	2334	0.15	1020	0.06
1982	480844	30.24	1050442	66.07	50558	3.18	2515	0.16	1194	0.08
1983	475797	29.93	1055075	66.36	48661	3.06	2710	0.17	1397	0.09
1984	470803	29.61	1059728	66.65	46835	2.95	2920	0.18	1635	0.10
1985	465862	29.30	1064402	66.95	45077	2.84	3147	0.20	1913	0.12
1986	460972	28.99	1069096	67.24	43386	2.73	3391	0.21	2239	0.14
1987	456134	28.69	1073811	67.54	41758	2.63	3654	0.23	2620	0.16
1988	451346	28.39	1078547	67.84	40191	2.53	3937	0.25	3066	0.19
1989	446609	28.09	1083303	68.13	38682	2.43	4243	0.27	3587	0.23
1990	441921	27.79	1088081	68.43	37231	2.34	4572	0.29	4198	0.26
1991	437283	27.50	1092879	68.74	35833	2.25	4926	0.31	4912	0.31
1992	432693	27.21	1097699	69.04	34489	2.17	5308	0.33	5748	0.36
1993	428152	26.93	1102540	69.34	33194	2.09	5720	0.36	6726	0.42
1994	423658	26.65	1107403	69.65	31949	2.01	6164	0.39	7871	0.50
1995	419211	26.37	1112287	69.96	30750	1.93	6642	0.42	9210	0.58
1996	414811	26.09	1117192	70.27	29596	1.86	7157	0.45	10778	0.68
1997	410457	25.82	1122119	70.58	28485	1.79	7712	0.49	12612	0.79
1998	406149	25.54	1127068	70.89	27416	1.72	8310	0.52	14758	0.93
1999	401886	25.28	1132038	71.20	26387	1.66	8954	0.56	17269	1.09
2000*	397668	25.01	1137031	71.51	25397	1.60	9649	0.61	20208	1.27
2001	390569	24.56	1144050	71.95	24087	1.51	10437	0.66	20356	1.28
2002	383596	24.13	1151112	72.40	22844	1.44	11289	0.71	20505	1.29
2003	376748	23.70	1158218	72.85	21665	1.36	12210	0.77	20656	1.30
2004*	370023	23.27	1165368	73.30	20548	1.29	13207	0.83	20807	1.31

Note: Observed data (*) obtained by using LANDSAT images and the other years obtained by employing Markov chain model.

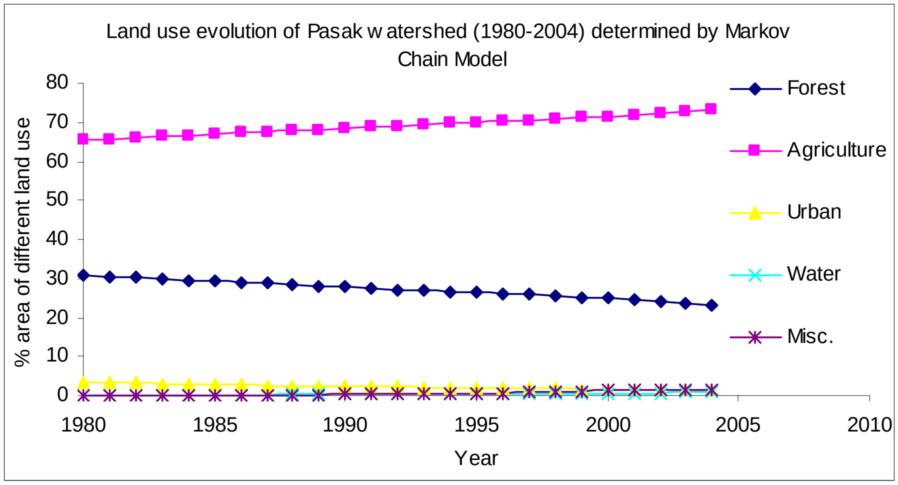


Figure 22 Landuse evolution of Pasak watershed (1980-2004) determined by Markov chain model

2. Streamflow characteristics in concurrence of land use changes

In this section streamflow characteristics were evaluated in terms of water yield, rainfall-runoff relationship , monthly and seasonal distribution of runoff. The basin average annual rainfall determined by Thiessen polygon method measured at different rainfall stations (Appendix B) and total annual runoff of Pasak measured at three gaging stations (S9 in the lower part, S13 in the middle part and S4B in the upper part as shown in Figure 17) using historical annual and monthly streamflow data for the period 1980-2002 were shown in Table 23, 24 and 25.

