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The Relationship between Vegetation Changes and Cut-offs in the Lower Yellow River Based on Satellite and Ground Data

Xiufeng WANG[1], Nobuhiro MATSUOKA[2], Guirui YU[3] and Zhongxue ZHANG[3]
[1]Graduate School of Agriculture, Hokkaido University
[2]Faculty of Horticulture, Chiba University
[3]Institute of Geographical Sciences and Natural Resources Research, Chinese Academy of Sciences

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ABSTRACT

Absences of water flow (cut-offs) have occurred frequently since 1972 in the Yellow River, China. Satellite and ground data were used to determine the causes and to understand the river's present state. Actual conditions of river flow/cut-offs were analyzed by means of ground data. Fluctuation trends of the average NDVI for 20 years were obtained from satellite data over the study area. Relationships between the flow/cut-offs of the Yellow River obtained from ground data and NDVI change in the lower reaches of the river obtained from satellite data were analyzed as was the relationship between changing NDVI and precipitation (or temperature). Multiple regression analyses of cut-offs that used predictor variables of the average NDVI, precipitation, and temperature also were performed. The absence of water flow (cut-off) was assumed to be caused by marked water intake from the Yellow River as a result of the increased area for the cultivation of wheat.

1. INTRODUCTION

In China's Yellow River, the absence of flow due to the drying up of river water (referred to as cut-offs in China) has occurred frequently since 1972, and in almost every year of the 1990s. The main causes of these cut-offs are presumed to be the long-term decrease in precipitation and rise in temperature in the Yellow River basin as a result of climate change, together with excess intake of irrigation water due to the increase in farmland in the basin and in agricultural methods change (Chen and Mu, 2000; Yu and Zhang, 2002; and Li 1998 (unpublished document)).

Shortages of water for Chinese food production will be felt throughout the world particularly in Japan. It is believed that the global supply of and demand for crops will tighten in the near future because China will become a large-scale crop importing state in order to continue its lifestyle improvement. Consequently, worldwide food problem is anticipated, resulting in rising global food prices. In particularly, the food issue in China will exacerbate global and Japanese food problems. The authors have conducted this study with the objective that solving one Chinese water issue may provide a partial solution to global and Japanese food problems; more generally, it may provide a solution to global environment problems.

This study, that uses satellite data and ground data, was intended to clarify the cause of the Yellow River cut-offs by investigating flow fluctuation, cut-off conditions, and precipitation, temperature change, and farm land area change in the river's area in the Yellow River.

2. MATERIALS AND METHODS

2.1 Study Area

The satellite data area encompasses the lower Yellow River basin, from 34° 40' to 38° 00' N, and 115° 40' to 119° 00' E (about 300 km × 330 km). The area studied is shown in **Fig. 1**.

2.2 Data Used

(1) Ground Data

Daily precipitation data in the Yellow River basin from 1961

Fig. 1 Study area.
(○Temp.Ob., ◎Temp.+Preci.Ob, ●Flow Ob., ▲Boundary of basin)

KEY WORDS: vegetation change, cut-off, NDVI, satellite data, the lower Yellow River

through 2000 were obtained from meteorological stations at Lanzhou (upper), Mengjin (middle), and Jinan (lower). Monthly flow data from 1980 through 1997 were provided by gauging stations at Toudaoguai (upper), Huayuankou (middle), and Lijin (lower). River cut-off data from 1972 through 1999 were supplied by the Yellow River Lijin gauging station. In additions, daily temperature data from 1961 through 2000 were provided by meteorological stations in Xinghai, Lanzhou, Zhongning, and Linhe in the upper reaches, from Hequ, Suide and Mengjinin in the middle reaches, and from Jinan in the lower reaches.

(2) Satellite Data

The twenty-year Global 4-minute AVHRR NDVI data set at Chiba University (hereafter referred to as NDVI data) was used. These data, composed of 10-day NDVIs, (Normalized Differential Vegetation Index) for 20 years from 1981 to 2000, were compiled by the Center for Environmental Remote Sensing, Chiba University, Japan.

