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RECONSTRUCTION OF HISTORICAL DROUGHTS IN THE LAKE BIWA BASIN, CENTRAL JAPAN, USING DAILY WEATHER RECORDS OF OLD DIARIES

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SYNOPSIS

Weather records in old diaries provide useful sources of information on hydrological environments in periods when instrumental records were unavailable. In this study, we collected daily weather records from nine old diaries for 18–20th centuries in the Lake Biwa basin, central Japan, and tried to utilize them for evaluating the severity of historical droughts in this region. In order to make a quantitative evaluation, the annual maximum duration of continuous no-rain (no-rain or light rain) days and the annual minimum PI (Precipitation Index) for 30, 60, 90 days, which is calculated by summing up the number of precipitation days for 30, 60, 90 days with the weights of 'light rain : rain : heavy rain = 1 : 2 : 5,' were calculated for each diary. Though these indices are sometimes largely dependent on the writer because of their subjectivity or the oversight of precipitation, the fluctuation patterns are generally synchronous among diaries and major drought years in the historical period such as 1768, 1832, 1853, and 1858 were selected by referring to plural diaries. These results were generally consistent with the descriptions of dry spells found in the historical documentary records, which implies the validity of this method to evaluate drought severity.

INTRODUCTION

It is crucial for efficient water resources management to obtain accurate information about droughts that actually happened in the past for as long time period as possible. In Japan, hydrological or meteorological stations were first installed in the Meiji era (1868–1912) for most regions and instrumental records are usually available for no more than a century. However, long-term trend or periodicity over centuries is often important to know when investigating the magnitude and frequency characteristics of droughts. Historical drought information that extend instrumental records is necessary to deal with this issue.

Lake Biwa is the largest lake in Japan (670 km^2 in area) and situated near from Kyoto, the former capital city of Japan for 794–1869. Due to its geographical importance, the Lake Biwa basin developed since its early days, and is known as the home of many wealthy merchants in the Edo era (1603–1868), which contributes to the abundance of historical records in this region.

The first meteorological station in the Lake Biwa basin was established in 1893 at Hikone (Hikone Meteorological Observatory). For the preceding period, the occurrence of several severe droughts such as 1770, 1821 and 1853 are known from descriptions in historical documents like "The lake water level dropped by 3.03 m," "There have been no rain for 100 days," "Seven tenths of the pine trees died." But it is difficult to evaluate the

severity of the droughts objectively from these descriptions.

In this paper we focus on weather records in old diaries as the sources of proxy data for the severity of historical droughts. Historical daily weather records, which have the advantage of high time resolution and broad range of application, are widely available and utilized in Japan for climatic reconstruction for the relatively recent past (see e.g. T. Mikami (4), (5)). This paper aims at making a quantitative evaluation of historical droughts since the mid-Edo era (18th century) in the Lake Biwa basin based on the several indices derived from daily weather observation records.

HISTORICAL DAILY WEATHER RECORDS IN THE LAKE BIWA BASIN

We acquired weather observation records for 1731–1912 from nine old diaries in the Lake Biwa basin. The location and the temporal span of weather observation for each diary together with Hikone Meteorological Observatory is shown in Fig. 1 and Fig. 2, respectively. Overviews of the diaries used in this study are described below :

a) Tomonori Diary

A private diary written by Tomonori, a samurai who served the feudal Hikone Clan. It contains a weather record for 38 years spanning 1731–1768, which correspond to his age of 46 to 83. Some of the daily weather records include information about detailed weather change with time. The number of missing observations is relatively small.

b) Ii Diary

Diaries included in a group of the patrimonial documents of the Ii family, the lord of the feudal Hikone Clan. These diaries were written at the several houses in Hikone where children of the Ii family were fostered and educated. Weather records for 1744–1749 and 1786–1794 can be found among records on daily affairs in fosterage.

c) Komuro-han Diary

An official diary of the feudal Komuro Clan ("Komuro Han" in Japanese), which was situated in today's Azai. It contains a weather record for 42 years spanning 1746–1787. Its weather description is simple, typically written in one word for each day. The number of missing observations is extremely small.

d) Ichida Diary

A private diary written by several successional masters of the Ichida-Seibee family, a dealer in cloths and sundries based on Omi-Hachiman. It contains weather records for nearly 100 years starting at 1804 despite many hiatuses for the early part of the diary. This is because the writers had traveled to remote branch offices for several months almost every year.

