Water Resources Systems—Hydrological Risk, Management and Development (Proceedings of symposium HS02b held during IUGG2003 at Sapporo. July 2003). IAHS Publ. no. 281. 2003.

Testing trends in annual maximum discharge series in Israel

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Abstract A variety of statistical tests were carried out on 64 annual maximum discharge series observed in Israel during the last six decades. The period of observation at each of the stations selected is at least 25 years, with an average of 42 years per station. The tests aimed at detecting trends in the central values of the discharges, as well as in their variation. Except for one region, the detected changes are of local extent, if any. A decline in the annual maximum discharges and in their variability is found for the Upper Jordan River and its tributaries. A general rise in the variability is found over most other regions. These appear to result from changes in the meteorological causes of high discharges. Few high discharges occurred in the 1970s and in the early 1980s, whilst many occurred in the 1990s.

Key words annual maximum discharges; arid areas; Israel; regional analysis; semiarid areas; statistical tests; trend

INTRODUCTION

Assignment of recurrence intervals to extreme discharges is commonly done through probabilistic analyses of past events. In these analyses, the selected discharges are considered as being independent, identically distributed random variables. Trends, which might prevail in the records, preclude the suitability of pure probabilistic analyses. Methods and tests for detection and consideration of trends are already available (e.g. Helsel & Hirsch, 1992; Porporato & Ridolfi, 1998), but few studies that look into trends in series of peak discharges have been published.

Trends may occur in the central values of the series (i.e. the mean, the median), as well as in other statistical properties (the variance, the skewness, etc.). Since a trend in any statistical property might bias probabilistically predicted values of extreme discharges, identification of trends is an important stage in statistical analyses of discharge series.

Trends in discharge values might result from trends in physiographic or climatic characteristics of the drainage basin, be they natural or man-induced ones, or appear as a result of fluctuations in the values of these characteristics. Apparent trends might also result from technical changes in data production and processing, or be accidental effects of sampling variation. A regional search for trends has a better chance to identify accidental and local effects.

The present work searches for trends in peak discharges throughout Israel, whose climatic and physiographic characteristics are highly variable (e.g. Shentsis *et al.*, 1997). This was done by use of a variety of statistical tests for identification and quantification of trends in the central values and in the variability of peak discharges. For simplicity reasons, the series examined were of annual maximum discharges.

DATA

The data selected are annual maximum discharges at hydrometric stations whose net period of observation is of at least 25 years (not necessarily uninterrupted). Missing records were not substituted by synthetic values. Series for stations whose basins underwent a substantial change (e.g. dam construction) were considered either prior or subsequent to the change.

Series for 64 stations, located throughout Israel, were found suitable for the analysis (Fig. 1). Their period of observation extends from 25 to 59 years each, with an average of 42 years. These stations and some properties of their watersheds and discharges are listed in Table 1.

METHODS

Each series underwent a number of parametric and non-parametric tests for trend identification. These include evolution of magnitudes throughout the period of observation and differences in statistical properties between the first and the second halves of this period. In the case of an odd number of observation years, the middle-year value was considered to belong to the first half of the period.

The tests selected were (see e.g. Helsel & Hirsch, 1992 for the techniques):

- linear regression with a Student t test for the slope;
- Kendall's τ for the differences between successive values;
- Mann-Kendal's trend in the slope;
- F-test for the difference between the variances of the two halves of the observation period;
- Mann-Witney-Wilcoxon (MWW) test for the difference between the medians for these halves;
- MWW test for the difference between the medians of the absolute deviation from the mean for these halves. This is a non-parametric alternative test for the difference between the variances.

The results are listed in Table 2.

INFERENCES ON THE RESULTS WITH RESPECT TO THE TESTS

Linear regression Negative trends in annual maximum discharge with respect to time are found for the Upper Jordan River and its tributaries (stations 1–9). For four of these stations the trend is two-sided 5% significant. Positive trends, mostly insignificant, are found for stations in the northern Mediterranean basin (stations 13–27) and in the Arava basin (stations 59–64). Positive trends, significant at the two-sided 5% level, are found for stations 17, 36, 44 and 50, that are not adjacent to one another, and a negative trend is found for station 35. The latter trends appear to result from local circumstances.