2.3 Analysis Procedure

Three categories of analysis were carried out: (1) actual condition analysis based on ground data, (2) fluctuation trend analysis over the study area based on satellite data, and (3) correlation analyses of ground and satellite data.

(1) Actual Condition Analysis based on Ground Data

Analyzed items include (1) monthly average flow in the middle reaches; (2) cut-off conditions; (3) yearly flow in the upper, middle, and lower reaches; (4) yearly precipitation in the upper, middle, and lower reaches; and (5) yearly average temperature in the upper, middle, and lower reaches.

(2) Fluctuation Trend Analysis over the Study Area based on Satellite Data

Precipitation and temperature change may affect vegetation within the area. Therefore, the fluctuation trend of vegetation over the entire study area based on the NDVIs of satellite data (Cong *et al*. 1999) was analyzed. Four items were analyzed: (1) the fluctuation trend for 20 years based on the yearly average NDVI, (2) seasonal change based on the monthly average NDVI, (3) monthly variation in the fluctuation trend for 20 years, and (4) local characteristics in the yearly average NDVI.

(3) Correlation Analyses of Ground and Satellite Data

The average NDVI correlation was analyzed from satellite data, and the cut-offs, flows, precipitation, and temperature in the Yellow River basin, from ground data. Multiple regression analysis of a cut-off based on the average NDVI, precipitation, and temperature also was performed.

3. RESULTS AND DISCUSSION

3.1 Actual Condition Analysis based on Ground Data

The monthly average flow in the middle reaches of the Yellow River is shown in **Fig. 2**. This figure indicates that a drought season from December to June and a high-water season from July to November are usual in the Yellow River basin. Furthermore, the monthly average flow from 1971 through 1980 is less than that from 1934 through 1970, indicative that the average flow decreases from May in the drought season to November in the high-water season. Particularly, from 1971 through 1980 in June, it was below the minimum flow for the period 1934 - 1970, evidence that cut-offs are likely to occur in June. In fact, data show that cut-offs began normally in late May and ceased at the end of June during the period 1972 - 1991. In 1992 - 1999, however, cut-offs typically began in late February and ended in mid-October.

Fig. 3 shows the cut-off period (days) and cut-off distances in the Yellow River from 1972 through 1999. The longest cut-off distance is 700 km in 1997, the average 248 km. Cut-offs increased markedly in the 1990s. Although previously cut-offs were observed only near the river mouth, the yearly longest cut-off distance recently often has exceeded 500 km.

Cut-offs were observed in the 22 years of the 28-year period 1972 to 1999. They also occurred in six years of the 1970s, totally 86 days; in seven years of the 1980s, 105 days; and in nine years of the 1990s, 901 days. No cut-off has been recorded since 2000 because the Chinese government has restricted water intake, but the future is unpredictable because of the anticipated increase in water consumption and climate change.

Fig. 4 shows the three-year moving average of the monthly average flow in the upper, middle, and lower reaches of the Yellow River for 1980 through 1997. It indicates that the flow is highest in the middle reaches and is decreasing year after year throughout the basin. Although flow in the lower reaches temporarily was

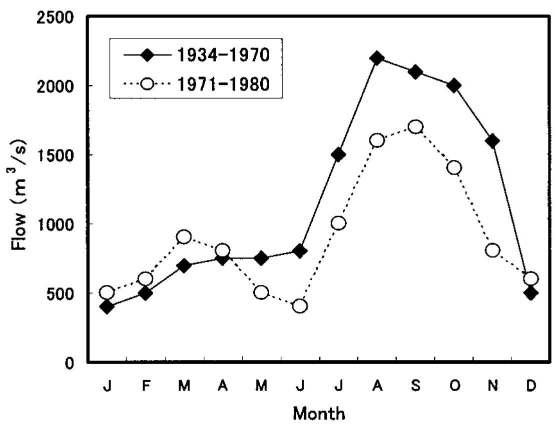

Fig. 2 Monthly average flow in the middle reaches of the Yellow River.