e) Yamamura Diary

A diary written by three successional masters of the Yamamura family, a financier and ojouya (the headman of neighboring villages) in Minakuchi. Though it is thought that the diary was kept for 61 years from 1816 to 1876, what is left today is that for only 44 years because of dissipation. A continuous weather records is available for the period since 1827 with some hiatuses.

f) Zeze-han Diary

A diary included in the official documents of the feudal Zeze Clan ("Zeze Han" in Japanese), which was situated in today's Otsu. Although the documents themselves span nearly two centuries starting at 1690, a continuous weather record is available for the period since 1843. There are many hiatuses and missing observations in the weather records. Typically daily weather is recorded simply in one word.

g) Mori Diary

A diary written by several successional masters of the Mori-Gorobee family, a dealer in cloths based on Omi-Hachiman. Though it is thought that the diary was kept for more than a century starting at 1772, a continuous weather record is today available for the period from 1843 to 1868. Daily weather is recorded for the morning, afternoon and evening separately.

h) Nishikawa Diary

A private and business diary of the Nishikawa-Den'emon family, a merchant family based on Omi-Hachiman.

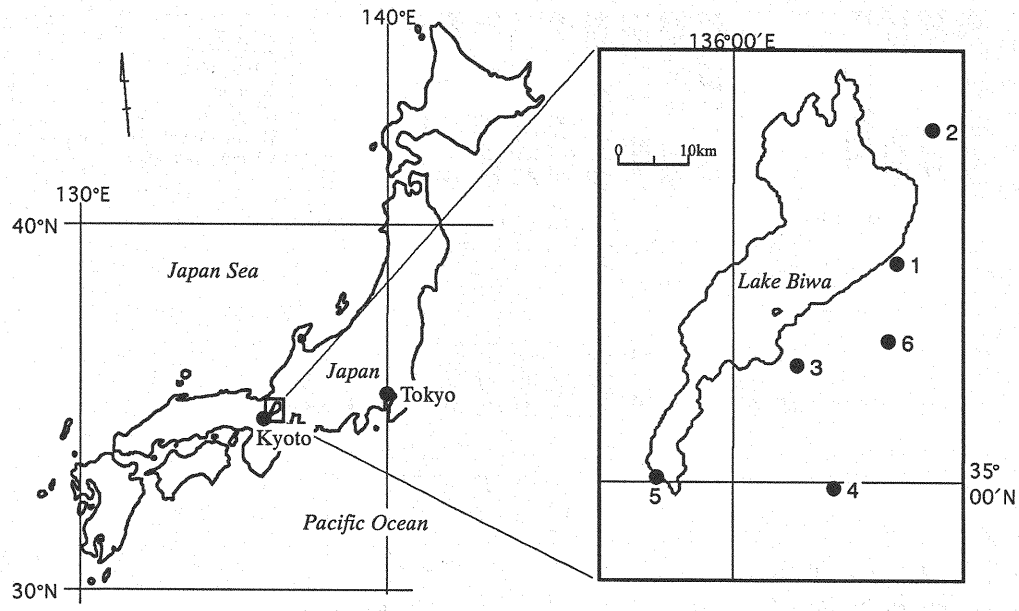

Fig. 1. Maps showing the location of the weather observation records and the meteorological station used in this study: (1) Hikone (Tomonori Diary, Ii Diary, Hikone Meteorological Observatory), (2) Azai (Komuro-han Diary), (3) Omi-Hachiman (Ichida Diary, Mori Diary, Nishikawa Diary), (4) Minakuchi (Yamamura Diary), (5) Otsu (Zeze-han Diary), (6) Hatasho (Muranishi Diary).

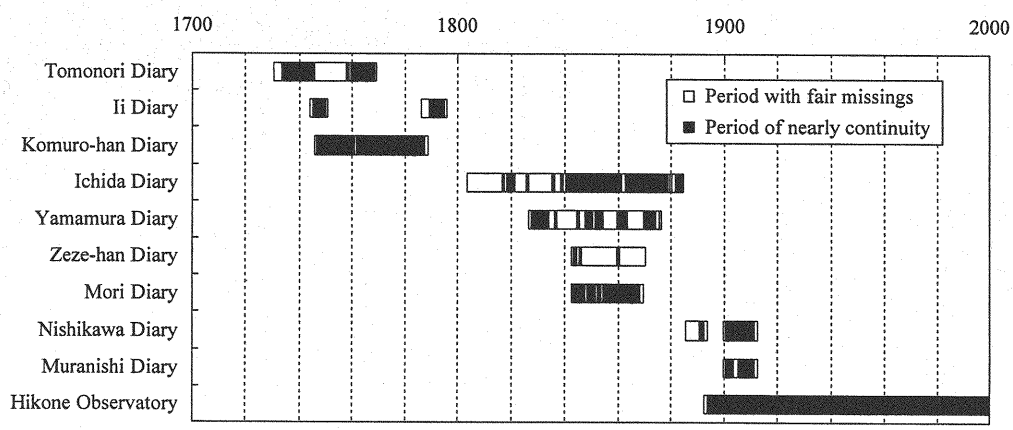

Fig. 2. Temporal span of weather observation for each diary and the meteorological station.