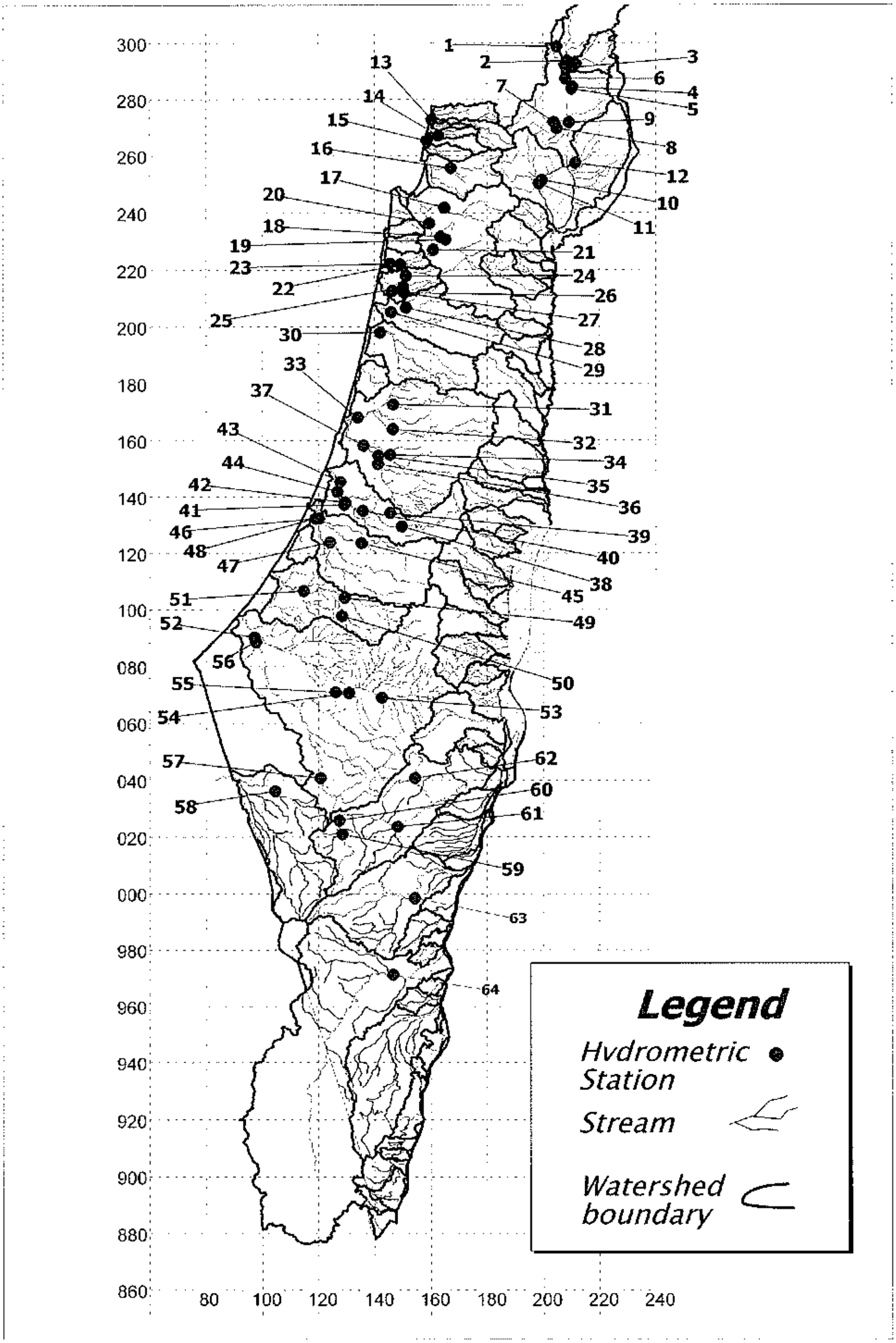

Fig. 1 Location of the 64 stations.