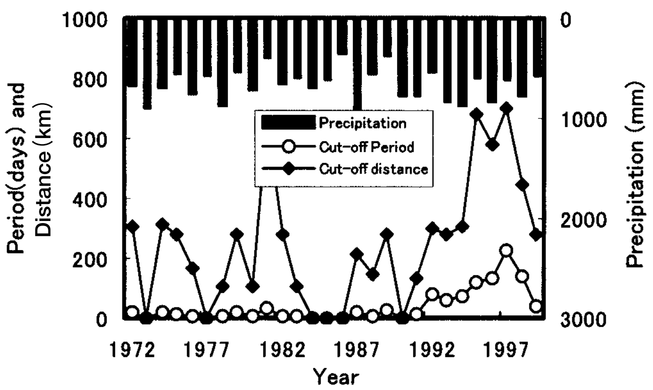

Fig. 3 State of dried up water in the Yellow River and annual precipitation in the lower basin.

close to that in the middle reaches, it is equal to or less than that in the upper reaches in recent years. We have analyzed the causes for this in a later section.

Fig. 5 shows the three-year moving average of annual precipitation in the upper, middle, and lower reaches of the Yellow River for 1961 to 2000. Regression lines are shown to illustrate the downward trend except in the upper reaches. Comparison of the slopes of the regression lines in the upper, middle, and lower reaches indicates that the trend is the greatest in the middle. Consideration of the effect of precipitation on cut-offs and the flow of the Yellow River suggests that precipitation in the upper and middle river is more influential than that in the lower reaches. The decrease in precipitation in the middle reaches therefore may be related to the decrease in the flow of the Yellow River.

The change and three-year moving average of the annual mean temperature for 1961 to 2000 at three points in the upper, middle, and lower reaches of the Yellow River are shown in **Fig. 6**. Regression lines are included to show fluctuation trends. There is an upward trend on the whole. In particular, the upsurge of temperature at Lanzhou is large about 2℃. Data at other points in the upper reaches also show a larger upward trend than in the middle and lower reaches; i.e. the temperature upsurge in the upper reaches tends to be higher. This may reflect the progress of global warming and desertification in the inland area.

3.2 Fluctuation Trend Analysis over the Study Area based on Satellite Data

The 20-year fluctuation trend of the average NDVI over the entire study area was investigated. The average NDVI for 1981 to 1999 shows a yearly upward trend (**Fig. 7**). Moreover, the average NDVI peaks in 1984, 1990, and 1995, whereas it has valleys in 1982, 1986, 1992, and 1996, indicative of periodicity. Calculation of the period by the autocorrelation method based on data transformed to a moving average suggests a 4 to 5 year periodicity. Furthermore, the monthly fluctuation trend for 20 years is evidence that there is a certain upward yearly trend January through June, but that this trend is small from July through December. **Fig. 8** gives typical examples of the NDVI in May and August. The regression coefficients show that the upward trend in May is greater than in August.

Seasonal variation in the average NDVI is shown in **Fig. 9**. There are peaks in May and August, which months are peak of leaf coverage respectively for fall-sown wheat and common crops (especially corn). Moreover, this finding agrees with the research

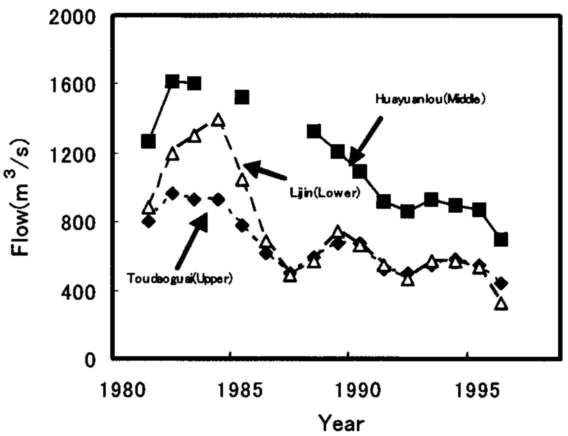

Fig. 4 Three-year moving averages of the Yellow River flow.