2.1 Water yield

The mean annual runoff or streamflow during 1980-2002 was found 2,417.13 MCM (million cubic meters) or 239 mm with a mean specific yield of 0.17 MCM/sq. km or 0.017 mm/sq. km at S9 gaging station of lower Pasak. Accordingly it was found 648.33 mcm with a mean specific yield of 0.186 MCM/sq. km during the period of 1980-2001 at S4B gaging station of upper Pasak and 82.98 MCM with a mean specific yield of 0.235 MCM/sq. km during the period 1980-2002 at S13 gauging station of middle part of Pasak.

2.2 Rainfall-runoff relationship

In case of Lower part of Pasak as shown in Table 22 the average annual rainfall in 1980 – 2002 was 1222.51 mm/year or 26,929 MCM, this transformed into runoff at approximately 2417.13 MCM or 239 mm in height or about 8.9 % of annual rainfall that were classified as 2199.97 MCM or 90.14 % of wet flow and 217.17 MCM or 10 % of dry flow. The percentage of rainfall transformed into runoff during the period 1980-1998 i.e. before dam construction as shown in Figure 23C indicate the decreasing trend with little variation (13.44% is the highest and 2.89% is the lowest. This may be because forest area changed to other land uses particularly agriculture which required more water supplies for the paddy fields. High demand for water supply and evapo-transpiration caused water loss resulting to less runoff.

In case of middle part of Pasak as shown in Table 23 the average annual rainfall in 1980-2002 was 1201.90 mm /year, this transformed into runoff at approximately 234.63 mm in height or about 19.65% of annual rainfall that were classified as 88% of wet flow and 12% of dry flow. The percentage of rainfall transformed into runoff during the period 1980 – 2002 as shown in Figure 23B indicate decreasing trend with a high fluctuation (31.86 % is the highest and 6.84% is the lowest). This may be due to the water use by seasonal agricultural cropping. Another reason behind annual rainfall variation might be the rainfall stations encountered in calculating basin average rainfall are not representative to the basin.

In case of upper part of Pasak as shown in Table 24 the average annual rainfall in 1980-2001 was 1052.78 mm/year, this transformed into runoff at approx. 186.28 mm in height or about 17.62% of annual rainfall that were classified as 88.52% of wetflow and 11.48% of dryflow. The percentage of rainfall transformed into runoff during the period 1980-2001 as shown in Figure 23A indicate decreasing trend with 21.745 % as highest and 8.37% as the lowest.

Table 23 The observed average annual rainfall and runoff in Pasak Basin (S9)

Period	Annual rainfall 1/		Annual runoff 2/		% of rain 3/	Wet flow 4/		Dry flow **5/**	
	MCM 1.2/	mm 1.1/	MCM 2.1/	mm 2.2/		MCM	%	MCM	%
1980	25785.26	1170.55	2912.8	204.60	11.30	2768.30	95.04	144.5	4.96
1981	28569.54	1296.94	2358.5	165.66	8.26	2163.30	91.72	195.2	8.28
1982	24885.87	1129.72	2955.9	207.63	11.88	2721.80	92.08	234.1	7.92
1983	25235.69	1145.60	2711.9	190.49	10.75	2438.80	89.93	273.1	10.07
1984	27583.63	1252.19	2769.2	194.51	10.04	2517.60	90.91	251.6	9.09
1985	26449.53	1200.70	3555.7	249.76	13.44	3253.50	91.50	302.2	8.50
1986	26378.23	1197.47	1129.1	79.31	4.28	921.30	81.60	207.8	18.40
1987	28179.27	1279.23	3039.5	213.50	10.79	2863.40	94.21	176.1	5.79
1988	27968.16	1269.64	1838.4	129.13	6.57	1486.20	80.84	352.2	19.16
1989	28355.04	1287.21	1327.1	93.22	4.68	1234.50	93.02	92.6	6.98
1990	26952.16	1223.52	2164.5	152.04	8.03	2065.60	95.43	98.9	4.57
1991	24883.72	1129.62	2872.8	201.79	11.54	2735.20	95.21	137.6	4.79
1992	21739.60	986.89	1222.5	85.87	5.62	1139.60	93.22	82.9	6.78
1993	23024.54	1045.22	664.8	46.70	2.89	594.00	89.35	70.8	10.65
1994	27154.10	1232.69	2687.1	188.74	9.90	2573.40	95.77	113.7	4.23
1995	32783.67	1488.25	4015.8	282.07	12.25	3905.60	97.26	110.2	2.74
1996	28521.75	1294.78	3141.2	220.64	11.01	2845.90	90.60	295.3	9.40
1997	25893.71	1175.47	1765.35	124.00	6.82	1646.95	93.29	118.4	6.71
1998	29656.35	1346.28	1390.12	97.64	4.69	1308.45	94.12	81.67	5.88
1999	31622.52	1435.54	1861.2	130.73	5.89	1510.00	81.13	351.2	18.87
2000	28261.25	1282.95	4669.4	327.98	16.52	4111.40	88.05	558	11.95
2001	21714.33	985.75	1139.5	80.04	5.25	813.80	71.42	325.7	28.58
2002	27786.55	1261.40	3401.7	238.94	12.24	2980.60	87.62	421.1	12.38
Average	26929.76	1222.51	2417.133	239.01	8.90	2199.97	90.14	217.17	9.86