It contains a weather record spanning 1886–1912 with some hiatuses. It should be pointed out that this diary can be used for making a comparison between historical weather records and instrumental data since the first meteorological station in this region (Hikone Meteorological Observatory) was established in 1893.

i) Muranishi Diary

A diary written by Muranishi Mozaemon, a merchant in Hatasho. It contains a weather record spanning 1900–1912 and also can be used for making a comparison with the instrumental data.

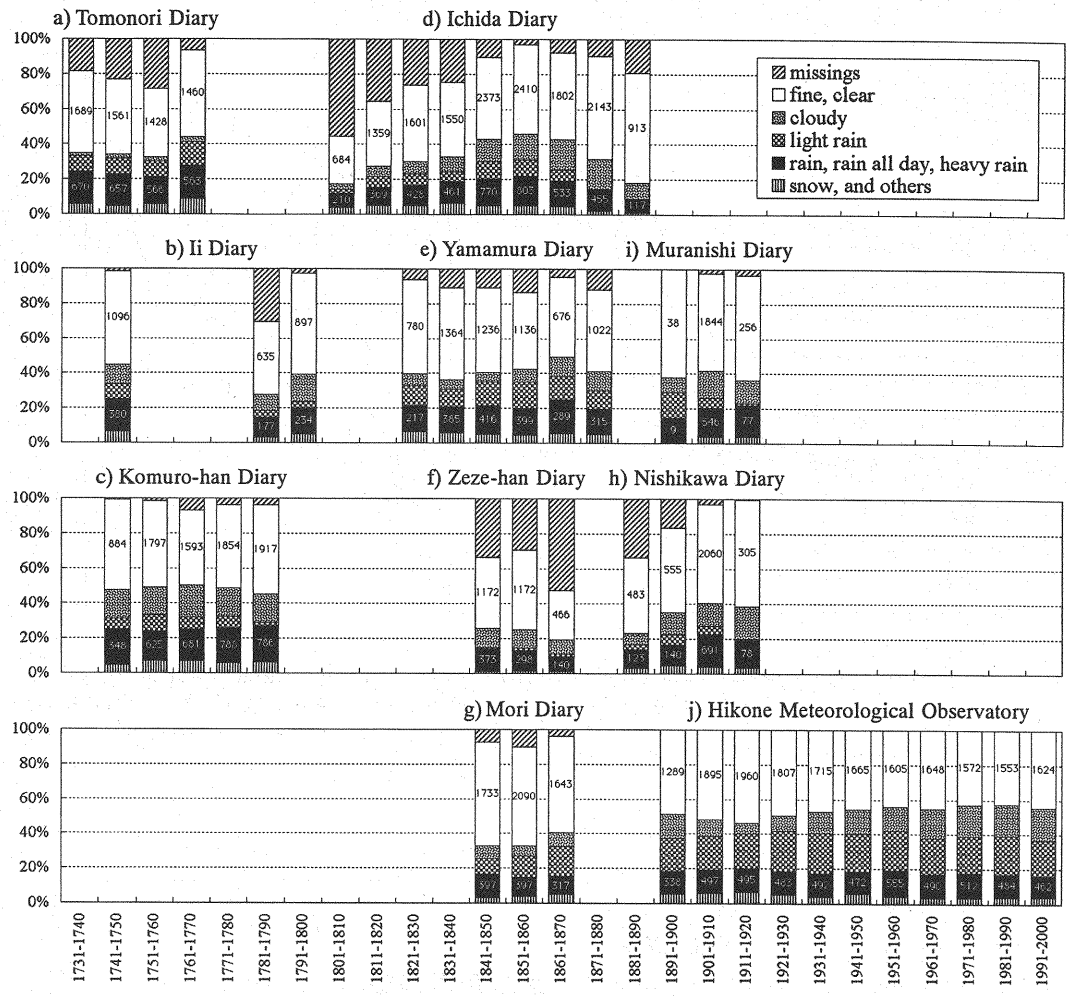

Fig. 3 shows the composition graphs of decadal dominant weather from each diary. The numbers of the data belonging to the dominant weather "fine" (including "clear") and "rain" (including "rain all day" and "heavy rain") are indicated in each bar.