Table 1 The hydrometric stations with their drainage basins and discharges (continues on p.44).

No.	Stream	Area	Precipitation	Period	Max	10%	50%	Min
1	Iyyon	35	–	50–98	27	14	6.1	1.2
2	Senir	563	–	40–98	250	175	73	10.6
3	Hermon	140	–	40–98	103	80	33	3.7
4	Yardenon	10	–	67–91	13	10	4.7	~0
5	Orevim	40	772	62–98	33	25	12.8	~0
6	Jordan 1	800	–	43–98	280	249	130	31.9
7	Dishon	136	708	44–89	21	15	4.9	0
8	Hazor	32	691	41–98	25	8	2.7	0
9	Jordan 2	1380	–	60–98	214	133	97	33.6
10	Ammud	124	734	45–75	63	14	5.1	0
11	Zalmon	103	667	62–98	35	14	2.8	0
12	Meshushim	160	596	70–98	211	176	63	2.2
13	Keziv	131	873	45–98	90	38	7.9	0
14	Ga'aton	41	746	69–98	25	10	1.8	~0
15	Bet Ha'emeq	72	755	45–98	19	14	4.0	0
16	Hillazon	158	703	44–98	70	42	13.3	0
17	Zippori	211	599	44–92	133	14	3.1	0
18	Bet Lehem	19	625	58–98	28	25	2.5	~0
19	Nahalal	41	575	66–96	40	26	2.7	0.2
20	Qishon	694	456	54–98	218	135	18.8	1.5
21	Hashofet	12	700	66–98	28	19	1.2	0.1
22	Daliyya 1	42	662	56–98	125	52	5.5	0.1
23	Daliyya 2	70	645	50–98	115	20	7.0	0
24	Tanninim	51	656	68–98	81	24	5.8	0
25	Ada 1	18	641	45–97	60	13	3.0	0
26	Barqan	29	647	67–98	56	31	5.4	0.3
27	Ada 2	66	638	56–98	68	47	7.6	0.3
28	Iron	61	649	44–98	67	27	3.2	0
29	Hadera	519	609	50–98	227	128	29	0
30	Alexander	492	698	39–98	260	126	25	0
31	Kana	240	619	44–98	127	78	6.0	0
32	Shilo	357	613	44–97	192	120	21	0
33	Yarqon	953	611	41–98	508	290	49	0
34	Bet Arif	46	575	58–98	54	24	3.6	0
35	Natuf	251	757	40–98	230	156	20	0
36	Ayyalon 1	135	540	57–98	130	59	10.7	0
37	Ayyalon 2	526	577	56–98	377	235	41	0.4
38	Soreq 1	245	590	51–98	120	40	5.2	0
39	Har'el	13	530	65–98	7	4	0.9	0
40	Soreq 2	405	574	38–98	154	65	14.1	0
41	Soreq 3	492	562	38–92	122	104	36	0
42	Eqron	63	536	52–98	119	68	18.8	0.5
43	Gamli'el	613	557	61–92	87	78	34	1.7
44	Soreq 4	613	557	54–98	87	67	22	2.4
45	Haela 1	286	507	61–98	60	26	3.8	0
46	Haela 2	423	500	75–98	174	125	38	1.9
47	Guvrin	204	468	50–98	120	47	5.1	0
48	Lakhish	992	470	44–98	410	124	51	1.9
49	Adorayim	207	371	55–98	218	89	10.1	0
50	Shiqma 1	38	311	63–98	82	44	7.3	0
51	Shiqma 2	378	366	52–98	178	98	15.4	0.7
52	Gerar	658	276	65–98	270	169	33	0
53	Be'er Sheva 1	405	–	64–88	875	227	34	4.6
54	Beqa	96	165	51–98	145	70	9.5	0
55	Be'er Sheva 2	1220	258	73–98	1090	402	110	1.4