.Note: 1/ mm = Basin average determined by Thiessen polygon method based on 19 stations observed data of RID

MCM = (mm/10^3 * Basin area (sq. km) * 10^6)/ 10^6= mm*Basin area /10^3

2/ MCM = Derived from original unit in cms observed by RID

= (Cu. M /sec *60*60*24)/10^6

mm =[(MCM*10^6)/(Basin area (sq. km)*10^6)]*10^3

= MCM*10^3 / Basin area

3/ % = (mm of runoff / mm of rainfall)* 100

4/ Wetflow measured from flow during May to October

% = (Wetflow/Annual runoff)*100

5/ Dryflow measured from flow during Nov. to April

% = (Dryflow/ Annual runoff)*100

Table 24 The average annual rainfall and runoff in small catchment of middle part of Pasak at S13 gaging station

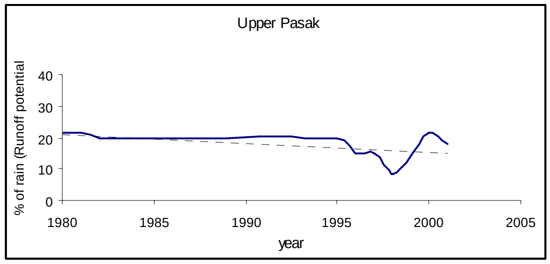
Year	Rainfall	Runoff	% fo rain	Wetflow		Dryflow		Peakflow	
	mm	mm	%	mm	%	mm	%	mm	%
1980	1219.04	247.76	20.32	234.72	94.73	13.06	5.27	18.07	7.29
1981	1071.10	268.60	25.08	217.13	80.84	51.50	19.17	22.53	8.39
1982	1088.76	266.89	24.51	249.39	93.45	17.53	6.57	30.36	11.37
1983	1188.98	194.95	16.40	175.22	89.88	19.77	10.14	26.07	13.37
1984	1083.54	238.62	22.02	224.70	94.17	13.97	5.85	8.13	3.41
1985	1139.81	363.09	31.86	334.60	92.15	28.53	7.86	33.57	9.25
1986	1104.22	143.91	13.03	122.19	84.91	21.75	15.11	17.76	12.34
1987	1253.85	330.46	26.36	305.27	92.38	25.22	7.63	27.19	8.23
1988	1182.98	211.63	17.89	139.53	65.93	72.11	34.07	13.09	6.19
1989	1184.65	114.77	9.69	106.16	92.49	8.63	7.51	10.74	9.35
1990	1020.68	252.20	24.71	226.15	89.67	26.02	10.32	16.97	6.73
1991	1184.83	227.95	19.24	214.35	94.03	13.57	5.95	11.90	5.22
1992	1148.28	78.59	6.84	72.48	92.22	6.14	7.81	12.35	15.72
1993	1105.71	190.91	17.27	137.18	71.86	53.79	28.17	9.74	5.10
1994	1372.37	235.38	17.15	218.62	92.88	16.74	7.11	17.32	7.36
1995	1415.74	399.38	28.21	381.43	95.50	17.96	4.50	19.89	4.98
1996	1330.64	224.84	16.90	183.62	81.66	41.26	18.35	10.31	4.59
1997	1078.28	148.53	13.77	135.88	91.49	12.70	8.55	12.01	8.08
1998	1380.35	177.44	12.85	156.10	87.97	21.35	12.03	11.15	6.28
1999	1564.35	191.09	12.22	155.90	81.59	35.15	18.40	7.44	3.89
2000	1505.91	426.19	28.30	366.64	86.03	59.56	13.97	53.68	12.60
2001	891.45	262.12	29.40	226.80	86.52	35.35	13.49	49.82	19.01
2002	1128.15	201.29	17.84	173.92	86.40	27.43	13.63	20.43	10.15
Mean	1201.90	234.63	19.65	206.87	87.77	27.79	12.24	20.02	8.65

Table 25 The average annual rainfall and runoff in upper part of Pasak at S4B gaging station