METHODS FOR EVALUATING HISTORICAL DROUGHTS

Transformation into Dominant Weather

The difficulties in utilizing historical weather records for reconstruction of climate record come from their subjectivity, uncertainty and difference in quality among writers. In this study, in order to make quantitative analyses, we classified all daily weather records into eleven categories of "dominant weather," i.e., clear, fine, cloudy, light rain (including shower), rain, rain all day, heavy rain, light snow, snow, heavy snow, and the others (sleet, hail, etc.) (see Y. Ogasawara (6), M. Yoshimura (9)). "snow all day" was omitted because there is no corresponding description in the diaries used in this study. When more than one kind of weather was included in one daily record, generally the worst or the most significant weather was adopted as the dominant weather (For example, "cloudy, then rainy from the noon" was transformed into "rain").

The composition graphs of decadal dominant weather from each diary are shown in Fig. 3. Here the Japanese traditional calendar used in old diaries (lunisolar calendar) was converted to the Gregorian calendar. For the

instrumental period, dominant weather was generated from the daily precipitation and the daily mean cloud cover data at Hikone Meteorological Observatory by the criteria shown in Table 1, according to the conventional classification criteria used by Japan Meteorological Agency. Though the observation frequency of cloud cover has been varied with time between 3 and 15 times a day, it does not practically affect the results.

The actual relationships obtained by comparison between the instrumental data and the weather records in Nishikawa Diary and Muranishi Diary are shown in Table 2 and Fig. 4. From the mean values of the daily precipitation data corresponding to each dominant weather shown in Table 2, it can be deduced that the classification criteria for "light rain," "rain" and "heavy rain" in Table 1 are fairly reasonable. As for "clear," "fine" and "cloudy," the mean values of the corresponding instrumental data exceed the criteria in Table 1 in many cases. This is likely because of the oversight of precipitation by the writers of diaries as mentioned later. The relationships between the cloud cover data and the dominant weather "clear," "fine" and "cloudy" shown in Table 2 and Fig. 4b do not correspond with the classification criteria in Table 1, but this does not practically affect the results of the analyses in this study.

Fig. 3 shows a large difference in composition of dominant weather among diaries, even among those from the same observation location. Such a difference appears to be attributed to subjectivity of writers rather than spatial distance among observation points.

Evaluation with Annual Maximum Duration of Continuous No-Rain (No-Rain or Light-Rain) Days

It is quite reasonable to evaluate drought severity according to the length of time without rain. Fig. 5a shows the fluctuations of the annual maximum duration of continuous "no-rain" days (dominant weather "clear," "fine" or "cloudy") for each diary. Since some writers tend to record only significant weather, missing observations were treated as "no-rain" within the limit of five days. As may be seen from Fig. 5a, there are apparent peaks indicating that no-rain days persisted for approximately thirty days while some peaks are anomalously large. These anomalies seem to be closely related to the oversight of precipitation by the writers. The oversight rates for the two old diaries that are comparable with the instrumental data are shown in Table 3. It can be seen from Table 3 that a considerable portion of days with little precipitation, for example, nearly 1/4 of total days with daily precipitation of 1 mm or larger and approximately 1/10 of that of 5 mm or larger, are recorded as no-rain ("clear," "fine" or "cloudy") in both diaries.

In order to reduce the effect of the oversight of little precipitation, "light rain" ("light snow") was incorporated into "no-rain" and the annual maximum duration of continuous "no-rain or light-rain" days ("clear," "fine," "cloudy," "light rain" or "light snow") was introduced as another indicator of drought severity (Fig. 5b). As is shown in Fig. 5b, there are apparent peaks exceeding forty days while there are several anomalies such as in Fig 5a, which infers the possibility that this indicator is still subject to the oversight of precipitation.