No.	Stream	Area	Precipitation	Period	Max	10%	50%	Min
56	Besor 2	2630	200	65–92	1000	370	49	0
57	Besor 1	185	107	51–98	116	73	12.6	0
58	Lavan	217	92	51–95	439	176	21	0
59	Zin 1	125	–	57–98	552	24	2.5	0
60	Zin 2	233	–	55–98	551	200	3.2	0
61	Zin 3	660	–	56–98	572	124	30	0
62	Mamshit	64	–	56–98	99	44	3.4	0
63	Neqarot	697	–	59–98	708	216	13.7	0
64	Paran	3350	–	52–98	1160	371	39	0

Area: drainage basin area (km^2), **Precipitation**: mean annual depth of precipitation for 1951–1980 (mm), **Period**: period of observation (years are 19NN and refer to the hydrological year from October 19N(N–1) through September 19NN), **Max**: maximum observed discharge (m^3 s^{-1}), **10%**: higher ten-percentile value of the annual maximum discharges (m^3 s^{-1}), **50%**: median of the annual maximum discharge series (m^3 s^{-1}), **Min**: minimum value of the annual maximum discharges (m^3 s^{-1}). Missing values are designated by –.

Note: Areas of stations 36 and 37 do not include the sub-basin upstream from Mishmar Ayyalon reservoir, which never overflowed. Owing to drainage short cuts, stations 43 and 44 share the same basin.

Table 2 Results of the statistical tests.

