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Water resources management of the Yellow River Basin –Current problems and future perspective–

Yoshihiro FUKUSHIMA[1)], Yoshinobu SATO[1)], Akio ONISHI[1)]
[1)]Research Institute for Humanity and Nature (RIHN),
457-4 Kamigamo-motoyama, Kita-Ku, Kyoto 603-8047, JAPAN
e-mail: yoshi@chikyu.ac.jp

Abstract

The most severe dry-up has occurred in the downstream of the Yellow River in 1997. After that, it was legislated for the conservation of water, and was improved on the order of water use in each irrigation area. Since 2000, incidents relevant to dry-up seem to have not happened. The river water of the Yellow River at the mouth, however, continues to let low volume flow as the same as 1997. Its reasons and effect were/are studied as follows. The Yellow River project in RIHN was started to clarifying why the dry-up has occurred and what kinds of effects are to be occurred in surrounding circumstances. Now, the reason of the dry-up are considered due to the complicated factors, these are the decrease of precipitation, over-use of river water in large irrigation districts and recovery of vegetation on Loess Plateau. Though sediment production on Loess Plateau seems to decrease, the river bed in downstream of the Yellow River continues to rise up. It will enhance the danger of flood disaster in the North China Plain. On the other-hand, the environment of Bo-Hai Sea has changed in both water and material inputs from the Yellow River. Its effects are now investigated.

Key words: *Yellow River Basin, water resources management, dry-up, water consumption, water quality*

1. Introduction

As shown in Figure 1, the Yellow River is the second large river basin in China. It has 752,443 km² in basin area and the length of main channel is 5,464 km. The primary production of Bohai Sea seems to change by the decrease of river flow volume, increase of chemical fertilizer from irrigated farms through river and groundwater flow. It should be examined by the model simulation in Bohai Sea. In the Yellow River, dark blue line in Figure 1 is called as upstream, normal blue is as mid-stream and light blue is as downstream.

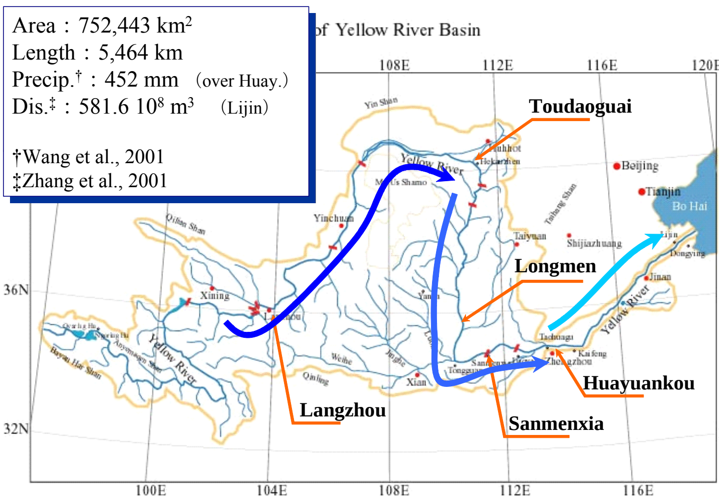

Figure 1 A map of the Yellow River domain

2. Situation of the North China Plain

As the whole Yellow River basin is located in rather dry climate condition in which annual precipitation amount is almost 450 mm, it seems difficult to maintain agriculture for crop production by using only water provided from vertical rainfall (1).

Actually, most of farmlands are use to take groundwater for irrigated water. Therefore, groundwater level was gradually lower down shown in Figure 2. It is named as Luancheng Agricultural Station where is located at near Shijianzhang city. The drop ratio of groundwater level is 0.77 m every year. Therefore, water supply from the Yellow River was essential issues since 1970s.

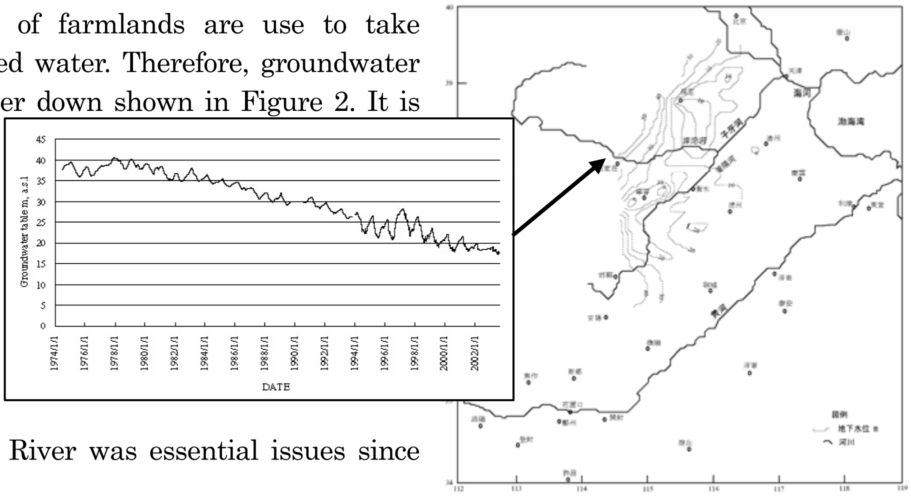

Figure 2 Long-term drop of groundwater level in the North China Plain (2)

As a result, Figure 3 shows the days and length of dry-up in the Yellow River. It shows that the dry-up have been occurring almost every year since 1970s, but the most severe dry-up occurred in 1997.

The feature of the dry-up happened in 1990s was that it became extend its length to upstream. In particular, it was a year small rainfall amount in 1997. As this phenomenon surprised world peoples as related environmental problems, Chinese government had to begin the planning of countermeasures.

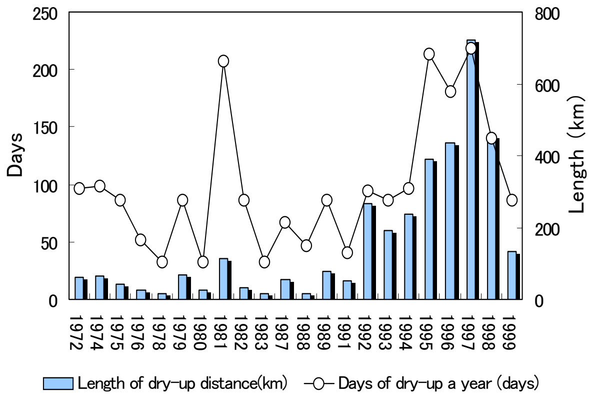

Figure 3 long-term Change of dry-up in the Yellow River (3)

At first, the execution of law was studied and a new water law was actually promulgated n 2002. The most principal feature of the new law is that the competence for water use of the Yellow River has moved to the government from each province. Furthermore, a big domestic project to clarify the cause and how to manage in the Yellow River were to be better, has started after that. Professor Changming LIU has engaged in a section leader.

We also started the Yellow River study in 2003 as a RIHN project with an international view point, to clarify real reason of dry-up in the Yellow River and how does affect to the surrounding circumstances such as Bohai Sea and other areas. It was thought that the world food demand is asking its increase of supply due to the expansion of human population. The objective was including analysis of water use in the Yellow River on considering food product. Therefore, agricultural development of dry region is not only Chinese particular case, but also common issue in other dry regions.

Precipitation amount in the whole Yellow River Basin has a tendency of decrease since 1990s. Water loss in the irrigation areas has clarified to be rather large amount than that officially reported by our analysis over 40 years. It seems to be needed unexpected water in order to wash out saline chemicals in the irrigated field. In the middle area of the Yellow River, almost 20 billion m^3 a year was recently decreased compared with 40 years ago, in spite of no evidence against the increase of agricultural area. This loss is calculated as an increase of almost 58mm a year. We assumed the reason is due to cover surface ground by reforestation from the southern part to the middle part in Loess Plateau. It also might contribute to decrease of sediment yield from Loess Plateau.

Nevertheless, the altitude of river bed of the Yellow River in the North China Plain still continues to rise up by sediment deposit consisted of fine particle (4). It seems to enhance danger of flood disaster in the North China. Plain. For avoiding such a disaster, it seems to construct a new river channel, though it will request tremendous expenditure. But preparation of such a safety net could help the reduction of disaster damages because it is rather easy to forecast water flow course and flooding water level could be down before being attacked by more miserable disaster with unexpected floods.

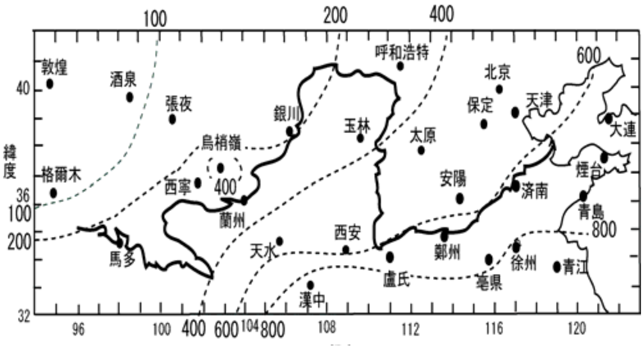

Figure 4 Distribution map of annual precipitation in the Yellow River domain (1)

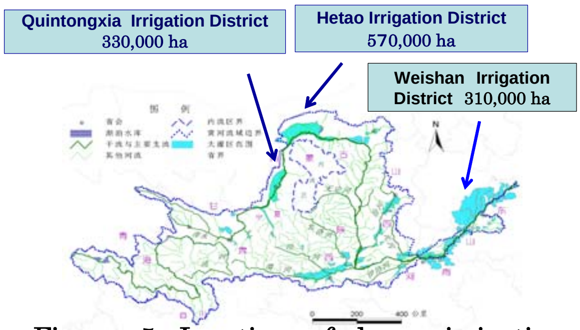

Figure 5 Location of large irrigation districts in the Yellow River (5)

3. Irrigated agriculture dune in the Yellow River

Concerning a water consumption issue, the area of large irrigated agriculture districts located shown as Figure 5. Its areas are very large and cities and industrial factories are also included inside the districts. Therefore, drained water is considerably polluted because no treatment water enters to irrigation drain channels. The result officially reported, diverted and return waters are shown in Table 1 (5). Totally, three large irrigation districts uses river water almost 7.4 billion m³ from the Yellow River. It is not included small scale of irrigated farmlands, generally 80 % of the river water estimated roughly are used for irrigated agriculture. Finally, water used in irrigation will be estimated by newly developed water resources model.