Evaluation with Annual Minimum PIs

As described above, the annual maximum duration of continuous no-rain (no-rain or light-rain) days is based only on binomial information on whether there was any precipitation, and is easily affected by the oversight by the writers. From daily weather records, however, qualitative information on the amount of rainfall is often available as well as binomial information. Typically it can be classified into three categories, i.e., light rain, rain, and heavy rain. Though their correspondence to daily precipitation is largely subjective and ambiguous (see Fig. 4a), quantitative treatment may be possible by considering the accumulation for many days. Yoshimura (9) introduced the Precipitation Index (PI) as a proxy of precipitation, which is calculated by summing up the number of precipitation days with the weights of 'light rain : rain : heavy rain = 1 : 2 : 5.'

In this study, this index was utilized for evaluating drought severity. We assigned the weight 1, 2, and 5 to the dominant weather "light rain" or "light snow," "rain" or "snow," and "heavy rain" or "rain all day" or "heavy snow," respectively, and calculated the annual minimums of PI for 30, 60, and 90 days for each diary. Missing observations were treated as weight 0 within the limit of 1/6 of the length of the calculation period (i.e., 5, 10, 15 days for 30, 60, 90 days' PI, respectively). Moreover, since the classification criteria of "light rain," "rain" and

Table 1 Classification criteria to generate dominant weather from the daily precipitation and the mean cloud cover data at Hikone Meteorological Observatory

Dominant weather	Daily precipitation (mm)	Daily cloud cover (tenths)
Clear	< 1	< 1.5
Fine	< 1	1.5 – 8.5
Cloudy	< 1	≥ 8.5
Light rain (light snow)	1 – 10	
Rain (snow)	10 – 30	
Heavy rain (heavy snow)	≥ 30	

Table 2 shows the mean values of the daily precipitation and the mean cloud cover data corresponding to each dominant weather for Nishikawa Diary and Muranishi Diary

Dominant weather	Daily precipitation (mm)		Daily cloud cover (tenths)	
	Nishikawa Diary	Muranishi Diary	Nishikawa Diary	Muranishi Diary
Clear	5.0	0.6	4.9	3.2
Fine	1.4	1.2	4.9	4.9
Cloudy	3.6	4.0	7.9	8.1
Light rain	6.4	5.9	7.7	7.5
Rain	14.1	15.3	8.9	9.0
Heavy rain	31.6	42.9	9.0	9.8

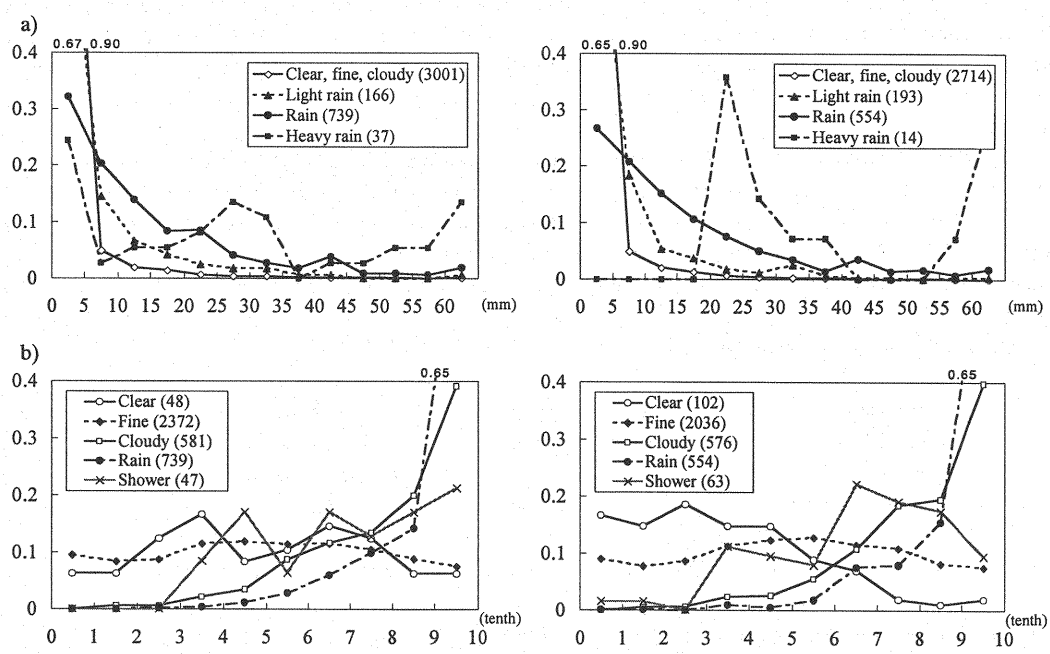

Fig. 4. These graphs show the relative frequency distribution of (a) daily precipitation and (b) daily mean cloud cover at Hikone Meteorological Observatory corresponding to each dominant weather from Nishikawa Diary (left) and Muranishi Diary (right). The total numbers of data for each dominant weather are indicated in parentheses in the legends.