No.	N_y	Slope	R^2	t	Z(τ)	α(τ)	Med.	F	α(F)	$2W/n^2$	α(W)	$2W_u/n^2$	α(W_u)
1	49	−0.08	0.05	1.6	−1.5	0.13	−0.09	2.7	0.01	0.40	0.01	0.49	0.38
2	59	−0.91	0.09	2.4	−2.2	0.03	−0.73	2.3	0.02	0.40	0.00	0.51	0.64
3	57	−0.04	0.00	0.2	−0.1	0.96	−0.04	0.5	0.94	0.46	0.15	0.57	0.97
4	25	−0.19	0.15	2.0	−1.8	0.07	−0.19	0.8	0.64	0.45	0.23	0.56	0.86
5	37	−0.16	0.04	1.3	−0.9	0.38	−0.18	1.3	0.30	0.47	0.27	0.50	0.49
6	52	−1.48	0.11	2.5	−1.6	0.11	−1.40	1.6	0.12	0.44	0.04	0.47	0.18
7	29	−0.03	0.00	0.3	+3.4	0.00	0.000	0.8	0.65	0.45	0.17	0.56	0.94
8	56	−0.08	0.11	2.6	−1.5	0.13	−0.04	2.5	0.02	0.40	0.00	0.53	0.73
9	39	−0.51	0.03	1.0	−0.1	0.95	−0.25	1.2	0.32	0.51	0.62	0.57	0.93
10	47	+0.13	0.03	1.2	+2.7	0.01	+0.07	0.7	0.79	0.51	0.56	0.48	0.37
11	37	−0.00	0.00	0.0	−0.1	1.00	0.00	2.1	0.07	0.52	0.69	0.51	0.55
12	29	+0.84	0.01	0.6	+0.3	0.78	+0.37	0.4	0.93	0.50	0.51	0.61	0.98
13	52	+0.15	0.02	0.9	+1.3	0.19	+0.04	1.3	0.23	0.48	0.22	0.55	0.85
14	30	+0.01	0.00	0.1	+1.4	0.18	+0.07	2.7	0.04	0.55	0.73	0.55	0.73
15	50	+0.02	0.01	0.5	+2.6	0.01	+0.06	2.5	0.01	0.54	0.78	0.50	0.37
16	51	+0.01	0.00	0.1	+1.0	0.33	+0.07	1.5	0.15	0.47	0.27	0.51	0.65
17	40	+0.51	0.10	2.0	−1.8	0.07	−0.02	0.0	~1	0.55	0.76	0.53	0.63
18	41	+0.16	0.06	1.5	+2.0	0.04	+0.07	0.6	0.84	0.55	0.87	0.49	0.46
19	30	+0.07	0.00	0.3	+0.2	0.82	+0.11	1.6	0.20	0.48	0.25	0.49	0.34
20	45	+0.10	0.01	0.2	+0.0	0.98	−0.11	0.6	0.86	0.49	0.41	0.54	0.84
21	33	+0.02	0.00	0.2	−1.0	0.34	−0.15	0.7	0.76	0.46	0.20	0.57	0.92
22	43	+0.28	0.03	1.1	−0.2	0.81	−0.04	0.2	1.00	0.47	0.26	0.53	0.74
23	48	+0.31	0.05	1.5	0	1.00	−0.03	0.2	~1	0.49	0.35	0.54	0.73
24	31	+0.13	0.01	0.4	−0.7	0.48	−0.06	0.3	~1	0.45	0.18	0.34	0.00
25	48	+0.08	0.01	0.8	+0.2	0.86	0.00	0.2	~1	0.46	0.13	0.59	0.96
26	32	+0.07	0.00	0.3	−0.2	0.82	−0.03	0.6	0.85	0.48	0.25	0.51	0.45
27	39	+0.34	0.06	1.5	+2.5	0.01	+0.17	0.5	0.94	0.49	0.38	0.54	0.78
28	37	−0.16	0.03	1.0	+7.0	0.00	+0.06	1.8	0.11	0.53	0.71	0.50	0.50
29	45	−0.09	0.00	0.2	+1.6	0.11	+0.16	1.0	0.50	0.50	0.52	0.42	0.03
30	58	−0.08	0.00	0.2	+1.4	0.16	+0.23	2.9	0.00	0.50	0.38	0.40	0.00
31	42	+0.30	0.02	0.9	+4.4	0.00	+0.02	0.4	0.98	0.49	0.35	0.53	0.64
32	47	+0.00	0.00	0.0	+0.9	0.15	0.000	0.6	0.75	0.44	0.08	0.51	0.58
33	57	+0.96	0.02	1.0	+2.1	0.03	+0.59	0.9	0.57	0.56	0.95	0.46	0.15
34	39	+0.11	0.01	0.7	−0.4	0.67	−0.01	0.4	0.98	0.46	0.18	0.48	0.36
35	56	−0.93	0.07	2.0	−1.1	0.27	−0.23	1.5	0.17	0.42	0.02	0.47	0.18
36	42	+0.74	0.10	2.1	+1.8	0.06	+0.24	0.2	~1	0.58	0.93	0.48	0.27