Table 1 Intake amount and other factors of the large irrigation districts in the Yellow River (5)

	Unit	Qintonxia	Hetao	Weisan
Total area	10^3ha	624	1190	360
Irrigated area	10^3ha	330	576	310
Intake from the Yellow River	10^9m^3/y	6.2	5.0	0.89(※)
	mm/y	1880	868	274
Return flow to the Yellow River	10^9m^3/y	3.53	0.53	≒ 0
	mm/y	1070	92	≒ 0
Saline inflow	10^3t/y	280	215	-
Saline outflow	10^3t/y	400	63	-
Saline budget	10^3t/y	-120	168	-

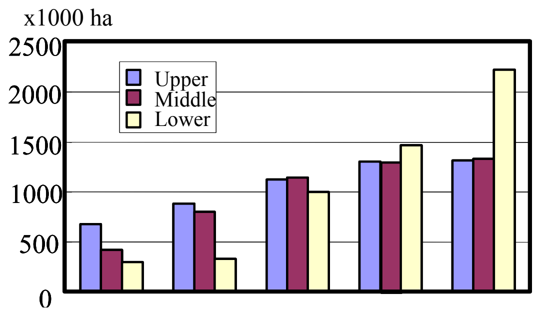

Figure 6 Changes of irrigation area in each decade (6)

Decadal changes of irrigated area are shown in Figure 6. It shows that upper and middle reaches of the Yellow River were mainly developed to irrigation fields by 1980s, but the lower reaches have been developing through 1990s.

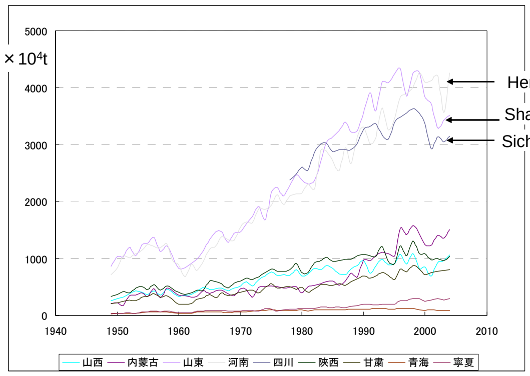

Figure 7(a) Crop production in the Yellow River Domain (7)

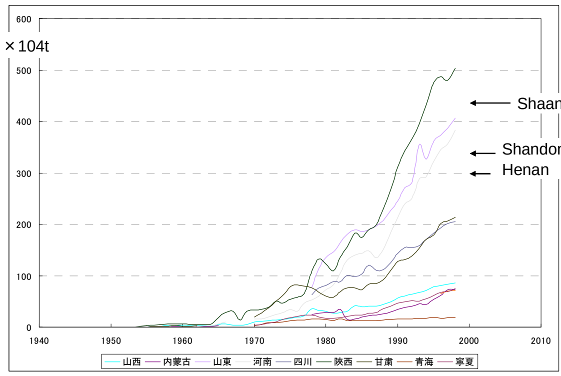

Figure 7(b) Use of chemical fertilizer in the Yellow River Domain (7)

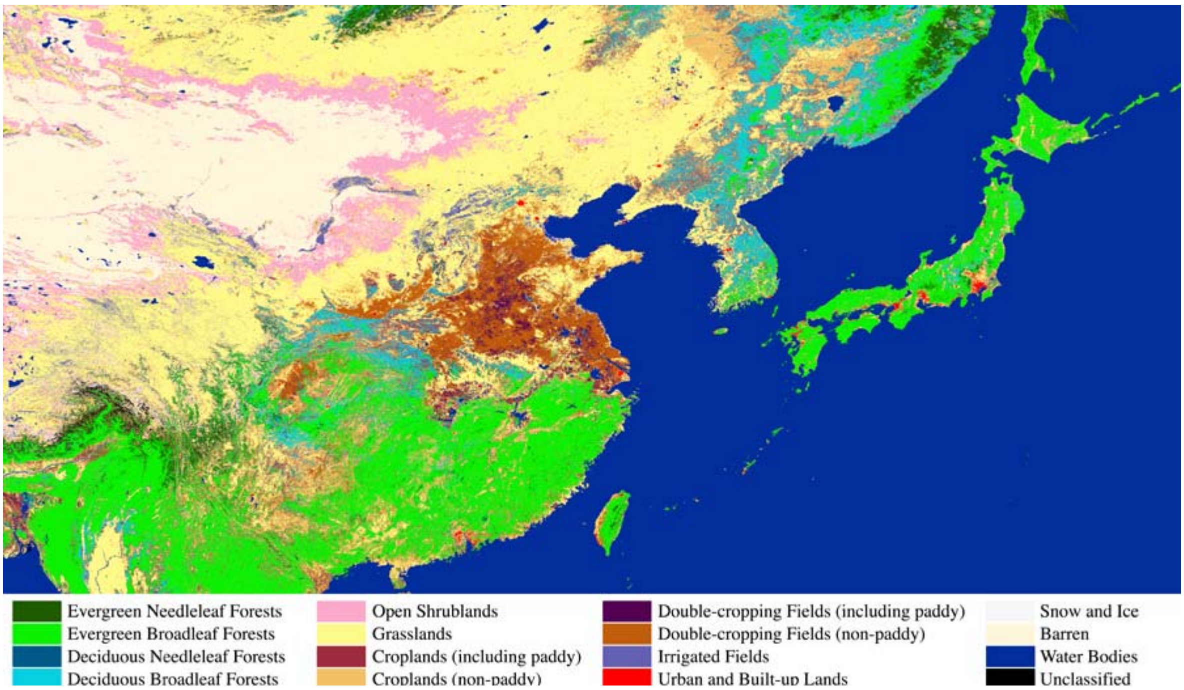

Figure 8 Land classifications of 2000 by MODIS (8)

By the statistical data relevant to crop production and usage of chemical fertilizer as shown in Figure 7(a) and 7(b), the lower reaches of the Yellow River domain were strongly increased its production and use of chemical fertilizer (7). It seems Chinese Government asked higher production of crop in the North China Plain to have to supply food for increasing human population in China.

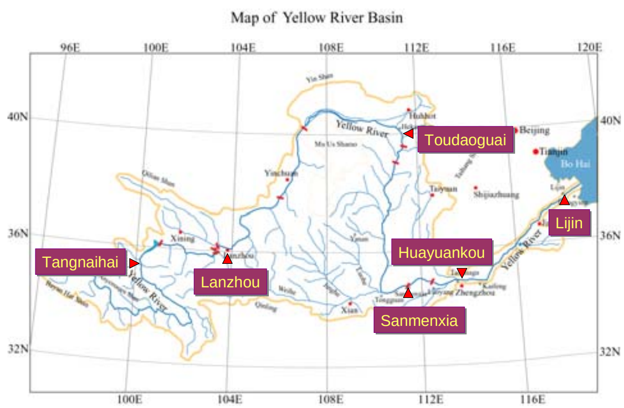

Figure 9 Six stations observing river discharge in the Yellow River

4. Water resources model developed

In order to estimate the change of river discharge during 40 years from 1960 to 2000, including not only natural change, but also human activities like irrigated agriculture, a new water resources model was developed in this project.

Basically, we need the land-use category related to hydrological model. A new map based upon MODIS image data of 2000 is shown in Figure 8 (7). In the same time, we developed water resources model and validated model applicability using river discharge data at six stations in the Yellow River shown in Figure 9.

In each section, water budget is written as follows;

$L = P + Q_{in} - Q_{out} \pm \Delta S$---------(1)

$L \fallingdotseq E$--------------------------------(2)

where, L; water loss, P: precipitation, Qin; inflow to the section, Qout; outflow from the section, E; evaporation.

If the period is taken as one year interval, $\Delta S \fallingdotseq 0$.

Ep is used as potential evaporation estimated by Kondo & Xu's way based upon the bulk method, and Ea is defined as a actual evaporation written as Figure 10 which is a function of Ep, f(LAI) and $\beta(\theta)$. Here, LAI is leaf area index and θ is soil moisture index. This model is developed by Sato *et al.* (9).

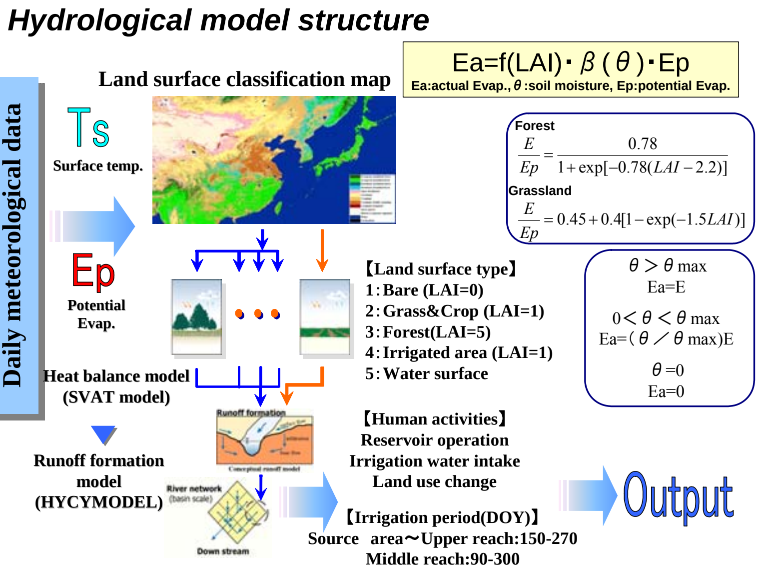

Figure 10 Developed Model structure of Hydrology and water resources

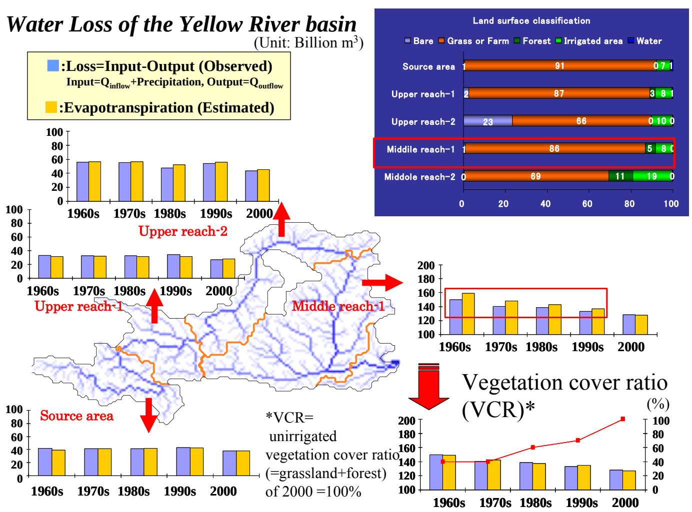

Figure 11 Long-term decadal water budgets in upstream and midstream

After vegetation covers were fixed at 2000, decadal loss and evaporation were compared in each section. Water budgets of three sections in upstream agreed with the calculated value almost. But, in the midstream which flows down and carves Loess Plateau with many tributaries, water loss in previous decade shows small amount compared the calculated value. It seems to be grown vegetation planted as soil and water conservation works started from 1950s, at first. And recent decrease of precipitation is also influenced for the evaporation drop as soil moisture deficit.