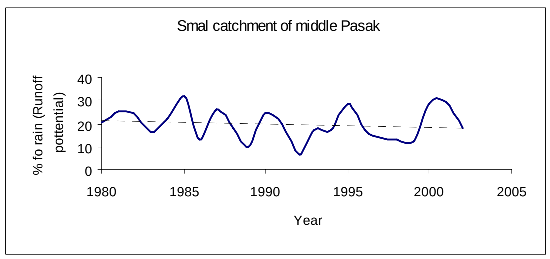
Year	Rainfall	Runoff	% rain	Wetflow		Dryflow		Peakflow*	
	mm	mm	%	mm	%	mm	%	mm	%
1980	1150.91	244.05	21.21	201.98	82.76	42.08	17.24	4.01	1.64
1981	869.13	188.92	21.74	149.07	78.91	39.85	21.09	3.80	2.01
1982	853.98	168.52	19.73	127.40	75.60	41.12	24.40	3.95	2.34
1983	939.38	187.34	19.94	146.78	78.35	40.56	21.65	3.57	1.91
1995	1245.11	243.15	19.53	234.80	96.57	8.35	3.43	4.33	1.78
1996	1279.54	191.96	15.00	176.31	91.85	15.65	8.15	4.02	2.10
1997	1160.62	175.78	15.15	170.58	97.04	5.20	2.96	3.85	2.19
1998	880.55	73.69	8.37	71.76	97.37	1.94	2.63	2.62	3.55
1999	1066.02	147.82	13.87	136.68	92.46	11.14	7.54	3.05	2.06
2000	1295.60	277.54	21.42	246.30	88.74	31.24	11.26	3.74	1.35
2001	839.70	150.30	17.90	141.47	94.12	8.83	5.88	3.97	2.64
Mean	1052.78	186.28	17.62	163.92	88.52	22.36	11.48	3.72	2.14

* Peakflow indicating highest daily peak of the year

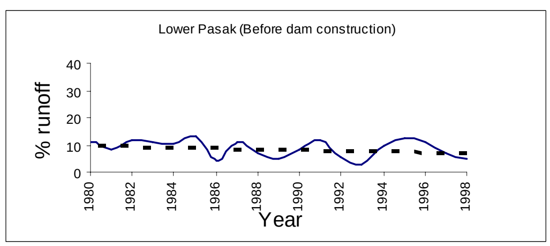
A.



B.



C.



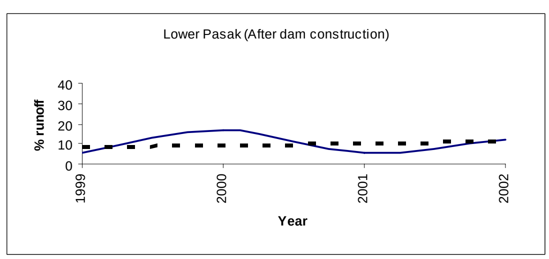


Figure 23 Trend of runoff potential (A. in upper part of Pasak basin at S4B gaging station, B. in small catchment of middle part of Pasak at S13 and C).in Lower part of Pasak before dam construction (above) and after dam construction (below) at S9.

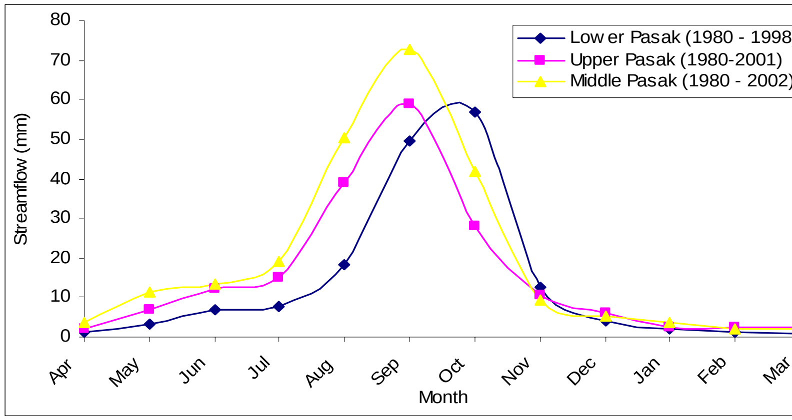
2.3 Monthly distribution of runoff

The monthly distribution of runoff as demonstrated in Table 26 and Figure 24 showed that the highest runoff was occurred in the month of October in the lower Pasak before dam construction which was about 810.38 MCM or 56.92 mm in height, in case of upper Pasak and middle part of Pasak highest streamflow were occurred in the same month of September that were about 205.02 MCM or 58.91 mm in height and 25.72 MCM or 72.73 mm in height respectively. The minimum flow which usually occurred in March were about 14.09 MCM and 0.67 MCM for lower and middle part of Pasak respectively. In case of upper Pasak the minimum flow occurred in April was also about 7.22 MCM.