No.	N_y	Slope	R^2	t	$Z(\tau)$	$\alpha(\tau)$	Med.	F	$\alpha(F)$	$2W/n^2$	$\alpha(W)$	$2W_a/n^2$	$\alpha(W_a)$
37	41	+0.92	0.02	0.8	+2.2	0.03	+0.62	0.7	0.82	0.54	0.81	0.44	0.12
38	35	–0.22	0.02	0.8	+1.0	0.34	0.000	1.7	0.14	0.50	0.49	0.51	0.57
39	33	+0.03	0.02	0.9	+1.0	0.31	+0.01	0.7	0.73	0.54	0.76	0.53	0.74
40	54	–0.02	0.00	0.1	+1.3	0.18	+0.07	0.6	0.92	0.49	0.28	0.52	0.64
41	54	+0.18	0.01	0.6	–1.2	0.22	–0.16	0.6	0.93	0.52	0.84	0.51	0.50
42	46	+0.40	0.05	1.4	+1.3	0.19	+0.16	0.6	0.92	0.54	0.78	0.52	0.56
43	32	+0.13	0.00	0.3	–1.5	0.14	–0.40	1.4	0.28	0.54	0.67	0.47	0.21
44	38	+0.68	0.17	2.7	+4.1	0.00	+0.61	0.3	~1	0.64	~1	0.56	0.85
45	37	–0.23	0.03	1.0	–1.4	0.17	–0.05	0.7	0.77	0.42	0.05	0.50	0.51
46	24	+1.25	0.03	0.9	+1.1	0.29	+1.21	0.8	0.61	0.63	0.96	0.44	0.09
47	48	+0.42	0.05	1.6	+2.5	0.01	+0.08	0.2	~1	0.56	0.88	0.88	0.41
48	46	+0.77	0.03	1.2	+3.9	0.00	+0.89	0.2	~1	0.52	0.60	0.54	0.74
49	41	+0.21	0.00	0.4	+0.2	0.88	–0.01	0.3	~1	0.48	0.37	0.54	0.83
50	35	+0.76	0.20	2.8	+3.5	0.00	+0.40	0.3	0.99	0.65	~1	0.45	0.15
51	47	+0.24	0.09	0.6	0.49	0.62	–0.01	0.4	0.98	0.48	0.35	0.54	0.86
52	34	–0.69	0.01	0.6	–1.3	0.19	–0.97	1.4	0.24	0.40	0.01	0.60	0.95\
53	25	+2.11	0.01	0.4	–1.9	0.06	–2.02	0.2	~1	0.40	0.04	0.49	0.45
54	47	–0.32	0.02	1.0	+0.3	0.74	–0.08	1.8	0.09	0.44	0.09	0.52	0.66
55	26	+10.0	0.09	1.5	+1.3	0.19	+5.34	0.6	~1	0.62	0.96	0.58	0.84
56	33	–4.93	0.05	1.6	–0.4	0.70	–0.86	1.6	0.18	0.45	0.19	0.52	0.67
57	47	–0.36	0.03	1.1	–0.3	0.76	–0.10	2.6	0.02	0.42	0.03	0.49	0.44
58	42	–0.98	0.02	0.9	–2.5	0.01	–0.47	0.6	0.84	0.44	0.07	0.56	0.84
59	38	+2.09	0.06	1.5	+0.1	0.91	0.000	0.0	~1	0.53	0.63	0.48	0.27
60	44	+1.80	0.05	1.5	+1.0	0.30	0.000	0.1	~1	0.54	0.71	0.56	0.86
61	40	+0.80	0.01	0.6	–1.0	0.32	–0.61	0.2	~1	0.46	0.14	0.57	0.89
62	43	+0.37	0.04	1.4	+1.8	0.08	+0.07	0.4	0.98	0.57	0.93	0.50	0.49
63	40	+1.90	0.02	0.9	+1.6	0.11	+0.30	0.6	0.90	0.57	0.89	0.48	0.25
64	47	+2.97	0.03	1.2	+1.9	0.06	+0.87	1.8	0.09	0.49	0.44	0.52	0.65

N_y: number of observation years; **Slope**: slope of the regression line with respect to time ($m^3s^{-1}year^{-1}$); ***R^2***: squared correlation coefficient; **t**: Student t test statistic for the regression; **$Z(\tau)$**: Standard Normal approximate value of Kendall's τ; **$\alpha(\tau)$**: significance level of this test; **Median**: median slope value by the Mann-Kendall test ($m^3s^{-1}year^{-1}$); **F**: statistic of the F test; **α(.)**: significance level of the specified test; ***W***: MWW test statistic; ***n***: number of observational years; ***W_a***: MWW test statistic for absolute deviations from the mean.

Note: Shaded values are statistically significant.

Kendall's τ Significant results, at the two-sided 5% level, are obtained for 16 stations. Two of these results indicate a negative trend, whilst 14 indicate a positive one.