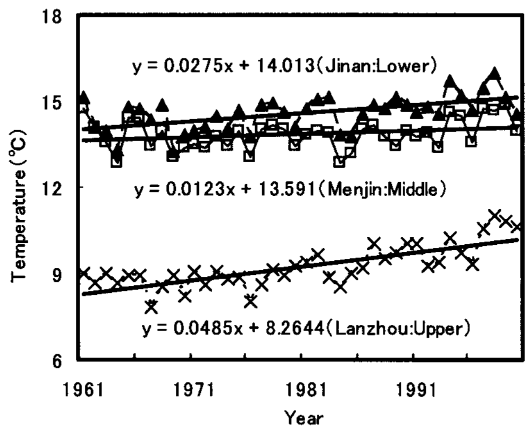

Fig. 6 Yearly transition of the annual mean temperature in the Yellow River basin.

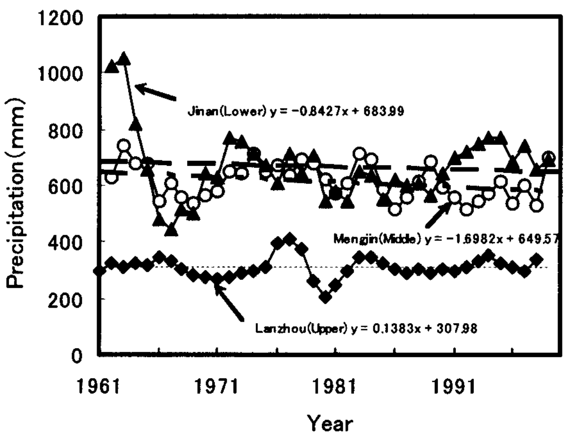

Fig. 5 Moving average of annual precipitation in the Yellow River basin.

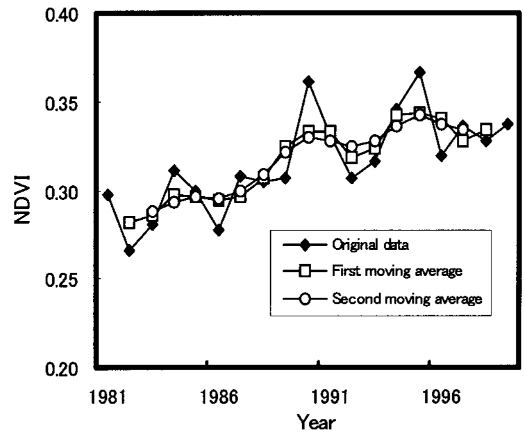

Fig. 7 Yearly change and moving average of the average NDVI over the study area.

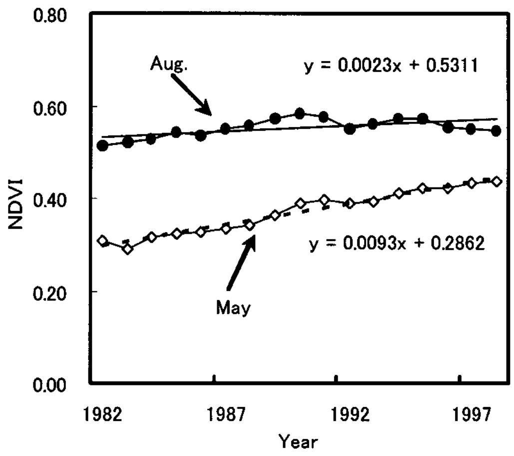

Fig. 8 Moving average of the yearly change of the monthly average NDVI in May and August.

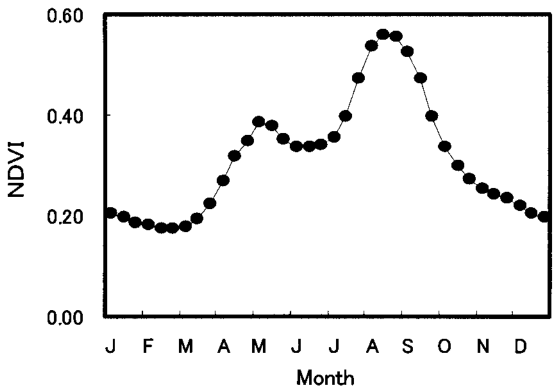

Fig. 9 Seasonal variation in the average NDVI.