Table 26 Mean monthly streamflow of Pasak Basin

Month	Lower Pasak (S9)				Upper Pasak (S4B)		Middle Pasak (S13)	
	1980-1998 (Before Dam construction)		1999-2002 (After Dam construction)		1980-2001		1980-2002	
	MCM	mm	MCM	mm	MCM	mm	MCM	mm
Apr	15.54	1.09	82.28	5.78	7.22	2.07	1.35	3.82
May	48.45	3.40	82.25	5.78	24.52	7.04	4.00	11.31
Jun	97.45	6.85	109.08	7.66	42.90	12.33	4.78	13.52
Jul	111.08	7.80	232.15	16.31	52.07	14.96	6.77	19.15
Aug	262.03	18.41	206.78	14.52	135.89	39.04	17.74	50.15
Sep	706.60	49.63	1051.85	73.88	205.02	58.91	25.72	72.73
Oct	810.38	56.92	602.08	42.29	97.51	28.02	14.85	42.00
Nov	180.00	12.64	152.03	10.68	37.11	10.66	3.29	9.32
Dec	55.28	3.88	33.60	2.36	20.69	5.94	1.80	5.08
Jan	26.91	1.89	60.88	4.28	9.07	2.61	1.24	3.52
Feb	15.45	1.09	92.88	6.52	7.99	2.30	0.76	2.15
Mar	14.09	0.99	62.13	4.36	8.33	2.39	0.67	1.90
Annual	2343.28	164.59	2767.95	194.42	648.33	186.28	82.98	234.65

A.



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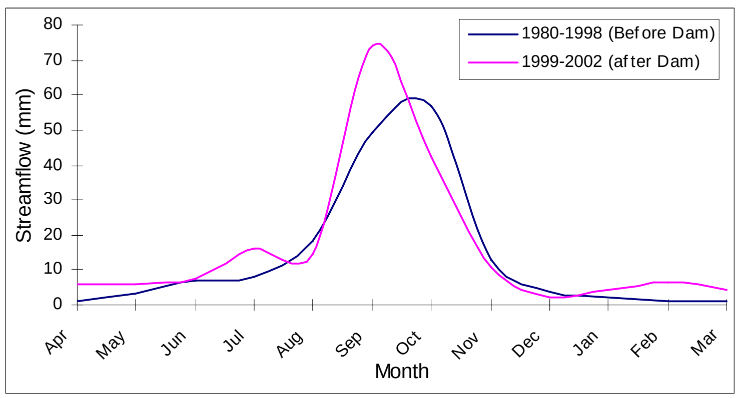


Figure 24 Hydrograph of Pasak Basin (A.Upper, middle and lower Pasak B. Before and after dam construction in lower Pasak)

2.4. Seasonal variation of flow

In case of lower Pasak the trend for runoff (as shown in Table 22 and Figure 25 A) during the wet season became higher while during dry season it was found become lower but the difference was small. About 90% of annual flow was occurred during wet period while only 10% flowed in dry season. The same result was also shown by Tangtham and Yuwananont (1996) in the study of Pasak.

The same trend was also found for upper part of Pasak (as shown in the table and figure 25.C) but at the sharp rate than lower part of Pasak which indicate the effect of deforestation.

In case of middle part of Pasak (as shown in Figure 25 B) the trend was found decreasing for wetflow and increasing for dryflow, unlikely than other two parts. The reason might be due to the extreme use of water for other purposes during wet season, small size of the watershed and rainfall amount during dry period.

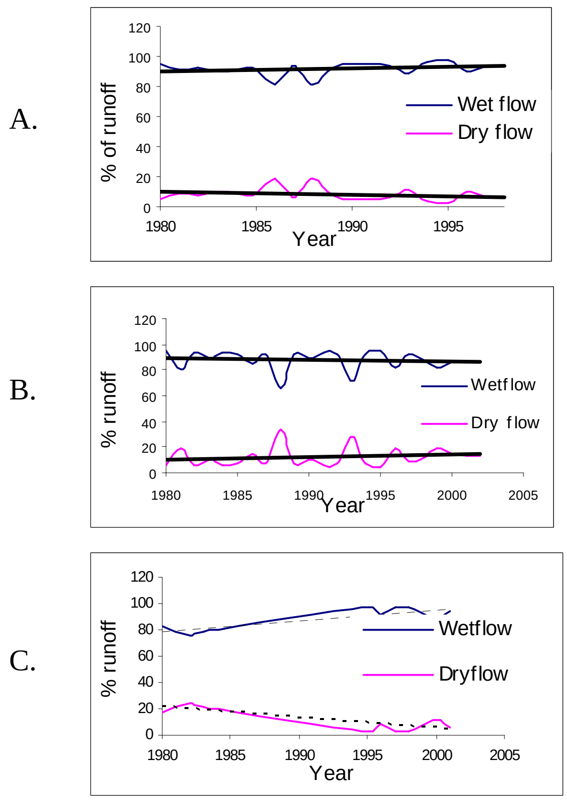


Figure 25 Seasonal variation of streamflow (A. in Lower part of Pasak before dam construction B. middle part and C. upper part of Pasak Basin)

2.5 Relationship between runoff and land use factors

It was evident from the above discussion that water yield, runoff potential, monthly runoff distribution and its seasonal variation were affected directly by land use changes along with precipitation. These cause and effect relationships among the causal factors (independent variables) and the affected factors (depended variables could be better explained in the form of correlation matrix as shown in the following Tables 27, 28 and 29. Highly correlated independent variables were used in regression analysis in order to predict unobserved values for the dependent variables.