Table 3 lists the rates of the number of days with daily precipitation of 0.1, 1, 5 and 10 mm or larger for each dominant weather of "clear," "fine," "cloudy" and "no-rain" (union of "clear," "fine" and "cloudy") for Nishikawa Diary and Muranishi Diary

Daily precipitation	Nishikawa Diary (percent)				Muranishi Diary (percent)			
	Clear	Fine	Cloudy	No-rain	Clear	Fine	Cloudy	No-rain
0.1 mm	52.1	31.2	55.6	36.3	14.7	29.2	69.6	37.2
1 mm	39.6	18.6	38.9	22.9	9.8	17.1	47.7	23.4
5 mm	22.9	7.9	18.8	10.3	3.9	6.9	21.9	9.9
10 mm	14.6	4.0	10.0	5.3	1.0	3.3	12.0	5.0

"heavy rain" are largely dependent on the writer, annual minimum PIs were standardized so that the averaged values over each diary (or writer, when the diary is written by more than one writers and their covering periods are known) are equal. Practically, annual minimum PIs were multiplied by proper constants for each diary (or writer) and the averages were adjusted to that for Hikone Meteorological Observatory. The fluctuations of the standardized annual minimum PI for 30, 60, and 90 days are shown in Figs. 6a, 6b, and 6c, respectively.

RESULTS AND DISCUSSION

Each graph in Fig. 5 and Fig. 6 shows a similarity of the fluctuation among diaries, but there are some considerable discrepancies. Thus, referring to plural diaries is necessary for reliable evaluation of drought severity. In this study, though the periods covered by plural diaries are limited due to insufficiency of data, several drought periods can be found from the graphs. For example, those dry years in which any of the five indices is greater than $m+\sigma$ (or less than $m-\sigma$ for the annual minimum PIs) for at least two diaries include 1746–48, 1759, 1768, 1832, 1843, 1845, 1848, 1853–54, 1858, 1903, and 1909, where m and σ are the mean and the standard deviation calculated for each diary (or writer), respectively. Among these years, 1853 was picked up by all of the five indices, which infer that the drought that occurred during this year was especially severe in both length and intensity. In fact, various documentary records describe the 1853 drought as one of the most severe droughts in history in the Lake Biwa basin. It appears that there is a period of anomalously severe droughts in the early 1880s from Fig. 5 and Fig. 6, but the reliability of the weather records for this period is questionable.

Also, a decreasing trend of the annual minimum PIs over the late 20th century is shown in Figs. 6b and 6c. The t-test showed significant difference between the mean values over 1951–1975 and 1976–2000 at the 95% level for annual minimum 60 days' and 90 days' PI. This implies an increasing tendency of the severity of long-term droughts that persisted for months over the recent several decades.

Table 4 lists major 20 historical droughts sorted by each index of the annual maximum duration of continuous "no-rain or light-rain" days and the standardized annual minimum PI for 60 days. In old documents from the Lake Biwa basin, many drought years in the historical period, such as 1770–71, 1832–33, 1843–44, 1853, 1855, and 1892, can be found through various descriptions. For example, 1770 is described as the year of the drought that had never been surpassed for 100 years, in which a dry spell lasted from late June and the lake water level dropped by 4.85 m by the next January (see Biwako Construction Office, Kinki Regional Construction Bureau, Japan Ministry of Construction *et al.* (2), K. Ohashi (7)). Also, in the following year, dry days continued from June until the "doyo" season (late July or early August). 1853 is also known as the year of an exceptional drought in the Lake Biwa basin, in which a long dry spell followed a several days' spell of heavy rain in late June, leaving many descriptions such as "There have been no rain for 100 days," "The earth dried to 12–15 cm deep from the surface," "About seven tenths of the pine trees died" (see Association of Educators in Echi County, Shiga Prefecture (1)). Likewise, dry spells recorded in old documents include July 14–August 24 of 1832, July of 1833, July–August of 1843, and August of 1844. Most of these drought years can be found in Table 4, which shows validity of the indices examined in this study as indicators for evaluating drought severity.