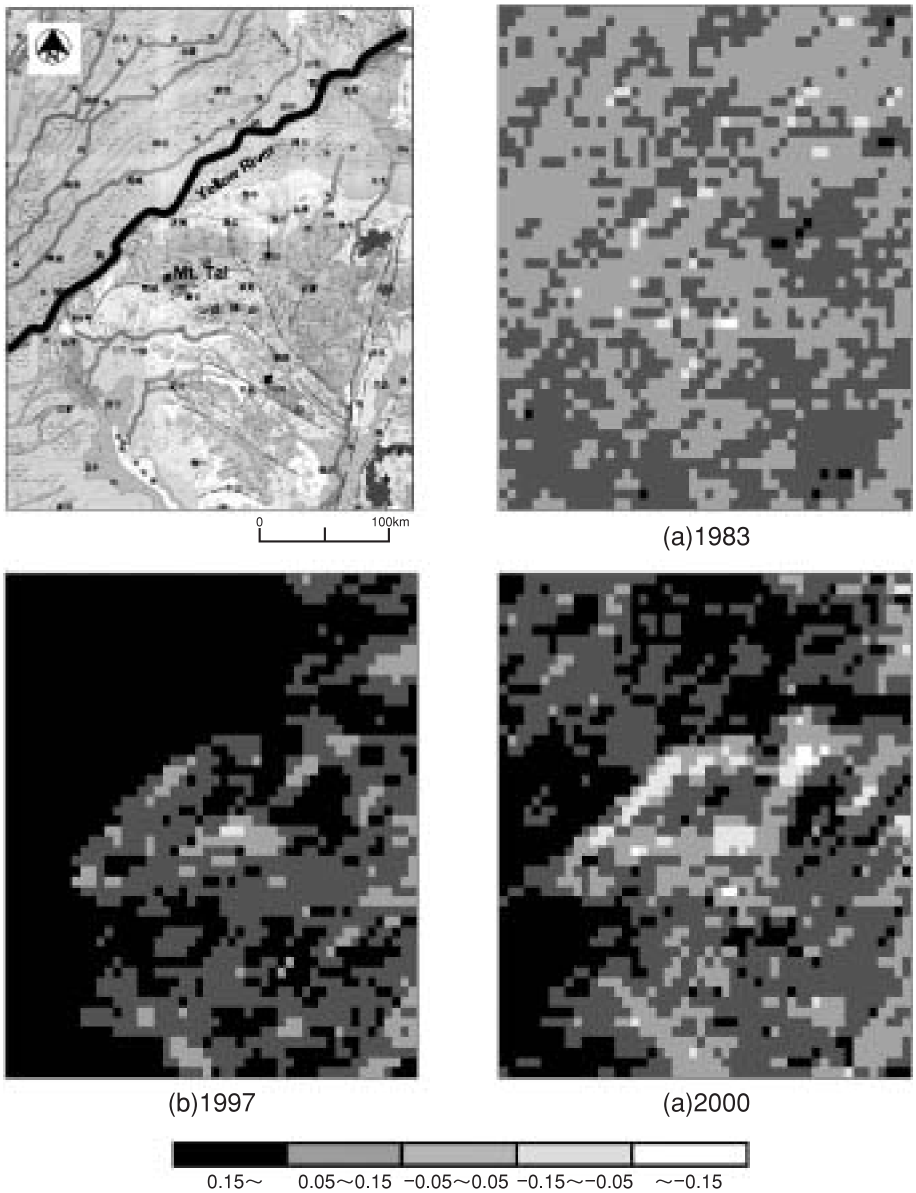

Fig. 10 Difference for each pixel of the NDVI in May on the basis of the NDVI in May 1982. (The area is equal to the square in **Fig.1**)

results of Jingfeng *et al*. (2002) who mapped crop seasons in the North China plain using satellite data. Images in **Fig. 10** express the difference in each pixel on the basis of the NDVI in May 1982 in order to investigate the upward trend in the local cultivation area of wheat. The darker portions of **Fig. 10** denote higher NDVIs.