The dependent variable such as Runoff was classified as annual runoff (Qtotal), runoff during wet period (Qwet), runoff during dry period (Qdry) and peak daily runoff (Qpeak). While those independent variables were average annual rainfall (Rannual), rainfall during wet period (Rwet), rainfall during dry period (Rdry) and area of each land use types over the period 1980-2004 simulated by Markov chain model for upper, middle and lower Pasak. The regression analysis was then carried out as stepwise linear and in non-linear that shown in Table 30 and 31.

In case of upper Pasak, wetflow (Qwet) is found to have better correlation ($r = 0.82$) with annual rainfall (Rannual) and almost no influence with forest ($r = -0.01$) and agricultural land (0.11) whereas dryflow (Qdry) have rather high correlation with forest ($r = 0.84$) and negative correlation with urban ($r = -0.6$) and miscellaneous land ($r = - 0.49$). Decreasing forest has very low influence on increasing wetflow due to withdrawal of more water for agricultural purposes in the upper Pasak area. On the other hand dryflow decreases as the forest decreases. So rainfall and decreasing forest area could be considered as major influential parameters in predicting the model for this part of watershed.

Table 27 Correlation matrix between land use change factors and runoff discharge in Upper Pasak (S4B) during 1980 – 2003

	Natural causal factor			Land use factor					Runoff			
	Rannual	Rwet	Rdry	For	Agr	Ur	W	Misc	Qwet	Qdry	Qpeak	Qtotal
Rannual	1											
Rwet	0.873	1										
Rdry	0.305	-0.19	1									
For	-0.265	-0.11	-0.32	1								
Agr	0.354	0.269	0.186	-0.09	1							
Ur	0.155	0.099	0.119	-0.83	0.016	1						
W	0.155	0.059	0.196	-0.72	-0.17	0.894	1					
Misc	0.222	0.038	0.373	-0.4	0.228	-0.12	-0.07	1				
Pop	0.115	-0.01	0.454	-0.14	0.673	-0.25	-0.14	0.635				
Qwet	**0.816**	0.722	0.509	-0.01	0.113	-0.14	0.016	0.268	1			
Qdry	-0.132	-0.02	-0.23	**0.84**	0.022	**-0.6**	-0.35	**-0.49**	0.192	1		
Qpeak	0.358	**0.581**	-0.19	0.264	-0.26	-0.24	-0.22	-0.39	0.688	0.28	1	
Qtotal	**0.704**	0.651	0.394	0.24	0.101	-0.32	-0.09	0.119	0.959	0.46	0.7	1
SS*	1	0.965	0.953	-1	0.997	0.999	0.997	0.998	0.998	0.99	1	0.99

*Note: Rannual – Annual rainfall, Rwet – Rainfall during wet period (May – Oct.), Rdry – Rainfall during dry period (Nov.-April), For – Forest, Agr – Agriculture, Ur – Urban, W – Water, Misc.- Miscellaneous, Pop – Population, Qwet – Wetflow, Qdry – Dryflow, Qpeak – Highest daily peak flow over the year, Qtotal – Annual runoff and SS – Suspended sediment. * Only the available 3 years data were employed.*

Table 28 Correlation matrix between land use change factors and runoff discharge in middle part of Pasak (S13) during 1980 – 2002

	Natural causal factor			Land use factor				Runoff				
	Rannual	Rwet	Rdry	For	Agr	Misc	Pop	Qwet	Qdry	Qpeak	Qtotal	SS
Rannual	1											
Rwet	0.762	1										
Rdry	0.664	0.021	1									
For	-0.355	0.039	-0.59	1								
Agr	0.354	-0.042	0.59	-1	1							
Misc	-0.265	0.057	-0.47	0.88	-0.85	1						
Pop	-0.343	-0.432	-0.09	0.23	-0.21	0.265	1					
Qwet	0.258	**0.425**	-0.09	0.05	-0.03	0.129	-0.206	1				
Qdry	0.116	-0.222	**0.44**	-0.16	0.18	-0.1	0.205	0.122	1			
Qpeak	-0.092	0.024	-0.17	-0.09	0.12	0.07	0.12	0.62	0.27	1		
Qtotal	0.27	0.36	0	0.02	0.00	0.101	-0.163	0.98	0.32	0.64	1	
SS	0.233	0.475	-0.19	0.31	-0.30	0.31	-0.25	**0.89**	0.11	**0.53**	0.87	1

Note: *Rannual – Annual rainfall, Rwet – Rainfall during wet period (May – Oct.), Rdry – Rainfall during dry period (Nov.-April), For – Forest, Agr – Agriculture, Ur – Urban, W – Water, Misc.- Miscellaneous, Pop – Population, Qwet – Wetflow, Qdry – Dryflow, Qpeak – Highest daily peak flow over the year, Qtotal – Annual runoff and SS – Suspended sediment.*

In case of middle part of Pasak, no significant effect was found on runoff discharge by any of land use change factors except little with rainfall during wet period (r = 0.425) and dry period (r = 0.44).