But, large irrigation districts upstream have used river water constantly. It's estimated almost 10 Billion m³ in these 40 years. Therefore, main reason for dry-up

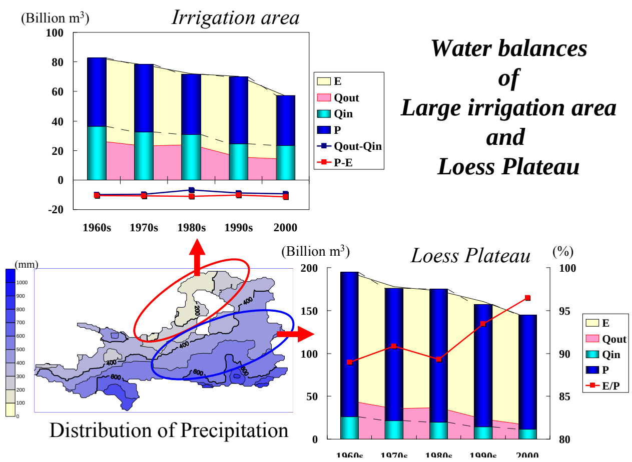

Figure 12 Comparison between upstream with large irrigation Districts and midstream

happened at 1997 was due to the decrease of precipitation at midstream and the gradual increase of evaporation by the success of the soil and water conservation works, mainly. Therefore, river discharge at Huayuankou station dropped down, but we don't forget the amount of sediment discharge has surely decreased. It must contribute the stability of river bed at downstream.

5. Effects to Groundwater in delta area and Bohai Sea

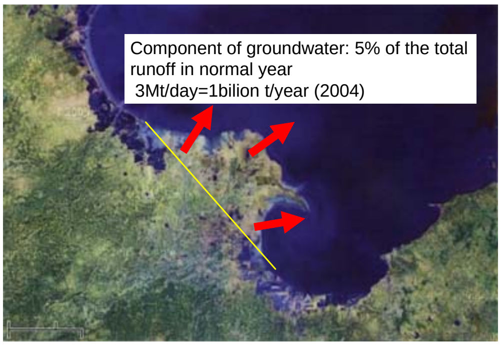

Figure 13 Delta area of the Yellow River (10)

Table 2 Water and nutrients material flow through groundwater in delta area of the Yellow River (11)

	Surface	Groundwater
Flow	100	5
Si conc.	100	1190
Discharge	100	60
TP conc.	100	1000
Discharge	100	50
DTN conc	100	50
Discharge	100	2.4

In the delta area of the Yellow River, how much of groundwater and chemical materials flowing in to the Bohai Sea were investigated in high-and low -amount of flow periods (10).

The results of groundwater show in Table 2. The flow rate of groundwater has only 5 % for surface water, but Si and P are rather high concentration (11). On the other-hand, Nitrogen seems to be increase in Bohai Sea recently by Chinese side. Therefore, it should be investigated in our final year. Figure 14 shows changes of heat transfer judged by satellite images. It shows warm sea water entering by SST from Bohai Strait (12). It may also affect the decrease of flow amount from the Yellow River.

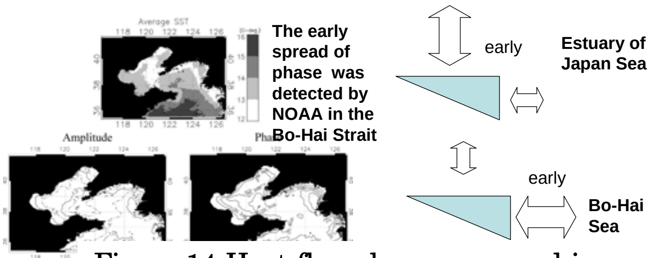

Figure 14 Heat flow change occurred in Bohai Sea (12)

6. Problems in large irrigated agriculture

We have mentioned issues relevant to water use in semi-dry area, but water quality issue should be more emphasized. Because we have found crop production in China is supported by the usage of lots of chemical fertilizer. It is not guaranteed sustainability because chemical world never permit animate nature. It is easily supposed that soil in agricultural field implied organism is to turn to inorganic circumstances. It may induce a monotone world without other living thing by the overuse of agrochemical.

7. Conclusions

1) The remarkable changes on both annual precipitation and annual mean air temperature are not so changed in the Yellow River basin except 1990s generally.
2) Annual evaporation during 40 years in the upstream seems to be not changed although there are two large irrigation districts.
3) Evaporation amount in the midstream during 40 years has almost decreased 10 billion m^3 y^{-1} less than that in 1960s in spite of no evidence for the reduction of agricultural field. If the reforestation and gully control works were succeeded on Loess Plateau, evaporation might increase. But actually evaporation decreased due to

soil moisture deficit occurred by the decrease of annual precipitation recently.

4) Nevertheless, the 70~80 percent of water resources of the Yellow River basin are used for irrigation. As decreased river discharge became usually weak in energy for sediment transport, the river-bed altitude in downstream continues to rise up. It means the danger for flood disaster is to be enhanced. As a countermeasures like flood control, new channels in both outsides of the existing channel seem necessary. Keeping water quality is more important for everywhere of the Yellow River basin. In particular, some scenic place like Lake Ulansuhai, Inner Mongolia, should be kept as safe and healthy area for fishes and birds. Because it has symbolic meaning that Chinese is making effort to maintain people's environment.

5) In the delta area of the Yellow River, material inflow from surface water and groundwater were investigated in different methods. Finally, it was found silica and phosphorus from groundwater are high concentration, but nitrogen concentration was not so high. Nevertheless, it is to be investigated further because nitrogen concentration in Bohai Sea is told as high by the information of Chinese scientists.

8. Acknowledgements

This project study was composed of not only Japanese, but also Chinese scientists concerned with the Chinese national key project team for the resolution of the Yellow River problems. In particular, Academician, Professor Changming LIU was/is supporting this study on his deep understanding international meaning. And we have to say that the part of this project, namely, the hydrology and water resources modeling of the Yellow River, is funded by the MEXT during five years research from 2002 as a part of the subject 5 of the Research Project 2002.

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Application of a reservoir operation model to the upper reaches of the Yellow River basin

Yoshinobu SATO[1], Xieyao MA[2], Yoshihiro FUKUSHIMA[1]

[1] Research Institute for Humanity and Nature (RIHN)
[2] Frontier Research Center for Global Change (FRCGC)

Abstract

A simple reservoir operation model was developed to estimate the influences of the artificial regulation of river runoff in the upper reaches of the Yellow River basin. The model controls discharges from the reservoirs using the following three parameters: (1) the amount of inflow to the reservoirs, (2) the amount of water storage of the reservoirs, and (3) the reservoir operating rules (standard monthly discharges). The monthly standard discharges were determined by analyzing the observed discharge obtained at downstream of the reservoirs (Lanzhou Hydrological station). The controlled discharges estimated by the model agreed well with the seasonal changes of the observed data. The simulated results indicated that the large dams constructed in the upper reaches of the Yellow River basin decrease the peak discharge in the wet season and increase the discharge in the dry season. It was also found that the river discharges are stabilized as the storage of the water reservoir dams increased. The model developed in this study will contribute as the effective tools for evaluating human activities on river discharges of the Yellow River basin.

1. Introduction

The Yellow River basin is the second largest river in China. In recent years, the river discharges have decreased rapidly particularly in the lower reaches because of dry climate conditions and heavy water demands. As a consequence, a drying up in the main river stream of the lower reaches had occurred since 1972. To mitigate the water shortage in the lower reaches of the Yellow River basin, it is important to control the water resources supplied from the upper and middle reaches. In the Yellow River basin, there are a lot of water reservoirs in the upper reaches. Because, the water reservoirs are one of the most effective means for controlling water supply and mitigating serious disasters such as flooding or drought. To clarify the hydrological process in the upper reaches of the Yellow River basin, a hydrological model can be used. However, it is difficult to apply existing hydrological models directly to the Yellow River basin because the river discharges are influenced by the artificial reservoir operations. Thus, we developed a simple model for forecasting the influences of the reservoir operations and applied it to the upper reaches of the Yellow River basin.

2. Study area

Figure 1 shows the study area of this study. The upper reach of the Yellow River basin is located upstream of Toudaoguai hydrological station (40.16°N, 111.04°E).

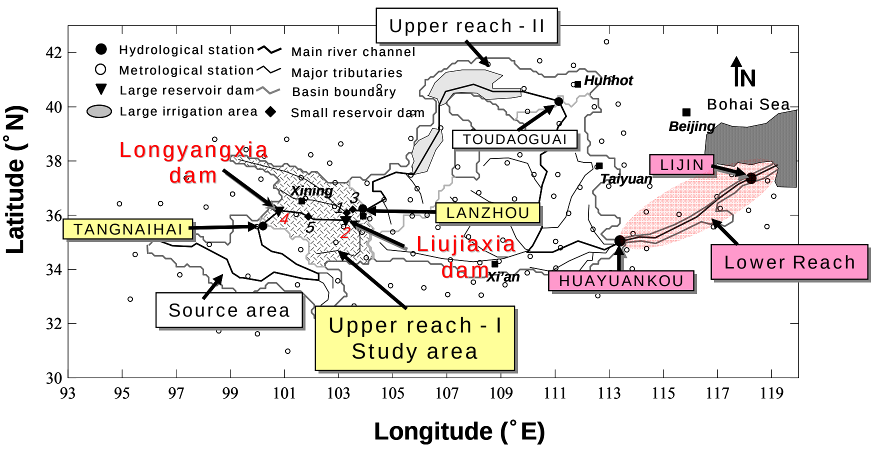

Figure 1 Yellow River basin

Based on the location of the large reservoirs and large irrigation areas, the upper reaches of the Yellow River basin can be divided into the following three sub-basins: (1) Source area (lying upstream of Tangnaihai (35.30°N, 100.09°E) hydrological station), (2) Upper reach–I (lying between Tangnaihai and Lanzhou (36.04°N, 103.49°E) hydrological stations), and (3) Upper reach–II (lying between Lanzhou and Toudaoguai hydrological stations). In particular, there are a lot of reservoir dams in upper reach–I due to the steep and narrow topological conditions. Thus, we focus on the upper reach–I to evaluate the influences of the reservoir operations on river runoff in detail.

The catchment area of this region is 100,636 km^2, which occupies about 13% of the Yellow River basin. The characteristics of the major reservoir dams constructed in the upper reach–I are summarized in Table I. Among them, we can see that there are two larger reservoir dams: Liujiaxia dam and Longyangxia dam. The river discharge observed downstream of these dams must be influenced by their operations. Thus, we focus on these two reservoir dams because the influences of other small reservoirs can be negligible.

Table I. Characteristics of major reservoir dams located in the upper reaches of the Yellow River basin

Code in Figure 1	Name	Begging of operation	Storage capacity ($10^8 m^3$)		
			Maximum	Regulating	Minimum
1	Yanguoxia	1961	2.2	0.1	2.1
2	Liujiaxia	1969	57.0	41.5	15.5
3	Bapanxia	1975	0.5	0.1	0.4
4	Longyangxia	1987	247.0	193.5	53.5
5	Lijiaxia	1998	16.5	0.6	15.9

3. Model structure

3.1. Hydrological model

The hydrological model used in this study is based on SVAT–HYCY model developed by Ma and Fukushima (2002). The model was modified to estimate the heat and water balances more precisely (Sato et al., 2007). The basic structure of the model is shown in the Figure 2. As the input parameters for the model, meteorological dataset from 1960 to 2000 were obtained from the China Meteorological Administration. The dataset includes 128 meteorological stations within or adjacent to the Yellow River basin at a daily temporal resolution. Meteorological parameters included precipitation, air temperature, wind speed, air pressure, vapour pressure, and sunshine duration. All the dataset was interpolated into a 0.1 grid scale over the Yellow River basin. Monthly discharge data observed at Tangnaihai and Lanzhou hydrological stations from 1960 to 2000 were obtained from the Yellow River Conservancy Commission (YRCC).