Fig. 10 (a) represents the 1980s, showing the difference between May 1983 and May 1982, and **Fig. 10** (b) represents the 1990s, showing the difference between May 1997 and May 1982. No great change occurred in the 1980s, whereas the NDVI increased in the 1990s. The upper left part of the area studied is cultivated land north of the Yellow River, and the lower right part is occupied by a mountain range, showing that the increase in the NDVI in and after the 1990s is remarkable in the cultivated land areas. This is considered to be the result of the increase in the cultivation area of wheat. **Fig. 10** (c) shows the NDVI difference between May 2000 and May 1982, May 2000 indicating a part with little change in the upper left part of the study area, which had increased until 1999. The cultivated area may have decreased due to the reported cut in water intake in 2000. No cut-off occurred in 2000 owing to that cut in water intake.

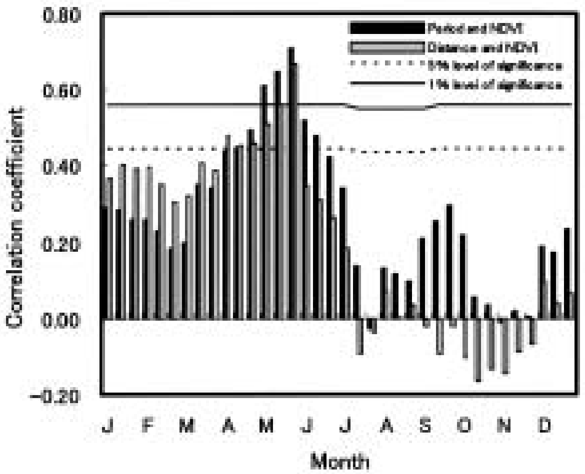

Fig. 11 Correlation between the monthly average NDVI and water cut-off.

3.3 Correlation Analyses of Ground and Satellite Data

Correlations were calculated to determine the relevance between ground and satellite data. **Fig. 11** shows the correlation between the monthly average NDVI in each year of the area studied and the yearly cut-off distance or cut-off period. The cut-off has a high positive correlation with the NDVI in early, middle, and late May; the NDVI in May is high in years with a heavy cut-off. Correlation between the monthly average NDVI for each year and yearly flow is shown in **Fig. 12**. Flow has a high negative correlation with the NDVI from mid-April to late May. These two results suggest that the increased cultivated area of fall-sown wheat raised the average NDVI; hence, water intake from the Yellow River increased, reducing the river's flow and causing a cut-off. Any cut-off beginning in February or March of a year with a heavy cut-off possibly may affect wheat cultivation.

Fig. 13 shows the correlation between the monthly average NDVI in the area studied by year and yearly precipitation in the lower reaches. Precipitation has a high correlation with the NDVI in late June to early August, being especially high in mid-July. The main crops currently grown during this period are assumed to be affected by precipitation. The correlations between cut-off and precipitation in the upper, middle, and lower reaches also were investigated. Precipitation in May in the upper and middle reaches shows a negative correlation, indicative that precipitation also is a factor in the occurrence of a cut-off. Moreover, the correlation of cut-off with monthly and yearly average temperatures in the upper, middle, and lower reaches was studied. There was a high correlation between yearly average temperature and cut-offs over the entire basin. That is, temperature also is considered to act as a cause of cut-offs.

Multiple regression analyses of cut-offs based on the predictor variables of the yearly average NDVI of the study area, yearly precipitation, and yearly mean temperature in the upper, middle, and lower reaches were made. In the middle and lower reaches, the standard regression coefficient of the yearly mean temperature was larger than that of the average NDVI and yearly precipitation (**Fig.**

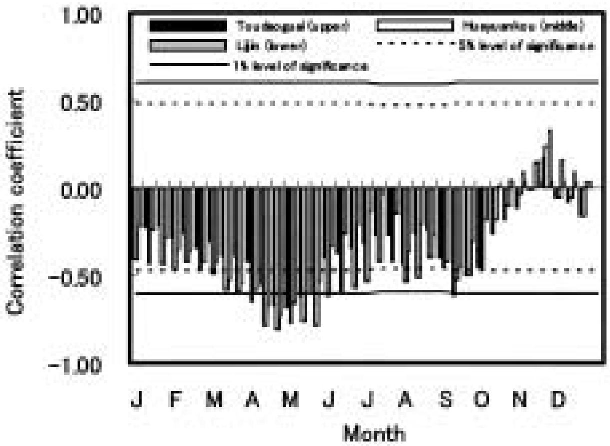

Fig. 12 Correlation between the monthly average NDVI and water flow.