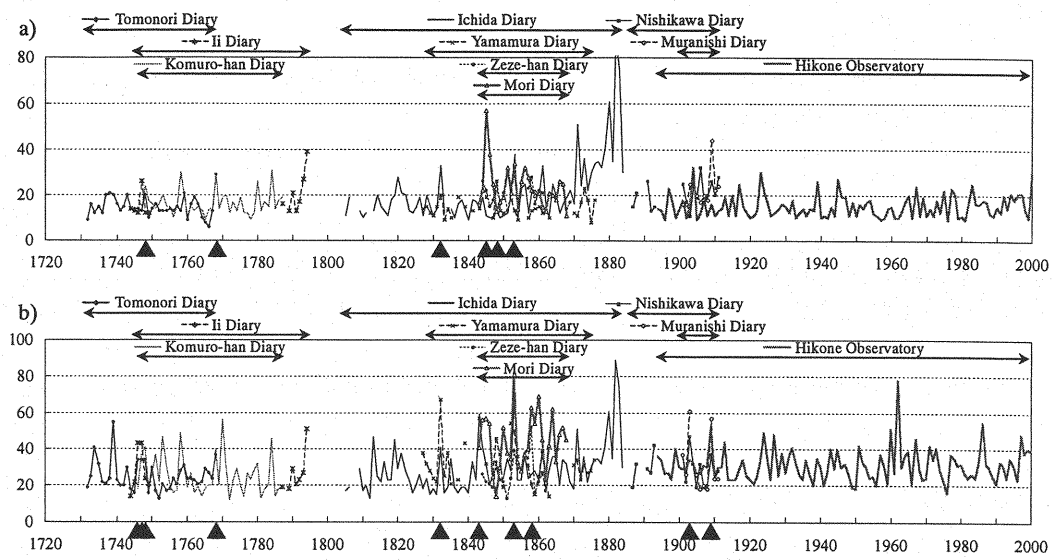

Fig. 5. Plots of the annual maximum duration of (a) continuous no-rain days, and (b) continuous "no-rain or light-rain" days calculated for each diary. The covering periods of each diary are indicated above the graphs. Solid triangles below each graph indicate drought years greater than $m+\sigma$ for at least two diaries, where m and σ are the mean and the standard deviation calculated for each diary (or writer), respectively.

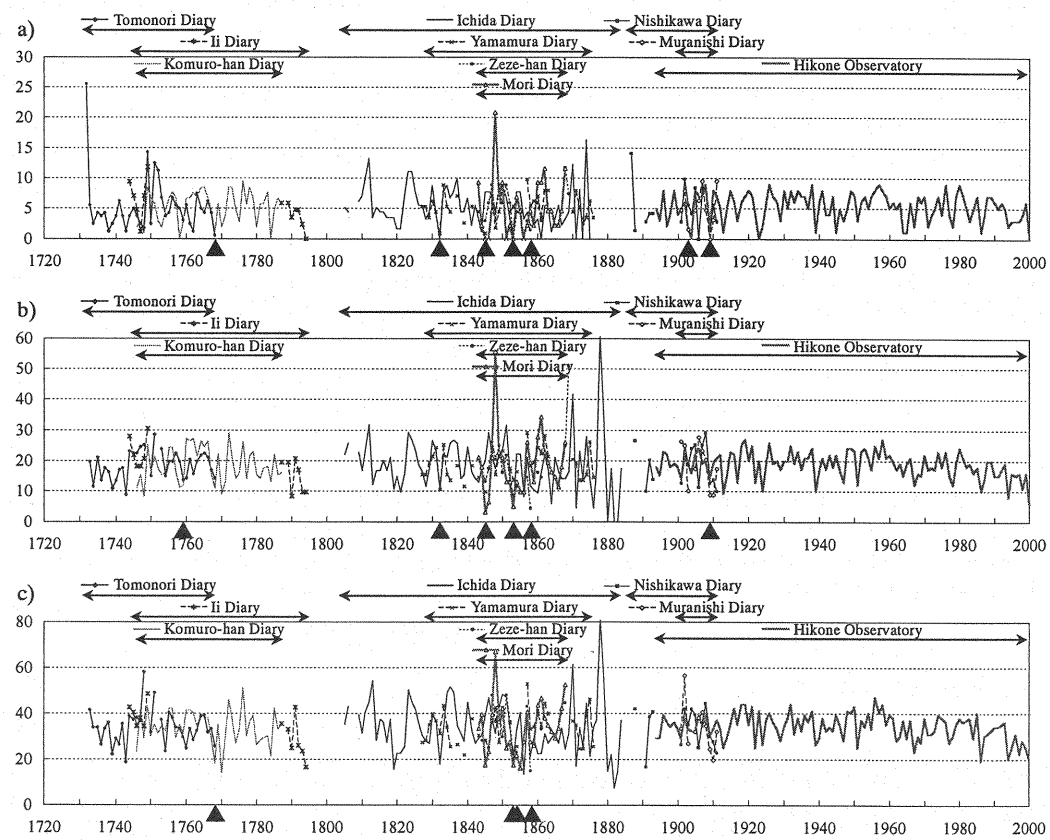

Fig. 6. Plots of the standardized annual minimum PI for (a) 30 days, (b) 60 days, and (c) 90 days calculated for each diary. Solid triangles below each graph indicate drought years less than $m-\sigma$ for at least two diaries.