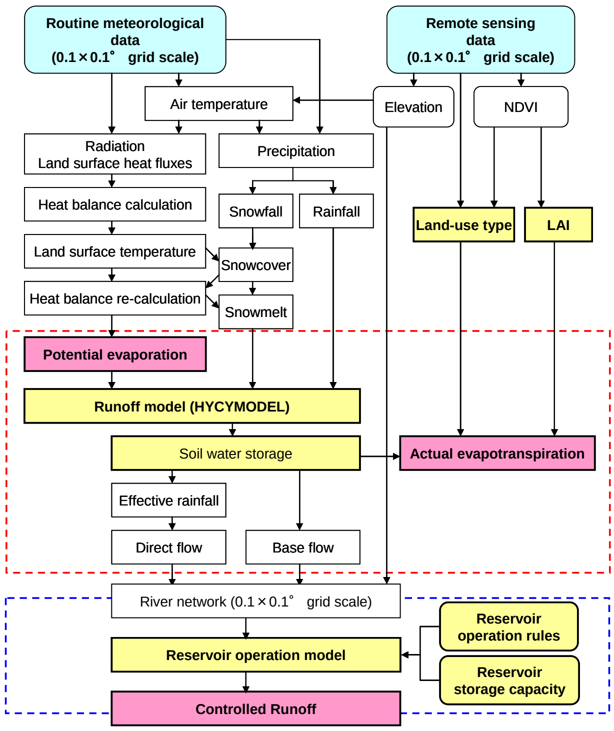

Figure 2 Basic structure of the hydrological model

3.2. Reservoir operation model

To detect the influence of the reservoir operation in detail, the period of analysis were divided as follows: (1) Period-I (1960-1968): There were no large dams in this period, (2) Period-II (1969-1986): The Liujiaxia dam controlled the river discharge in this period, and (3) Period-III: (1987-2000): The Longyangxia dam controlled river discharge together with the Liujiaxia dam in this period. The simple structure of our reservoir operation model is shown in Figure 3. In this model, the controlled outflow (*Qout*) from reservoir was regulated by the following three parameters: (1) the amount of inflow into the reservoir (*Qin*), (2) the amount of water storage within the reservoir (V), and (3) the standard monthly discharge patterns from the reservoir (*Qstd*), which can be correspond to the reservoir operation rules. The inflow into the reservoir (*Qin*) were calculated by the

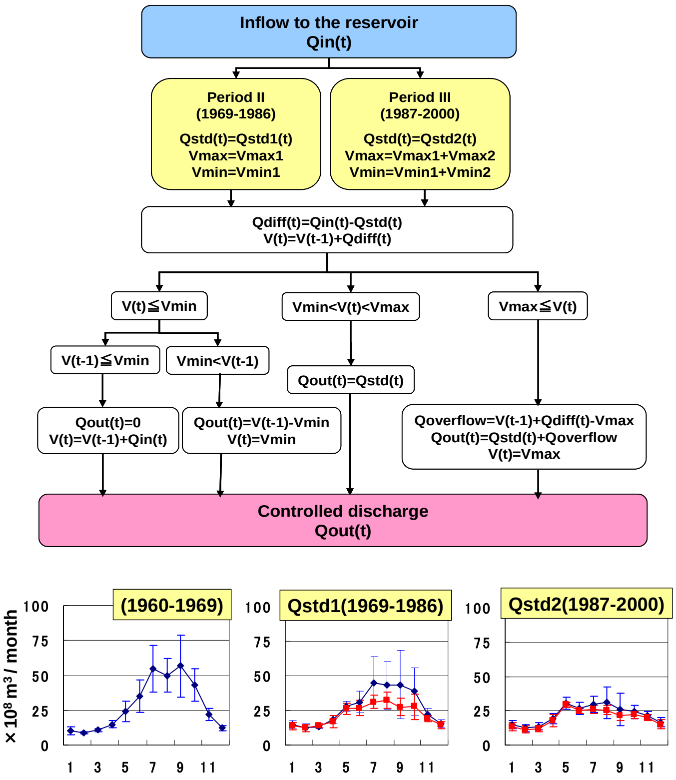

Figure 3 Outline of the reservoir operation model

hydrological (modified SVAT-HYCY) model. The standard monthly discharge patterns from the reservoir (*Qstd*) were estimated from the monthly discharge data observed at Lanzhou hydrological station. The two types of *Qstd* used in this study are also shown in Figure 3.

The controlled outflow from the reservoir (*Qout*) was calculated by the following procedures.

At first, the difference of Qin and Qout is calculated as follows.

$$Qdiff(t) = Qin(t) - Qstd(t) \qquad (1)$$

where *Qdiff* is the parameter which indicates the amount of surplus or deficit water, when the reservoir releases the amount of *Qstd*.

Then, $V(t)$ and $Qout(t)$ are calculated as follows.

$$V(t) = V(t-1) + Qdiff(t) \qquad (2)$$

$$Qout(t) = Qstd(t) \qquad (3)$$

When the value of $V(t)$ exceed the maximum reservoir storage capacity (*Vmax*) in the equation (2), $V(t)$ and $Qout(t)$ are modified as follows.

$$V(t) = V\max \qquad (4)$$

$$Qoverflow = V(t-1) + Qdiff(t) - V\max \qquad (5)$$

$$Qout(t) = Qstd(t) + Qoverflow \qquad (6)$$

where Qoverflow is the overflow discharge from the reservoir dams.

When the value of $V(t)$ decreases less than the minimum storage capacity (*Vmin*) in the equation (2), $V(t)$ and $Qout(t)$ are modified as follows.

If the amount of reservoir water storage in the previous time step is also less than Vmin, then

$$V(t) = V(t-1) + Qin(t) \qquad (7)$$

$$Qout(t) = 0 \qquad (8)$$

else

$$V(t) = V\min \qquad (9)$$

$$Qout(t) = V(t-1) - V\min \qquad (10)$$

The initial storage capacity of the reservoir $V(0)$ was set as 0 m^3. The values of $V(t)$ were also set as 0 m^3 until the Liujiaxia dam began its reservoir operations. Then, during the period-II (from 1969 to 1986), the following parameters were used.

$$Qstd(t) = Qstd1(t) \qquad (11)$$

$$V\max = V\max1 \qquad (12)$$

$$V\min = V\min1 \qquad (13)$$

In the same way, during the period-III (from 1987 to 2000), the following parameters were used.

$$Qstd(t) = Qstd2(t) \qquad (14)$$

$$V\max = V\max1 + V\max2 \qquad (15)$$

$$V\min = V\min1 + V\min2 \qquad (16)$$

4. Results and discussion

4.1. Hydrological simulation–1

Figure 4 shows the result of hydrological simulation using the original hydrological model which does not take the influences of reservoir operation into consideration. According to this result, it was found that the original hydrological model could not estimate the change of observed hydrographs.

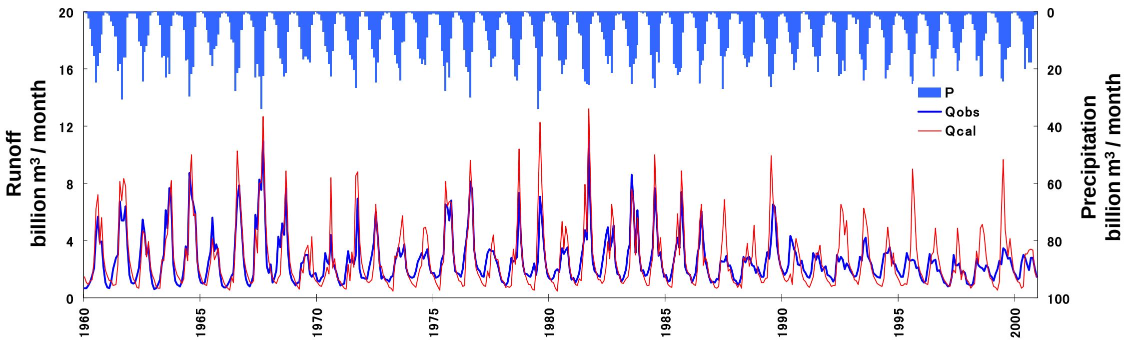

Figure 4 Hydrological simulations using the original hydrological model which does not include reservoir operations. Qobs: observed runoff, Qcal: calculated runoff, and P: precipitation

4.2. Hydrological simulation–2

However, by applying a reservoir operation model, the simulation performance was improved significantly (Figure 5).

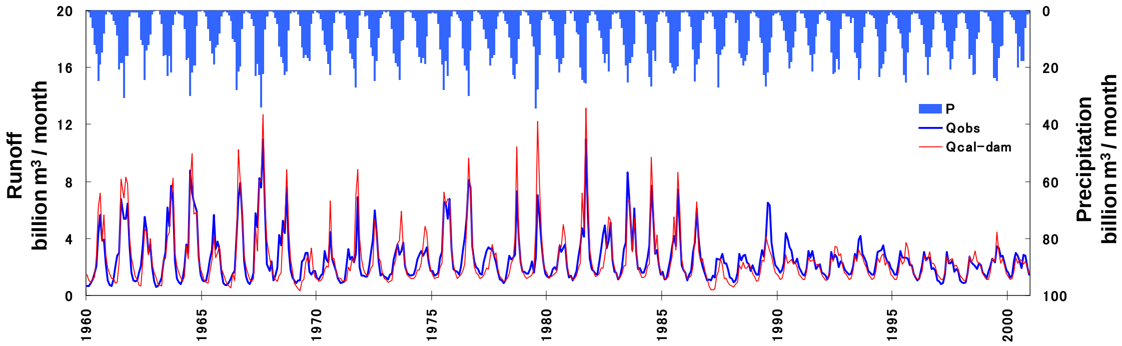

Figure 5 Hydrological simulations using a new hydrological model which include the reservoir operation model. Qobs: observed runoff, Qcal: calculated runoff, and P: precipitation

5. Conclusion

The results obtained in this study are summarized as follows:

1. The seasonal change of natural runoff coming from source area of the Yellow River basin were strongly regulated after the large reservoirs had constructed in the upper reaches of the Yellow River basin. Thus, our original hydrological model could not capture the observed hydrographs.
2. The influences of the reservoir operation can be estimated by the following three parameters: (1) inflow to the reservoir, (2) the storage of the reservoir, and (3) reservoir operation rules.
3. The simulated discharges calculated by our new model including reservoir operation model agreed well with the observed hydrographs.
4. The model developed in this study can be contribute as one of the useful tool for evaluating the influences of reservoir operations, such as the reduction of peak discharge and the stabilization of monthly discharges.