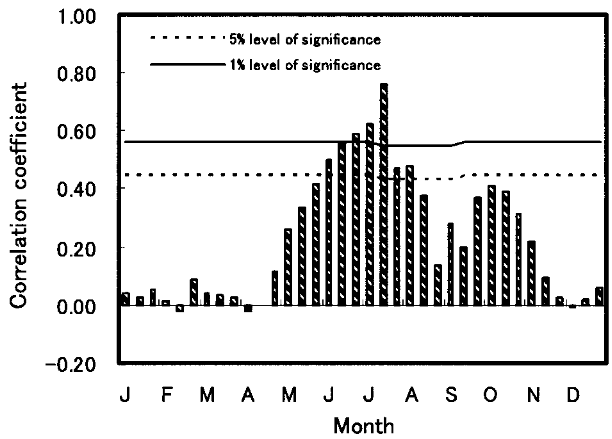

Fig. 13 Correlation between the monthly average NDVI and precipitation.

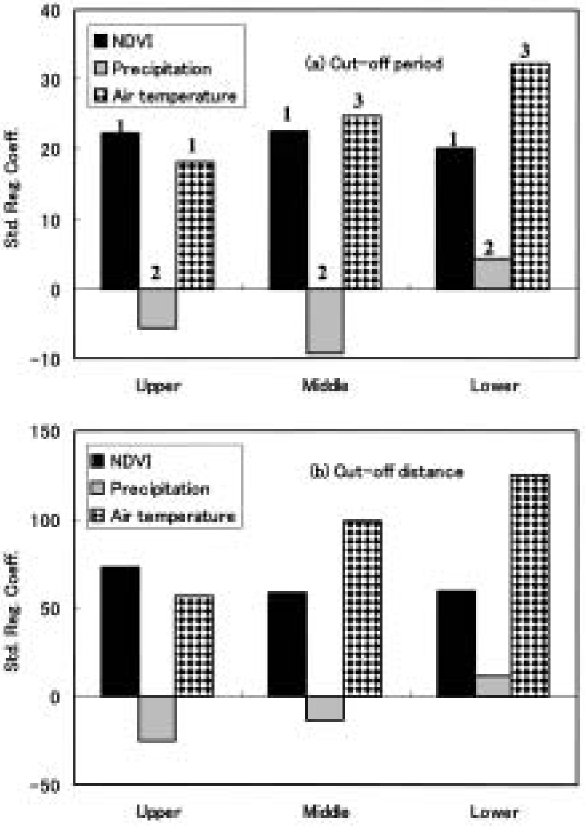

Fig. 14 Standard regression coefficients of multiple regression equations for the upper, middle, and lower reaches of the Yellow River based on yearly data (Correlation coefficient between the same number's items is significant at the 5 or 1% level).