Mann-Kendall's slope For most of the stations, the absolute value of the slope is smaller than the corresponding value obtained by the linear regression. This, and the regression slope, attain identical signs for 46 stations only. Two-sided 5% significance for both slopes, when they attain the same sign, is obtained for four stations. For one station the opposing slopes are both significant at the 10% level.

F test An F value of smaller than 1 indicates that the variance during the second half of the observation period is larger than that during the first half, and *vice versa*. Of the 64 values obtained, 39 are smaller than a unity. Significant values, at the two-sided 5% level, are obtained for 26 stations, 14 of which are 1% significant. $F < 0.25$ is obtained for 13 of these 14 stations, and $F = 2.89$ is obtained for the other station. These reflect marked changes in the variance during the observation period.

MWW test for the medians To clarify the comparison between different stations, a new variable $M = 2W/n^2$, was introduced. W is the sum of ranks of annual maximum discharges during the second half of the observation period, and n is the series length.

$M < 0.5$ is obtained where the sum of ranks during the second half is smaller than that during the first half, and *vice versa*. Significant values, at the two-sided 5% level, are obtained for seven stations, five of which are associated with a declining trend in the discharges. Geographical consistency in the negative trend is found for the regions where the stations 1–9 and 19–27 are located.

MWW test for the deviations No general trend is found. Significant results, at the 5% level, were found for three stations.

INFERENCES CONCERNING STATIONS WITH A NOTICEABLE TREND

The trend for **station 2** is most pronounced. Its linear value is –0.907 $m^3 s^{-1} year^{-1}$, significant at the 5% level. The hypothesis of no trend is rejected at the 6% level. The significance level for the decline in the median is 0.6%. The variance during the second half of the observation period is 2.26 times smaller than that during the first half, significant at the 3.4% level. These indicate a substantially large negative trend.

A 5% significant trend of –0.080 $m^3 s^{-1} year^{-1}$ is found for **station 8**. The hypothesis of no trend is not rejected at a significant level. But there is 0.4% significance that the median discharge during the second half of the observation period is lower than that during the first half. The variance during the second half is 2.48 times smaller than that during the first half, significant at the 3.8% level. These indicate a substantially large negative trend.

A 5% significant trend, of +0.507 $m^3 s^{-1} year^{-1}$, is observed for **station 17**. The hypothesis of no trend is rejected at the 7% level. Yet, the median discharge during the second half of the observation period is lower than that for the first half. The variance during the second half is 50 times larger than that during the first half, with an almost absolute significance,. It appears that most of these outcomes result from the occurrence of an exceptionally high discharge in 1992 (not shown here).

An insignificant trend of –0.155 $m^3 s^{-1} year^{-1}$ is observed for **station 28**, but the hypothesis of no trend is rejected at the 0.1% level. Despite the negative sign of the linear trend, the median slope is +0.058 $m^3 s^{-1} year^{-1}$, significant at the 0.1% level. The exceptionally high discharge in 1945 (not shown here) appears to cause the negative trend.

A 5% significant trend of +0.741 $m^3 s^{-1} year^{-1}$ is observed for **station 36**. The hypothesis of no trend is rejected at the 7.5% level. The variance during the second half of the observation period is 4.8 times larger than that during the first half, significant at the 0.2% level. The three largest discharges (not shown here) occurred during the 1990s, and they are as high as the high discharges prior to the construction of the Mishmar Ayyalon Reservoir (not included in the analysis), that reduced the basin area from 295 to 135 km^2. The opposing trends found for this and the neighbouring station (no. 35) appear as resulting from a shift in the location of the meteorological events causing high discharges.

A 1% significant trend, of +0.682 $m^3 s^{-1} year^{-1}$ is observed for **station 44**. The hypothesis of no trend is rejected at the 0.1% level. The median slope, of +0.607 $m^3 s^{-1} year^{-1}$, is 0.1% significant. The variance during the second half of the observation period is 3.2 times larger than that during the first half, significant at the 1.8% level. The median for the second half is larger than that for the first half, with 1% significance. The records (not shown here) indicate a substantial rise in the higher discharges, while the low and medium annual peaks appear unchanged. As no considerable change is observed for the neighbouring stations, the marked trend for this station is considered to result from local circumstances.