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Study on the efficiency of agricultural water use in the Yellow River basin

Akio Onishi*, Hidefumi Imura**, Tsugihiro Watanabe*, Yoshihiro Fukushima*
*Research Institute for Humanity and Nature,
**Graduate School of Environmental Studies, Nagoya University

1. Introduction

China faces the need to expand its food supply in order to meet the rising food demand of its growing population. The Yellow River basin, one of the important regions in China for agriculture production, has been able to increase its production thanks to by improvements in productivity. Environmental issues, water shortages in particular, have become more serious, however, and excessive agricultural water use may worsen the situation. Therefore, the effective use of water resources is essential if the country is to achieve sustainable food production.

In order to achieve above objective, this study creates administrative/watershed boundaries using available county- and city-level data, and attempts to measure agricultural water use efficiency in each part of the Yellow River Bain, by re-constructing these watershed boundaries using provinces associated with them. The analysis is conducted with a focus on the 1990s, when the river-stoppage phenomenon was at its worst. In addition, by identifying the factors that affect efficiency of agricultural water use calculated here, we suggest important directions for future policies and measures that affect water use. This analysis facilitates discussions about sustainable food production amid constraints on water resources in the river basin.

2. Background of food production issues

Food production in the Yellow River basin has been increasing steadily (**Fig. 1**). Food production is accomplished through the use of irrigation, which accounts for about 84% (calculated by authors from data on the amount of water loss for 1988 through 2002) of all usable water (Sun *et al*. 2001; Yellow River Conservancy Commission 1997-2002). In particular, Shandong Province and Inner Mongolia—home to some of the largest irrigation districts in the river basin—use enormous amounts of water for agriculture, accounting for about 50% of use in the entire river basin (**Fig. 2**). Meanwhile, food production per cubic meter of agricultural water used has been increasing in recent years, suggesting that the efficiency of water use has been improving (**Fig. 3**). The river stoppages were first noticed in 1972, but worsened dramatically in the 1990s, with the most extreme event occurring in 1997 (**Fig. 4**). During this period, the amount of water used for agricultural has been on a declining trend, but in the Yellow River Basin which has unstable water resource amounts, so excessive water use leads quickly to depletion of water resources. For this reason, it is very important that water be utilized efficiently and rationally. Furthermore, the amount of water going to new uses (industrial and urban household use) has been increasing in recent years, along with industrialization and urbanization driven by socio-economic development. Thus, it is likely that the agricultural use of water will be increasingly constrained in the coming years (Chinese Academy of Engineering 2001).

3. Target data and administrative/watershed boundaries

In cases where an analysis targets an area defined by natural boundaries like the Yellow River basin, statistical data for each province will generally include values from outside the watershed. Thus, when the aim is to analyze an area within a river basin, it is preferable to have more accurate spatial units than the provincial units. In such a case, in China it is possible to use data for the smallest administrative units: counties and cities. Meanwhile, for agricultural water data on the Yellow River basin, information is generally prepared using only province-level data. Because of this, some effort is necessary to ensure consistency with agricultural water data—by compiling statistical data from the county and city levels mentioned above to prepare data for each province connected with the river basin. The data prepared in this way therefore represents only the portion of spatial data associated with the provinces in the river basin. This procedure makes it possible to analyze the relationships between food

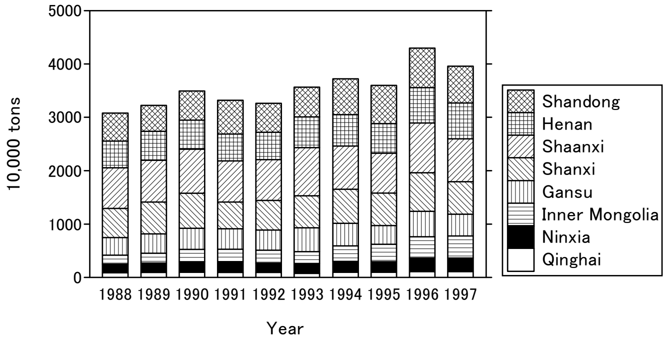

Fig. 1. Food production trends

Source: Prepared by authors from China Statistics Bureau (1989-1991), China Statistics Bureau (1989-1998), and China Natural Resources Database.

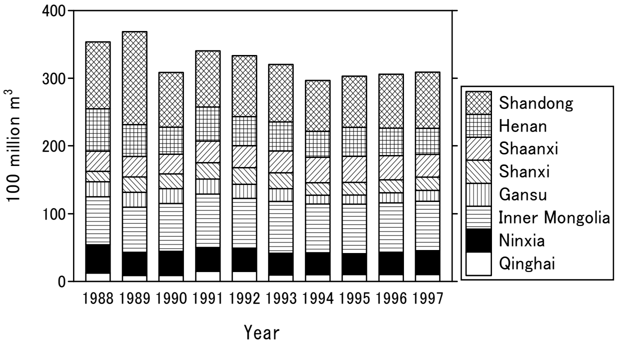

Fig. 2. Trends in agricultural water use

Source: Prepared by authors from Sun et al. 2001.

Note: Figures for 1996 and 1997 are estimates.

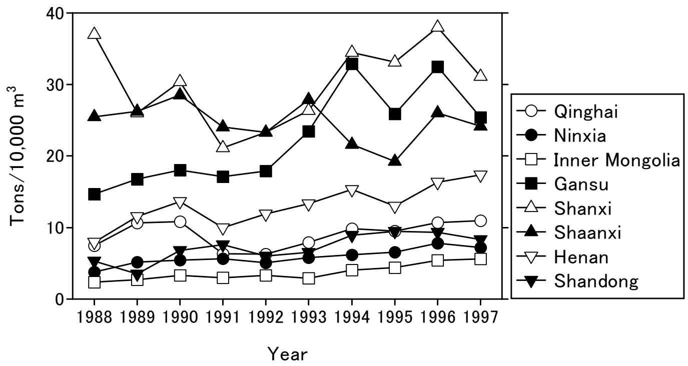

Fig. 3. Food production versus agricultural water use

Source: Prepared by authors.

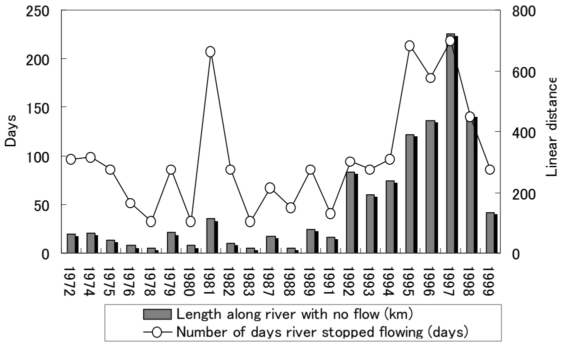

Fig. 4. River flow stoppages: duration and linear distance

Source: Prepared by authors from Sun et al. 2001.

production activities within the river basin and amounts of agricultural water use.

This study calculates the efficiency of agricultural water use in each province from 1988 through 1997. Also, it sub-classifies these provinces into zones (upstream, midstream, downstream) within the Yellow River basin, and conducts a comparative analysis of the efficiency values obtained. For this, it is necessary to determine which province is associated with each zone of the river basin.

Fig. 5 shows the administrative boundaries and river basin zones of the counties, cities and provincial jurisdictions in the Yellow River basin.

4. Analytical methodology

This study calculates the efficiency of agricultural water use in each region of the Yellow River basin, and analyzes the factors affecting the efficiencies thus calculated. To achieve this, analysis is done using the following three approaches. The variables used are summarized in **Table 1**. First, the factors that determine the agricultural water-use constant (amount of irrigation water per hectare of irrigation area) for each province are identified using the ordinary least squares (OLS) method. Next, using stochastic frontier analysis (SFA), we calculate the efficiency of agricultural water use for each region in the Yellow River basin area. Finally, using the Tobit model, factors that affect efficiency are identified.

4.1 Stochastic frontier analysis (SFA)

Stochastic frontier analysis (SFA) (Aiger *et al.* 1977; Meeusen and Julian 1977) is an analytical method that assumes a production function, which is assumed to be stochastically uncertain, to calculate inefficiencies by separating divergences from the production function into error and inefficiency. By this approach, it is possible to establish the production frontier curve as the most efficient possibility set, and this facilitates analysis of the

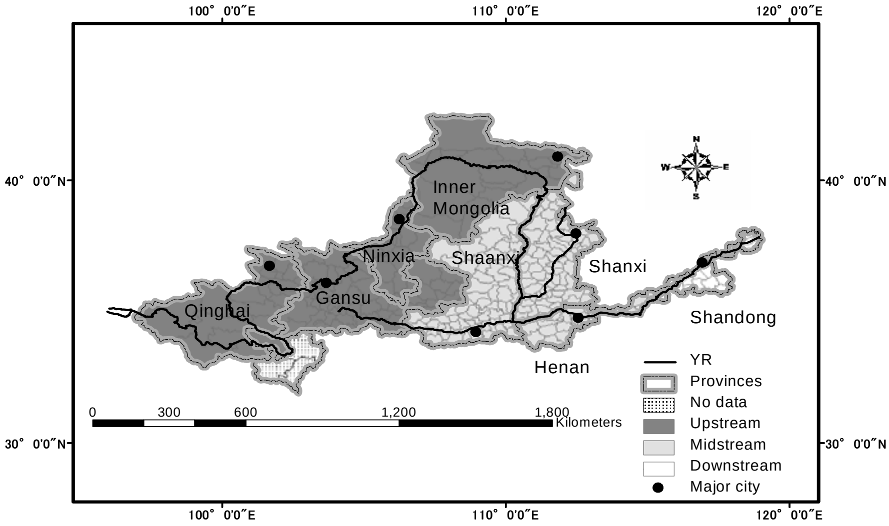

Fig. 5. Map of Yellow River basin showing watershed boundaries and zones

Table 1. Data used and details of estimates

Variable type	Agricultural water constant estimate	Variable selected	Stochastic frontier analysis	Variable selected	Tobit analysis	Variable selected
Non-descriptive	Agricultural water constant (m^3/ha)	Yes	Yield per hectare (kg/ha)	Yes	Value of agricultural water use efficiency	Yes
Descriptive	Times of plantings	Yes	Rural population (persons/ha)	No	No. of plantings	No
	Maize crop ratio (%)	Yes	Amount of mechanization (kW/ha)	Yes	Maize crop ratio (%)	No
	Wheat crop ratio (%)	No	Use of chemical fertilizers (kg/ha)	Yes	Wheat crop ratio (%)	No
	Rice crop ratio (%)	No	Agricultural water loss (m^3/ha)	Yes	Rice crop ratio (%)	No
	Precipitation (100mm)	Yes	Time-scale trends	No	Precipitation (100mm)	Yes
	Average temperature (℃)	No	Upstream dummy	Yes	Average temperature (℃)	Yes
	Sunlight hours (x 1,000 hours)	No	Downstream dummy	Yes	Sunlight hours (x 1,000 hours)	Yes
	Area ratio of large-scale irrigation districts (%)	Yes			Area ratio of large-scale irrigation districts (%)	Yes
	Area ratio of water-conserving irrigation districts (%)	Yes			Area ratio of water-conserving irrigation districts (%)	Yes
	Total dam capacity (100 million m^3)	Yes			Total dam capacity (100 million m^3)	Yes
	Rural household income (10,000 yuan: 1988 level)	No			Rural household income (10,000 yuan: 1988 level)	Yes
	Alkaline soil recovery area (%)	Yes			Alkaline soil recovery area (%)	No
	Time-scale trend	Yes			Time-scale trends	No
	Upstream dummy	Yes			Upstream dummy	No
	Downstream dummy	Yes			Downstream dummy	No

Notes
1. For agricultural water constant, the value used is each province's amount of agricultural water use divided by area under irrigation.
2. For values used in stochastic frontier analysis, values were divided by planted area.
3. No. of plantings ＝ planted area divided by cultivated area.
4. Crop ratios for maize, wheat, rice represent the planted area of the stated crop as a ratio of total planted area for food production.
5. Area ratio of large-scale irrigation districts and area ratio of water-conserving irrigation districts represent the relative area of each item compared to effective area under irrigation.

inefficiency of each production entity in relationship to the frontier.