Table 4 Major 20 historical droughts sorted by the annual maximum duration of continuous "no-rain or light-rain" days and the standardized annual minimum PI for 60 days

Annual maximum duration of continuous "no-rain or light-rain" days			Standardized annual minimum PI for 60 days		
Date of beginning	Length (days)	Source of data	Date of beginning	PI	Source of data
1882. 5.23	89	Ichida Diary	1880.12. 6	0.0	Ichida Diary
1853. 6.25	81	Mori Diary	1882. 5.23	0.0	Ichida Diary
1962.10.12	78	Hikone Observatory	1883. 4. 9	0.0	Ichida Diary
1883. 4. 9	75	Ichida Diary	1845.10.21	3.3	Mori Diary
1860. 6.30	69	Mori Diary	1858.10.24	4.4	Zeze-han Diary
1853. 7. 8	68	Ichida Diary	1853. 7. 8	4.7	Ichida Diary
1832. 7.15	67	Yamamura Diary	1871. 7. 7	4.7	Ichida Diary
1858. 2. 5	63	Mori Diary	1876. 7. 7	4.7	Ichida Diary
1864. 7. 9	62	Mori Diary	1853. 6.25	4.9	Mori Diary
1880.12. 6	61	Ichida Diary	1864. 7.11	5.8	Ichida Diary
1903. 7.24	61	Muranishi Diary	2000. 6.29	6.0	Hikone Observatory
1843. 7.13	59	Ichida Diary	1846. 7. 5	6.5	Mori Diary
1843. 7.19	57	Yamamura Diary	1994. 7. 9	8.0	Hikone Observatory
1845.10.24	57	Mori Diary	1748. 7. 1	8.1	Komuro-han Diary
1909. 7. 6	57	Muranishi Diary	1856. 7.10	8.2	Ichida Diary
1770. 7.23	56	Komuro-han Diary	1790. 7. 5	8.5	Ii Diary
1844. 7.16	56	Mori Diary	1853. 6.29	8.7	Zeze-han Diary
1739. 7.24	55	Tomonori Diary	1909. 7. 6	8.8	Muranishi Diary
1986. 7.24	55	Hikone Observatory	1910.10.13	8.8	Muranishi Diary
1852. 6.30	54	Yamamura Diary	1743. 7.22	8.9	Tomonori Diary
1846. 7. 5	54	Mori Diary			
1859. 9. 9	54	Mori Diary			

CONCLUSION

Weather records were collected from the nine old diaries in the Lake Biwa basin for 18–20th century aiming at reconstructing historical droughts. The annual maximum duration of continuous no-rain (no-rain or light-rain) days and the standardized annual minimum PIs were calculated as indicators of drought severity that are derivable from daily weather data, and major droughts in the historical period were sorted by these indices. Findings were generally consistent with the descriptions about dry spells seen in the old documents, which implies the validity of using these indices for evaluating drought severity. On the other hand, it was also found that a considerable number of precipitation days were missing in historical weather records and further accumulation of the daily weather data is needed for reliable quantitative estimation of historical droughts.

Fortunately, the Lake Biwa basin has the advantage of having a relatively large amount of historical hydrological records, which include lake water level records since 18th century. These records are useful because inflow into the lake, and thus rainfall into the drainage of the lake can be calculated from lake water level, given the stage–storage relationship of the lake, the stage–discharge relationship of the outlet and the rainfall–runoff relationship (including evapotranspiration) of the drainage. A model to estimate the mean areal rainfall total for flood periods by using historical water level and daily weather data has been proposed (see K. Sho *et al.* (8)). Although most of the historical level records are ones for peak water level of large floods, the information on ordinary or low water level is also included in some records, such as the monthly stage observation record by the feudal Zeze Clan. These records will be helpful for a better understanding of the magnitude–frequency relationship of droughts for this region.

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