The variance during the second half of the observation period at **station 55** is 20 times larger, with an almost absolute significance, than that during the first half. The median discharge during the second half is larger than that during the first half, at the 8.2% significance level. These results might reflect the late construction of the station, which missed the very high discharges in 1963/64 and 1964/65. Yet, medium and high annual maximum discharges reaching 200–800 $m^3 s^{-1}$ occurred several times in 1990s and only once in the 1970s and in the 1980s.

The variance during the second half of the observation period at **station 59** is 100 times larger, with an almost absolute significance, than that during the first half. This appears to result from the occurrence of the outlying discharges in 1979/80 and 1991/92 (not shown here).

DISCUSSION

Many local changes are found in the series of annual maximum discharges. An outstanding regional phenomenon is the decline in discharges over the Upper Jordan basin (stations 1–9). No information is available on withdrawals in Lebanon upstream from stations 1 and 2. Land-use changes are found affecting annual flow volumes at station 8 (Ben-Zvi & Langerman, 1989), and probably also at stations 7 and 10, but this is not the case for stations 3 and 4. The general decline in maximum discharges should, therefore, be attributed mainly to changes in magnitudes of the meteorological causes of high discharges.

Another important phenomenon is the abundance of flood events during the 1990s (not shown here). For simplicity, this is represented by the decade when the maximum discharge at a station was observed. To reduce inter-effects in the counting, stations located downstream from other stations are excluded from the analysis. Included are 45 stations with an average period of observation of 47 years. Had the occurrence times of maximum observed discharges, at the different stations, been purely random and independent from one another, the expected count for a decade would be 21% (i.e. 1/47) of the number of stations operated during that decade. Actual figures are presented in Table 3.

Percentage values for the 1940s through the 1960s are close to the expected value, but those for the 1970s and the 1990s are far away from it. Had the high discharges been related to the drainage or to land-use developments, a consistent trend with time would be observed. Most of the 1960s maxima occurred in 1968/69, which was the

Table 3 Count of maximum observed discharges.

Decade	1940s	1950s	1960s	1970s	1980s	1990s
Active stations	14	23	45	45	45	43
Observed maxima	3	4	10.5	1	6	20.5
Percentage of maxima	21	17	23	2	13	48

rainiest year over northern Israel. About one half of the 1990s maxima occurred in 1991/92, which was the rainiest year over most other regions of Israel. It appears, there fore, that the wide variation in the temporal distribution of maximum observed discharges at the hydrometric stations indicates a substantial fluctuation in the meteorological causes of floods, rather than in the drainage and land-use conditions on the ground.

The variance in annual maximum discharges declined at the stations in northern Israel where the discharges attained a declining trend, and rose at most of the other stations. Significant difference between the absolute deviations from the mean during the two halves of the observation period was found for a few stations only. The difference between the medians for the two halves of the observation period is consistent with the results of other tests.

CONCLUSIONS

- Use of a variety of tests for the central values of annual maximum discharges, as well as for their variability, provides a balanced view on the temporal and spatial changes of these discharges.
- Significant results for a test at a station were obtained for a large number of stations.
- Annual maximum discharges over the Upper Jordan basin (stations 1–9) are declining. As explained in the Discussion, this is largely attributed to meteorological causes, but certain man-induced changes on the ground might also have an effect.
- Maximum observed discharges during the 1970s were few, whilst those in the 1990s were abundant.
- The variance of annual maximum discharges declined in the Upper Jordan basin (stations 1–9) and generally rose in most of the other regions.
- Meteorological fluctuations appear as the major cause for changes in the statistical properties of annual maximum discharges in Israel.
- These changes should be inspected when preparing probabilistic predictions.

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