The stochastic frontier analysis (SFA) model is expressed as shown below.

$$\hat{Y}_{it} = f\left(X_{it}, W_{it}, \beta\right)\exp\left(V_{it} - U_{it}\right) \tag{1}$$

Where $\hat{Y}$ is the frontier production amount, X_{it} is production input factors other than agricultural water, W_{it} is agricultural water input, β is the estimated parameter, V_{it} is the ordinary error term($U_{it} \overset{iid}{\sim} N^{+}\left(0, \sigma_u^2\right)$), and U_{it} is assumed to follow a half normal distribution($V_{it} \overset{iid}{\sim} N\left(0, \sigma_v^2\right)$)

The Cobb-Douglas form (CD-form) and translog form are often used for stochastic frontier analysis (SFA). Of the two, the translog form is the most flexible, but because the estimate includes overlapping items, multicollinearity is likely to occur with the descriptive variable. Conversely, with the Cobb-Douglas form, although an elasticity of substitution of one is a precondition, it is easier to obtain more stable calculation results. Thus, in this study estimates are done using the maximum likelihood method assuming the Cobb Douglas function form shown below.

$$\ln \hat{Y}_{it} = \beta_0 + \beta_1 \ln K_{it} + \beta_2 N_{it} + \beta_3 \ln W_{it} + V_{it} - U_{it} \tag{2}$$

Where K_{it} is the amount of mechanization, N_{it} is the amount of utilization of chemical fertilizers, W_{it} is the amount of agricultural water loss, i indicates the province in the Yellow River administrative/watershed area, and t is the year.

Technical efficiency in this study is expressed by comparing the amount of maximum production from factor of production inputs and the amount of current production. **Fig. 6** shows the correlation between current production Y_R in relation to the amount of input of agricultural water W, and amount of production $\hat{Y}$ obtained from the frontier production coefficient. This figure shows that, as for technical efficiency, based on current amount of agricultural water input W_R,, it is possible to increase production from Y_R to $\hat{Y}$.Thus the current amount of production Y_R could be said to have an inefficiency of $Y_R/\hat{Y}$. Similarly, as for the efficiency of use of agricultural water, by fixing the amount of imports of other factors of production, by defining it as the smallest amount of agricultural water input that is input to in order to produce a certain amount of production, in order to reach production amounts Y_R at the current point R, it is possible to reduce the amount of agricultural water input from W_R to $\hat{W}$. . In other words, the current amount agricultural water input W_R could be said to have an inefficiency of $\hat{W}/W_R$. These efficiency values range from zero to one, and the closer they come to the frontier, the closer they approach one.

Thus, the technical efficiency is expressed as shown below.

$$TE_{it} = \exp(-U_{it}) \tag{3}$$

Efficiency of agricultural water use (WE_{it}) is expressed as shown below.

$$WE_{it} = \exp(-U_{it} / \beta) \tag{4}$$

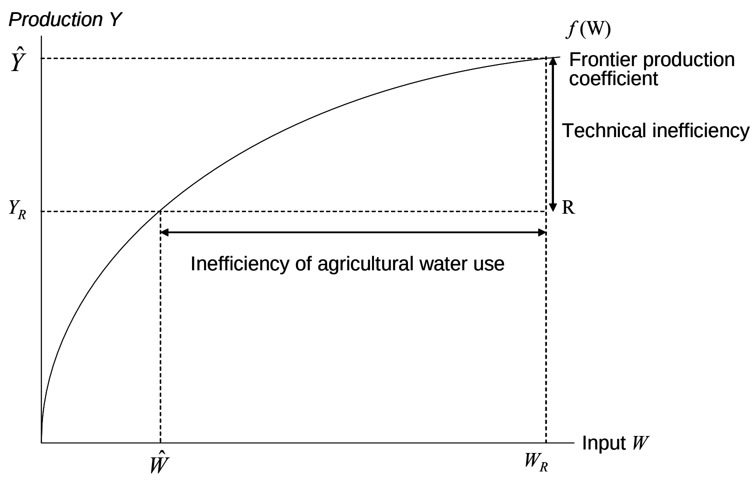

Fig. 6. Stochastic frontier analysis (SFA) and efficiency

4.2 Tobit analysis

In order to estimate what kind of factors determine differences in efficiency of agricultural water use, the Tobit model shown below is used. The Tobit model is used because efficiency takes a value ranging from zero to one.

$$WE_{it} = \begin{cases} 0 & if \quad \sum_j \lambda_j S_{ij} + \varepsilon_i \le 0 \\ \sum_j \lambda_j S_{ij} & if \quad 0 < \sum_j \lambda_j S_{ij} + \varepsilon_i < 1 \\ 1 & if \quad \sum_j \lambda_j S_{ij} + \varepsilon_i \le 1 \end{cases} \tag{5}$$

Where S_{ij} is the descriptive variable, λ_{ij} is the parameter being estimated (where j is an index of the descriptive variable), ε_i is the error term and $\varepsilon_{ij} \sim N\left(0, \sigma^2\right)$.

5. Results

5.1 Analytical results for irrigation constants

As a preliminary step to calculate efficiency of agricultural water use, here we consider what factors determine differences in the amount of agricultural water use. By considering this issue, we can come to understand the physical characteristics of agricultural water use.

Here, we selected variables after considering research by Kaneko *et al.* (2004).When regression is conducted using all variables, however, multicollinearity occurs between the descriptive variables. For this reason, we made a selection of variables. **Table 1** shows the variables that were selected. The results are shown in **Table 2**. Three points can be concluded: (1) the calculation results are favorable, producing high correlation coefficients, and (2) the coefficient obtained is significant, and descriptive variables that have a positive impact on non-descriptive variables include large-scale irrigation districts, upstream dummy, and downstream dummy, whereas (3) descriptive variables with a negative impact include the maize planting ratio, water-conserving irrigation districts, and time-scale trends.

In these results one notices that, in particular, in areas where the ratio of area of large-scale irrigation district is high, the agricultural water constant tends to be high, but in areas where the ratio of area of water-conserving irrigation districts is high, the agricultural water constant tends to be low. Furthermore, one can see that, similar to

Table 2. Results of calculations of factors in agricultural water constants

Name of variable	Partial regression coefficient	Standard partial regression coefficient
No. of plantings	-74.704 (-0.037)	-0.004
Maize crop ratio	-24326.266*** (-3.750)	-0.597
Precipitation	-94.399 (-0.354)	-0.040
Area ratio of large-scale irrigation districts	7416.102* -1.812	0.677
Area ratio of water-conserving irrigation districts	-14028.698*** (-8.099)	-0.537
Total dam capacity	0.872 (0.157)	0.018
Alkaline soil recovery ratio	10451.849 (0.200)	0.094
Time-scale trends	-303.408*** (-4.577)	-0.201
Upstream dummy	3544.276*** (5.239)	0.409
Downstream dummy	7751.202*** (2.670)	0.592
Constant	12755.100*** (6.134)	—
$\underline{R^2}$	0.946	
R^2	0.938	
Number of measurements	80	

Notes: (1) Values in parentheses are t values. (2) Asterisks (*, **, ***) represent 10%, 5%, and 1% significance, respectively.

findings of Kaneko *et al.* (2004), the higher the maize planting ratio, the lower the agricultural water constant tends to be. This may be due to the fact that maize requires relatively less water than other food crops (Chinese Academy of Engineering 2001). Besides these points, although the results obtained are not statistically significant, total dam capacity and area of alkaline soil recovery are factors with a positive sign, for example, while planting frequency and amount of precipitation have a negative sign. The signs here are intriguing, and in the future it will be important to consider these in more detail.

5.2 Calculation results for technical efficiency and agricultural water efficiency

Here, we use each variable shown in **Table 1**, but where no significant parameter is obtained, it is excluded from factors of production. Excluded variables are agricultural population and time-scale trends, as collinear relationships were identified between amount of mechanization and agricultural population, as well as chemical fertilizers and time-scale trends. The results are shown in **Table 3**. For reference, we also display the results of CD-form average production function calculated using the OLS method. The results obtained by both the SFA and OLS methods are favorable, and all the coefficients are significant. It is generally known that in China that elasticity of chemical fertilizers is high (Toyotya *et al.* 2005 ; Peng and Kawaguchi 2000). However, the elasticity of the amount of mechanization exhibits the highest value here. There are at least three reasons for this outcome: (1) the value for amount of mechanization includes the impacts of both mechanization and agricultural population, (2) factors of production in the Yellow River basin are characterized by large influence from the amount of mechanization and agricultural population, and (3) during the period of calculation—1988 through 1997—Chinese agricultural production was at a peak, so high elasticity of chemical fertilizers like during economic reforms and liberalization are not observed. Calculations of dummy coefficients for the upstream and downstream zones resulted in relatively low production upstream and high production downstream.

Technical efficiency (TE) and efficiency of agricultural water use (WE) are calculated based on the calculation results obtained above. The results are shown in **Table 4**. For technical efficiency and efficiency of agricultural water use, Shaanxi Province displayed the highest efficiency, while Inner Mongolia and Shanxi Province displayed the lowest efficiency. It is also evident that efficiency increases as one progresses from the upstream zone to the downstream zone.

Fig. 7 displays the changes in efficiency in the entire river basin from 1988 through 1997. From this figure is evident that both technical efficiency and efficiency of agricultural water use are gradually increasing. In particular one can see remarkable improvements in the minimum values. Based on this outcome, one can tell that technical efficiency is improving, and that the efficiency of agricultural water use is also improving. Meanwhile, efficiency, which had been on an increasing trend, started to decrease in 1997, and it is intriguing to think that this inefficiency in water use may have been a factor behind the river flow stoppages. It should be noted, however,

Table 3. Results of calculations of stochastic frontier analysis (SFA)

Name of variable	OLS	SFA	
	Coefficient	Coefficient	Standard area
Amount of mechanization	0.320*** (5.591)	0.317 (5.806)	0.055
Use of chemical fertilizers	0.157*** (2.779)	0.15 (2.797)	0.054
Agricultural water loss	0.057** (2.284)	0.065 (2.506)	0.026
Upstream dummy	-0.106** (-2.362)	-0.108 (-2.536)	0.043
Downstream dummy	0.187*** (3.623)	0.178 (3.581)	0.05
Constant	6.399*** (24.438)	6.470 (25.651)	0.252
R^2	0.922		
$\bar{R}^2$	0.917		
Log likelihood		63.100	
Number of measurements	80	80	

Notes: (1) Values in parentheses are t values. (2) Asterisks (*, **, ***) represent 10%, 5%, and 1% significance, respectively.