Table 29 Correlation matrix between land use change factors and runoff discharge in Lower Pasak (S9) during 1980 – 1998 (before dam construction)

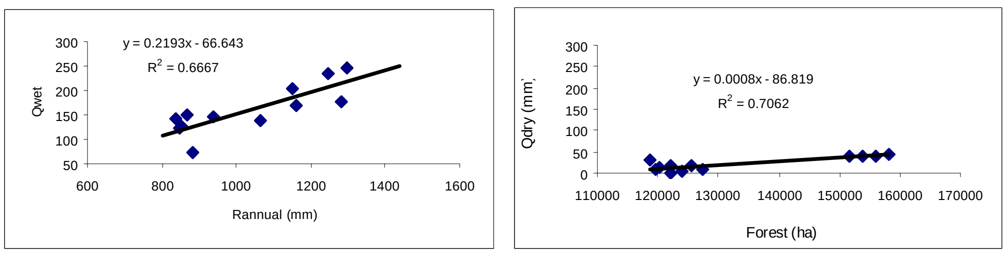
	Natural causal factor			Land use factor					Runoff			
	Rannual	Rwet	Rdry	For	Agr	Ur	W	Misc	Qwet	Qdry	Qpeak	Qtotal
Rannual	1											
Rwet	0.676	1										
Rdry	0.47	-0.33	1									
For	-0.183	0.12	-0.37	1								
Agr	0.191	-0.11	0.37	-1	1							
Ur	0.226	-0.06	0.37	-0.9	0.98	1						
W	0.263	-0.02	0.36	-0.9	0.94	0.98	1					
Misc	-0.17	0.13	-0.38	0.99	-0.99	-0.96	-0.9	1				
Pop	0.41	0.25	0.53	-0.9	0.99	0.99	0.99	-0.99				
Qwet	0.432	**0.83**	-0.45	0.19	-0.19	-0.16	-0.1	0.21	1			
Qdry	0.1	0.09	0.02	**0.46**	**-0.46**	**-0.45**	**-0.4**	**0.45**	0.31	1		
Qpeak	0.332	**0.72**	-0.43	0.15	-0.15	-0.13	-0.1	0.16	0.91	0.24	1	
Qtotal	0.428	**0.82**	-0.43	0.23	-0.23	-0.2	-0.1	0.24	0.99	0.39	0.9	1
SS	0.266	0.47	-0.22	-0.04	0.06	0.13	0.21	-0.01	**0.64**	0.24	**0.57**	**0.64**

Note: *Rannual – Annual rainfall, Rwet – Rainfall during wet period (May – Oct), Rdry – Rainfall during dry period (Nov.-April), For – Forest, Agr – Agriculture, Ur – Urban, W – Water, Misc.- Miscellaneous, Pop – Population, Qwet – Wetflow, Qdry – Dryflow, Qpeak – Highest daily peak flow over the year, Qtotal – Annual runoff and SS – Suspended sediment*.

In case of lower Pasak as shown in Table 29 and Figure 26, wetflow (Qwet) have better correlation with rainfall during dry period (Rdry) and almost no effect by forest (For), agriculture (Agr) or other land use types. It may be due to the increasing withdrawal of water for agricultural or other purposes. But dry flow are found to have little relationship (though not significant) with all land use change factors (forest, agriculture, urban, water and miscellaneous). It indicates that combination of land use change factors may have significant effect on dryflow.

Applying stepwise regression method, linear models as derived from relationship between runoff discharge and independent variables are shown in Table 30. It showed 7 equations. All equations had significant results with 6 equations at 99 % confidence interval and one at 95 % confidence interval which indicates that rainfall as an independent variable had the major influence on runoff. In case of upper Pasak runoff during year (Qtotal) was found better affected when combining with land use factor (Forest) with higher R^2 whereas in case of lower Pasak land use factor show no effect on runoff.