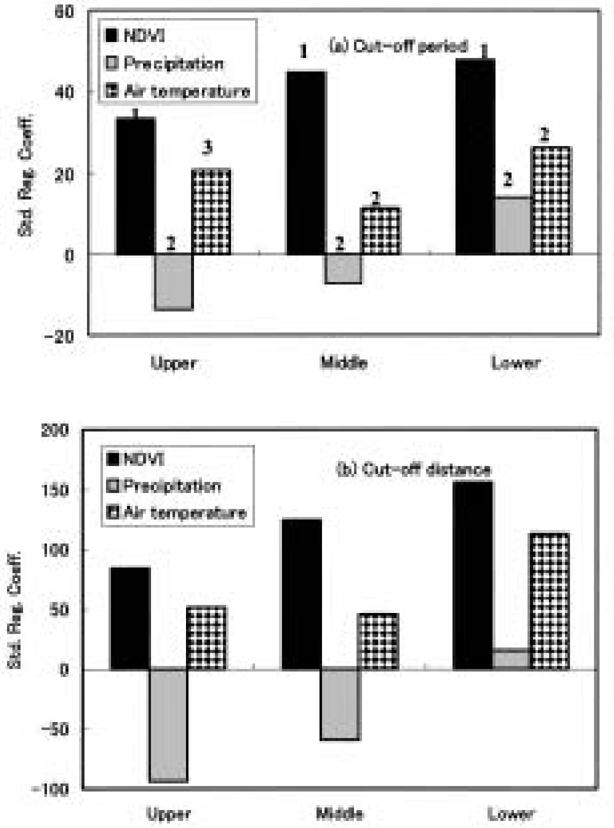

Fig. 15 Standard regression coefficients of multiple regression euations for the upper, middle, and lower reaches based on monthly data for May (Correlation coefficient between the same number's items is significant at the 5 or 1% level).

14). It is presumed that cut-offs are caused by the intake of irrigation water due to high temperature.

Multiple regression analyses for May, when the NDVI peaked and the upper NDVI trend was remarkable, were calculated by means of the predictor variables of the monthly average NDVI of the area studied, and the monthly precipitation and monthly mean temperature in the upper, middle, and lower reaches. The standard regression coefficient of the average NDVI was larger than that of precipitation and temperature in May (**Fig. 15**). The average NDVI is the main cause of the cut-offs in May.

4. CONCLUSIONS

Analysis of ground data showed the following: (1) The monthly average flow in the middle reaches of the Yellow River from 1971 through 1980 was less than that from 1934 through 1970; therefore, the average flow decreased from May in the drought season to November in the high-water season. (2) The longest cut-off distance was 700 km in 1997, 248 km on the average. The longest cut-off distance often has been more than 500 km in recent years. (3) Cut-offs took place in six years of the 1970s (totally 86 days), in seven years of the 1980s, (105 days), and in nine years of the 1990s (901 days). (4) Of the upper, middle, and lower reaches, flow is greatest in the middle reaches, but flow has decreased year after year throughout the basin. (5) A certain downward precipitation trend is seen in the middle and lower reaches, and a comparison of decrements in the upper, middle, and lower reaches suggests that it is greatest in the middle. (6) On the whole, an upward trend is seen in the yearly average temperature at eight sites in the upper, middle, and lower reaches, in particular the trend in the upper reaches was larger than in the middle and lower ones.

Satellite data analysis indicated (1) The average NDVI throughout the study area had an upward trend with a periodicity of four to five years, but it showed no cause for this periodicity. (2) The average NDVI peaks in May and August. These are the respective peak of leaf coverage for fall-sown wheat and common crops (especially corn) in this area. (3) The upward trend of the average NDVI is large in January through June as a result of the increased area for the cultivation of wheat. (4) The NDVI shows a remarkable increase in cultivated land in the upper left part of the area studied north of the Yellow River. The increase in NDVI in the cultivated land is considered to be due to the increased area for wheat cultivation.

Analysis of ground and satellite data suggested that (1) There are significant correlations in May between the average NDVI and the yearly cut-off period, cut-off distance, and flow. (2) A high correlation between the average NDVI and yearly precipitation occurred in early June through August. (3) Cut-offs therefore are considered to be affected by the increased area for the cultivation of wheat in the lower reach. (4) For that reason, flow in the lower reaches is the smallest.

Initially, in this study, our analysis was based on the assumption that cut-offs would impede crop growth in the lower reaches of the Yellow River, thereby decreasing the NDVI. However, we concluded that the NDVI is high in years of Yellow River cut-offs due to the increased area for wheat cultivation in the lower reaches. Future analyses that use high-resolution data, such as original NOAA data (resolution of 1.1 km), and ASTER data (resolution of 15 m), are needed to obtain greater detail. We will then obtain the details of regional increases and detailed characteristics of the yearly increase in the wheat cultivation area using this high-resolution data.

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