Table 4. Results for technical efficiency and agricultural water use efficiency

	Technical efficiency			Agricultural water use efficiency				Technical efficiency	Agricultural water use efficiency
	Ave.	Min.	Max.	Ave.	Min.	Max.		Ave.	Ave.
Qinghai	0.934	0.896	0.961	0.367	0.183	0.539			
Ninxia	0.920	0.898	0.954	0.283	0.190	0.486			
Inner Mongolia	0.892	0.768	0.976	0.276	0.017	0.690	Upstream zone	0.916	0.307
Gansu	0.918	0.832	0.965	0.301	0.058	0.579			
Shanxi	0.899	0.824	0.936	0.221	0.050	0.361			
Shaanxi	0.935	0.893	0.964	0.377	0.173	0.563	Midstream zone	0.922	0.312
Henan	0.931	0.902	0.951	0.340	0.202	0.458			
Shandong	0.923	0.863	0.951	0.313	0.103	0.462	Downstream zone	0.923	0.313
Ave.	0.919	0.859	0.957	0.310	0.122	0.517	Ave.	0.919	0.310

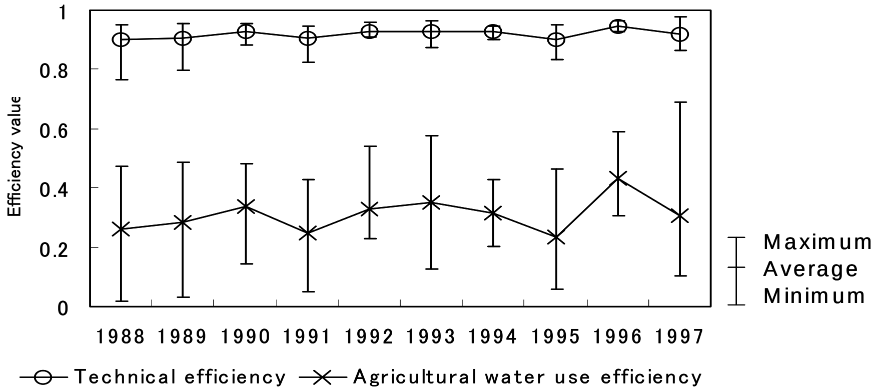

Fig. 7. Trends in technical efficiency and agricultural water use efficiency

Table 5. Estimates using Tobit model

Variable name	Coefficient	Elasticity
Precipitation	0.035** (2.200)	0.931
Temperature	0.001 (0.120)	0.074
Hours of sunlight	-0.088 (-0.840)	-1.403
Total dam capacity	0.000 (-0.610)	-0.029
Agricultural household income	1.444** (2.090)	0.496
Large-scale irrigation districts	-0.033 (-0.440)	-0.124
Water-conserving irrigation districts	-0.228* (-1.650)	-0.374
Constant	0.371* (1.880)	
Log likelihood	52.254	
Number of measurements	80	

Notes: (1) Values in parentheses are t values. (2) Asterisks (*, **, ***) represent 10%, 5%, and 1% significance, respectively.

that agricultural water use data for 1997 are estimated values in this study, so it will be necessary to reconsider these findings if actual figures become available in the future.

5.3 Results of factor analysis for efficiency of agricultural water use

Here we consider which factors influenced the differences in efficiency of agricultural water use obtained in the previous section. **Table 1** shows the variables that were used. The results are shown in **Table 5**. It is evident that the amount of precipitation and the rural household income have an impact on changes in efficiency, and that elasticities are also high.

Regarding the influence of precipitation, various explanations are possible, including (1) the fact that efficiency of agricultural water use is high in areas with high amounts of precipitation, may be due a relatively small need for agricultural water where it is likely that rain-fed agriculture is being conducted; and (2) because fluctuations in annual precipitation can improve or worsen efficiency, in low precipitation years like 1997, the efficiency of agricultural water use worsens.

Regarding the influence of rural household income, factors include the possibility that (1) regions with high income can afford to invest in water conservation-related improvements, and therefore are more efficient in agricultural production, and (2) higher income in a region may be associated with higher awareness about water conservation, so that economic growth is connected to improvements in efficiency of agricultural water use.

It should be noted, however, that the coefficients in water-conserving irrigation districts exert a negative influence, and water conservation contributes to a reduction in the actual agricultural water use, as shown in **Table 2**, suggesting that these are not directly connected to efficiency of agricultural water use. In other words this means that improvements in physical infrastructure, such as water-conserving irrigation districts, are expanding and have an impact on water conservation of agricultural water, but that they are not directly contributing to increases in production. Nevertheless, further discussion will be necessary in the future regarding the appropriateness of this conclusion.

6. Conclusions

Focusing on the 1990s, when river-flow stoppages became more serious, this study used stochastic frontier analysis (SFA) methods to calculate the efficiency of agricultural water use in each part of the Yellow River basin. It also analyzed what factors affect differences in the efficiencies obtained.

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A characteristic daily variation in water vapor in the atmospheric boundary layer and free atmosphere in the Loess Plateau of China

Atsuhiro TAKAHASHI[1)], Tetsuya HIYAMA[2)], Masanori NISHIKAWA[3)], Hatsuki Fujinami[2)], Atsushi HIGUCHI[4)], Wei LI[5)], Wenzhao LIU[6)], and Yoshihiro FUKUSHIMA[1)]

1) Research Institute for Humanity and Nature, Japan
2) Hydrospheric Atmospheric Research Center, Nagoya University, Japan
3) Graduate School of Environmental Studies, Nagoya University, Japan
4) Center for Environmental Remote Sensing, Chiba University, Japan
5) Institute of Atmospheric Physics, Chinese Academy of Sciences, China
6) Institute of Soil and Water Conservation, Chinese Academy of Sciences, China

1. Introduction

In East-Asia, vast areas belonging to severe climate spread in northern China. The Loess Plateau, the area of which is about 0.58 million km^2, is included in the semi-arid region and locates in the middle area of the Yellow River basin. It is important to clarify the water vapor transport over the plateau, and its influences to the water cycle in the Yellow River basin. In May 2004, we established the systems for measuring the atmospheric boundary layer (ABL) in southern region of the Loess Plateau. Broad areas are occupied by the agricultural fields planted with wheat, corn, and apples on the tableland of the plateau. In dry season, rare occurrence of rainfall causes severe drying of surface layer in the soil and increases of surface temperature. Under such condition, the ABL develops strongly (Nishikawa et al., 2005). Strong vertical wind, which can reach a free atmosphere, developed in daytime under calm wind condition (Nishikawa et al., 2005). However, the water vapor transport has not been fully understood in such condition.

We have conducted the observation of water vapor profile with a high-time resolution using the ground-based microwave radiometry, in order to clarify the water vapor transport in the Loess Plateau of China. This study reports the diurnal variations in water vapor in the atmosphere from the ground to a height of about 10 km, which were measured during summer in 2005 and 2006.

2. Observation and methods

The observation site is located in the southern part of the Loess Plateau. Agricultural fields of wheat, corn, and apple trees spread in and around the observation site. The ground-based microwave radiometry (MR) (TP/WVP-3000, Radiometrics Co., USA) was installed at the wheat field in the Changwu Agro-Ecological Experimental Station in Loess Plateau (35.24°N, 107.68°E, 1224m a.s.l.) to observe the one-dimensional vertical profiles of water vapor and air temperature up to a height of 10 km with a vertical spatial resolution of 100 m up to 1 km, above which the resolution was 250 m up to 10 km, and with a time resolution of 1 minute. The one-dimensional vertical profile of wind vector was also observed using the Wind Profiler radar (WPR) (L-28, Sumitomo Electric Industry, Japan) up to a height of 8 km with a vertical spatial resolution of 100 m and with a time resolution of 1 minute. The measurement of turbulence has also been conducted at this site from May 2004 by Flux-Radiation Observation System (FROS, Climatec Co., Japan). Three sonic anemometers/thermometers (R3, Gill Instruments Limited, UK) were installed to FROS at heights of 32 m and 12 m, and 2 m. Three dimensional components of wind velocity and air temperature were recorded to the logger (CR-5000, Campbell Co., USA) at a frequency of 10 Hz. Precipitation was measured using the tip-bucket type rain-gauge.

We conducted the integrated observations during the periods from 11 May to 13 July in 2005 and from 15 May to 10 July in 2006. During these periods, we have observed amount and types of clouds almost every 1 hour in daytime. Cloud amount was recorded as the value from 0 to 10 according to the cloud-covered area of the whole sky. Cloud types were recorded based on the category which distinguishes cloud types into 10 types.

3. Results

Figure 1 shows seasonal variation in daily averaged values of water vapor contents in the troposphere, fluxes of sensible heat and latent heat at the land surface, precipitation, and soil water content. We can see that water vapor content and heat fluxes had clear seasonal variations, although data of water vapor was missed during the period from July 2005 to April 2006, which was caused by troubles of the electric power. Most amount of precipitation occurs in summer but seasonal change of soil water is different between 2005 and 2006 according to the events of precipitations. That is, soil water content increased rapidly in late of June in 2005 and, on the other hand, in late of August in 2006. Latent heat flux in summer is a little larger in 2005 than in 2006.

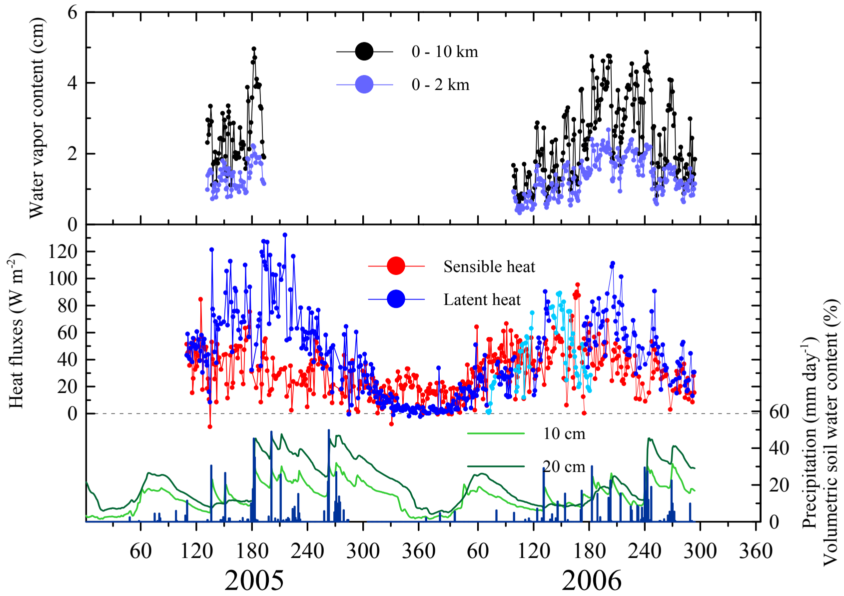

Fig. 1. Seasonal variations in daily averaged values of (upper panel) water vapor contents in the troposphere, (middle panel) surface fluxes of sensible heat and latent heat, (lower panel) precipitation and soil water content. In the lower panel, blue colored bars indicate precipitation.