Upper Pasak



Lower Pasak

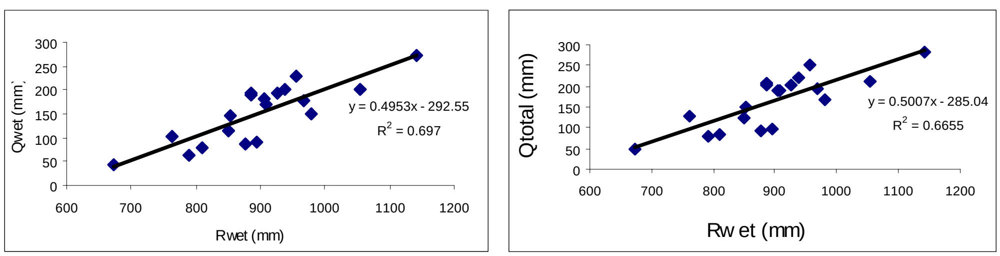


Figure 26 Linear relationship between runoff and annual rainfall (Rannual), rainfall during wet period (Rwet), rainfall during dry period (Rdry) and forest in upper and lower part of Pasak.

Table 30 Linear regression equations for streamflow prediction in Pasak watershed by stepwise regression method

	Dependent variable	Step no.	Model types	Equation	Regression no.	Statistical parameters				
						R	R^2	SEE	F ratio	p
Lower part of Pasak	Qtotal	1	Simple	Qtotal = -285.04 + 0.500701*Rwet	1	0.82	0.67	38.0492	33.83	0
	Qwet	1	Linear	Qwet = -292.562 + 0.49533*Rwet	2	0.83	0.70	75.0048	39.11	0
	Qdry	1	model	Qdry = 125.849 - 0.000104747*Agri	3	0.46	0.21	5.5934	4.55	0.048
Upper part of Pasak	Qtotal	1		Qtotal = -36.2866 + 0.210902*Rannual	4	0.70	0.50	40.8496	9.82	0.011
		2		Qtotal = -274.86 + 0.245322*Rannual + 0.00152243*For	5	0.83	0.68	34.0056	9.75	0.006
	Qwet	1		Qwet = -66.6419 + 0.219323*Rannual	6	0.82	0.67	29.7591	20	0.001
	Qdry	1		Qdry = -86.831 + 0.001*For	7	0.84	0.71	8.9470	24.06	0.001

Note: Q total = Total annual flow in mm, Qwet = Flow during wet season in mm, Qdry = Flow during dry season in mm, Rwet = Rainfall during wet season in mm, Rannual = Annual rainfall in mm, For = Forest in ha, Agr = Agriculture in ha.

Table 31 Non-linear regression equations for streamflow prediction in Pasak watershed by stepwise regression method

	Dependent variables	Step no.	Model type	Equation	Regression no.	Statistical parameters				
						R	R^2	SEE	F ratio	P
Lower part of Pasak	Qtotal	1	Power	$Qtotal = 3E\text{-}08*Rwt^{3.291}$	1	0.822	0.68	0.275	35.392	0
		2	Exponential	$Qtotal = 5.881*e^{0.004*Rwet}$	2	0.802	0.64	0.288	30.622	0
	Qwet	1	Power	$Qwet= 5.79\text{-}009*Rwet^{3.517}$	3	0.84	0.71	0.273	40.858	0
		2	Exponential	$Qwet = 4.305*e^{0.004*Rwet}$	4	0.821	0.67	0.288	35.076	0
	Qdry	1	Power	$Qdry= 4E+066*agri^{-10.861}$	5	0.532	0.28	0.441	6.705	0.019
		2	Exponential	$Qdry = 574602*e^{-1.0E\text{-}005*Agri}$	6	0.532	0.28	0.441	6.709	0.019
Upper part of Pasak	Qtotal	1	Power	$Qtotal = 0.032*Rannual^{1.234}$	7	0.632	0.35	0.289	6.644	0.028
		2	Exponential	$Qtotal = 49.9388e^{.001*Rannual}$	8	0.637	0.41	0.28	6.83	0.026
		3	Power	$Qtotal = -0.9625*Rannual^{1.46352} * For^{1.3688}$	9	0.77	0.604	0.104	6.86	0.016
	Qwet	1	Power	$Qwet = 00.008*Rannual^{1.418}$	10	0.756	0.57	0.226	13.3	0.226
		2	Exponential	$Qwet = 36.992*e^{0.001*Rannual}$	11	0.762	0.58	0.224	13.833	0.004
	Qdry	1	Power	$Qdry = 1.20E\text{-}028*For^{5.685}$	12	0.68	0.46	0.756	8.591	0.015
		2	Exponential	$Qdry = 0.061*e^{4.16E\text{-}005*For}$	13	0.685	0.45	0.751	8.829	0.014

Note: Q total = Total annual flow in mm, Qwet = Flow during wet season in mm, Qdry = Flow during dry season in mm, Rwet = Rainfall during wet season in mm, Rannual = Annual rainfall in mm, For = Forest in ha, Agr = Agriculture in ha.