Figure 2 shows similar figure but for the IOPs. In Fig. 2, amount and types of cloud are also shown. Active cumulus appeared frequently from late of June in each year. In presence of active cumulus, characteristic diurnal variations in water vapor contents were observed in the lower atmospheric layer and the upper atmospheric layer, as shown in Fig. 3 (a), in which time series of water vapor contents during 17-21 June in 2005 were shown. Here, we distinguished the atmosphere into two layers, which are divided by a height of 2 km. The solid line indicates water vapor in the lower layer, the dotted line indicates that in the upper layer and the dashed line indicates sum of those. During this period, water vapor decreased in the lower layer in daytime, and increased in the upper layer. Minimum in the lower layer and maximum in the upper layer appeared at around late of the afternoon.

Motion of air observed by WPR tended to be downward in the afternoon (figure is not shown). This downward wind could enhance the decrease in water vapor in the afternoon. Figures 3 (b) and (c) show the vertical profiles of potential temperature and absolute humidity, respectively, on 19 June 2005. Such opposite behavior of water vapor shown in Fig. 3 suggests that water vapor in the lower layer was transported vertically in daytime and this resulted in the increase in the upper air, the upper layer, in addition to the influence of horizontal advection of water vapor. The decrease of water vapor in the lower layer is dominant in the layer below around 1 km, and, the increase of water vapor in the upper layer was observed from around 2 km to around 7 km. On the other hand, such diurnal variations in water vapor were not observed under the conditions of the other cloud types or under no cloud cover. This suggests that active cumulus acts an important role in the diurnal variation in water vapor in the upper and lower atmosphere. Due to convective activity inside of the active cumulus like cumulonimbus, upward and downward motions were enhanced in and around the cloud layers. It can be considered that active cumulus acted like a pump that transports water vapor from the lower atmosphere to the upper atmosphere. Several researchers has reported decrease in precipitable water in daytime over an inland, mountain, and coastal areas and concluded that a local circulation had an important role (Takagi et al., 2000; Wu et al., 2003; Fujita et al., 2006). In such conditions, convective activity is considered to have a critical role to enhance the local circulations. This study showed that strong convective activity by active cumulus has actually significant effect on the vertical transport of water vapor between the ABL and free atmosphere. However, water vapor content in the lower layer already began to decrease in the early morning. The upward wind was observed in the lower layer from the ground to around 1 km in the morning (figure is not shown). Such motion of air may have a critical role in the decrease in water vapor in the lower layer in the morning. Fujita et al. (2006) showed that the downward motion driven by a local circulation resulted in daytime decrease in the precipitable water. Such downward motion of air might also occur in somewhere around our site as the compensate motion of the upward motion of air observed over our site. That is, a large-scale motion of the atmosphere might be formed around our observation site and had some influence to the observed diurnal variation in water vapor. We need more researches to clarify whether such local circulation is actually generated and its influences to the vertical transport of water vapor.

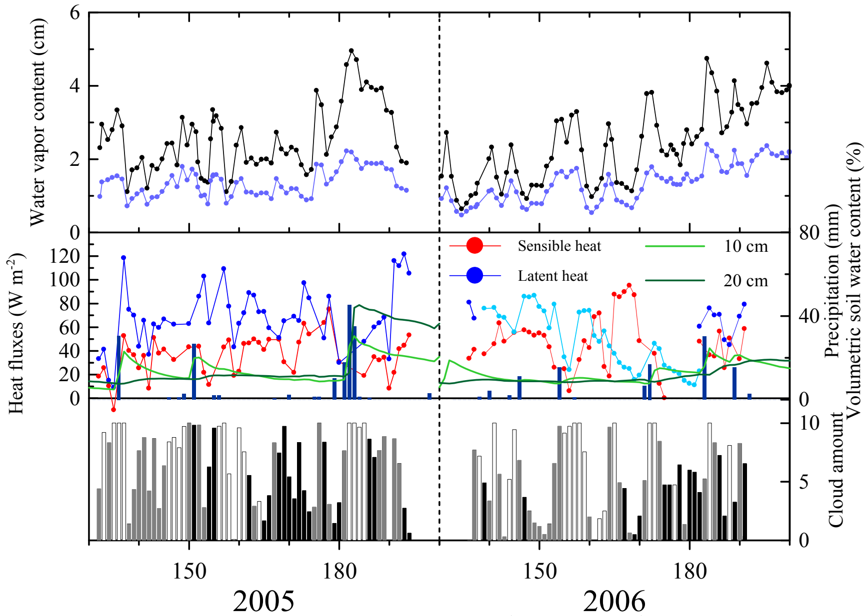

Fig. 2. Seasonal variations in daily averaged values of (upper panel) water vapor contents in the troposphere (black: 0-10 km, blue: 0-2 km), (middle panel) surface fluxes of sensible heat and latent heat, precipitation, soil water content, and (lower panel) amount and types of clouds. In the middle panel, the light blue-colored line is the latent heat flux measured at a height of 2 m, since the instrument at 32 m height had a trouble during this period. In the lower panel, the black-colored bars indicate the presence of active cumulus, the grey-colored bars indicates presence of forced cumulus but no active cumulus, and the white-colored bars indicate the other types of clouds.

4. Conclusions

This study revealed that characteristic diurnal variations in water vapor content in the atmosphere were observed in the southern part of the Loess Plateau in summer in 2005 and in 2006. Water vapor decreased from the early morning till late afternoon in daytime in the atmosphere lower than a height of 2 km and increased in the atmosphere above it up to a height of 10 km, when the active cumulus developed. Moderate upward motions of wind field were frequently observed in the lower atmosphere below than a height of about 1 km in the morning on clear days, and then the strong vertical wind was generated in the afternoon following the development of the atmospheric mixing layer. Such strong convective activity was especially observed under the conditions that strong sensible heat was supplied to the atmosphere from the ground, and that active cumulus developed in the afternoon. The enhanced vertical wind which was induced by active cumulus has a possible to have a critical role in such daily variation in water vapor. Such local conditions might also have relations with the heat low developed in synoptic scale.

More study will be needed to clarify the diurnal variations in water vapor in the troposphere in the Loess Plateau. We will promote further this study to investigate, in detail, how such variation was generated in Loess Plateau and how it influenced the water vapor transport in the Loess Plateau, using a cloud-resolved numerical simulation in future.

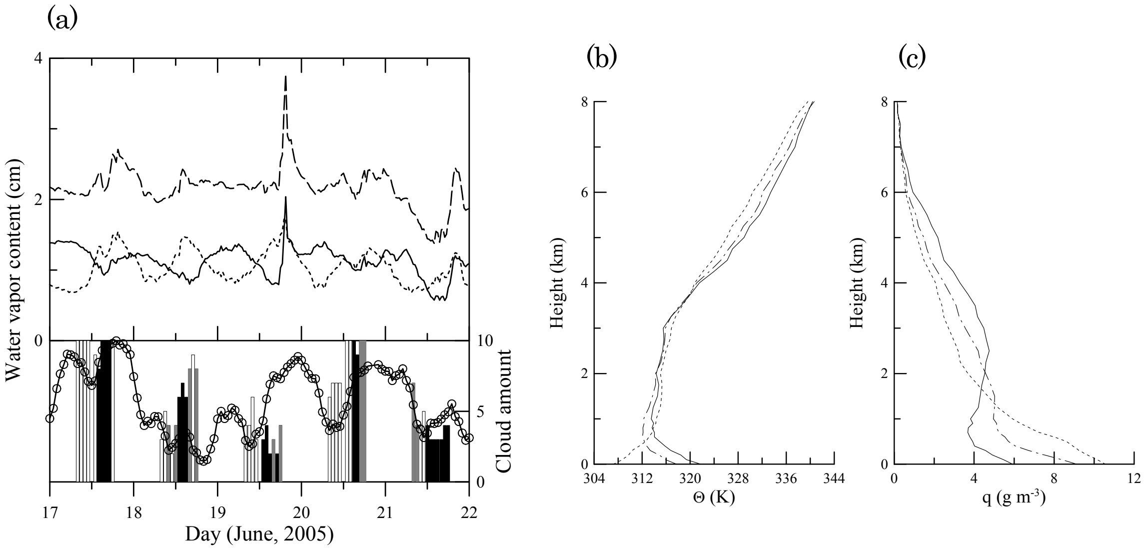

Fig. 3. (a) The upper panel shows the diurnal variation of water vapor content measured during 17-21 June 2005. Broken line shows the total amount of water vapor in the troposphere, the solid line shows the integrated water vapor from the ground to a height of 2 km, and the dotted line shows the integrated water vapor from a height of 2 km to a height of 10 km. The lower panel shows amount and types of clouds. The meanings of colors of each bar are same as those in Fig. 2. It should be noted that the observation of amount and types of clouds were done only in daytime. Open circles are the cloud amount estimated by GOES9 data over the region 32.5N-37.5N, 105E-110E. Right two figures are the vertical profiles of 30 minutes-averaged (b) potential temperature and (c) specific humidity on 19 June 2005. Dotted line: 7:30-8:00LST, dashed-dotted line: 11:30-12:00LST, solid line: 15:30-16:00LST.

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International activities on Yellow River Studies

(1) The First International Symposium of RIHN (Research Institute for Humanity and Nature) was held on Oct 1-3, 2006 at Kyoto. The results of YRiS were presented by project leader Prof. Yoshihiro Fukushima at the session of "Human- Water Interaction".

(2) The third international workshop on YRiS was held on Feb. 22-23, 2007 at Kyoto

(3) The research results of YRiS will be presented at International Association of Hydrological Sciences (IAHS) of IUGG at Italy, on July 2 to 14, 2007.

(4) The second international symposium of RIHN will be held at Kyoto on Oct. 30-31, 2007. The project leader Prof. Yoshihiro Fukushima will present the summary of the results of YRiS project.

Yoshihiro Fukushima, Project Leader
Makoto Taniguchi, Secretary General
Research Institute of Humanity and Nature (RIHN),
Inter-University Research Institute
Ministry of Education, Culture, Sports, Sciences, and Technology, Japan (MEXT)

457-4 Motoyama Kamigamo, Kita-ku, Kyoto 603-8047, Japan
Tel: +81-75-707-2230, Fax: +81-75-707-2506
E-mail: YRiS@chikyu.ac.jp, URL: http://www.chikyu.ac.jp/index_e.html

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