Estimation of land use and water usage in the huaihe river basin from field survey and satellite analysis

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Abstract

Keyword: landuse/landcover; crop type; NDVI; NDWI; VSW index

1. Introduction

GAME-Huaihe river Basin EXperiment (HUBEX) is one of four intensive field-based regional experiments of the GEWEX Asian Monsoon Experiment (GAME). Huaihe river basin has been suffering from flood disaster caused by the Meiyu front for a long time. Therefore land-atmosphere interaction and its role in the formation of meso-scale precipitation systems are some of the most important research targets.

The energy and water budget of Huaihe River Basin is calculated using land-surface scheme for understanding these targets. Landuse dataset which is based on the USGS global landuse/landcover classification is used previous study, but the accuracy of all global classification are not enough in this area. For example, according to this dataset, more than 60% of the study area is occupied by paddy field, but this value is obviously higher than actual condition.

Besides, not only the crop type but also the cropping cycle must be specified in good accuracy for the detailed wateruse and hydrological analysis. In this sense, global landcover datasets have not been validated well enough, and there is some problem in its direct use. In this study, new landuse classification, especially detailed crop pattern, in Huaihe River Basin is produced from satellite derived vegetation indices (30sec resolution) and surface meteorological data. Agricultural statistic data of 187 prefectures in Henan Province are used for validation.

2. Satellite derived vegetation indices

SPOT-VEGETATION 10 day composite data, which has 30 minutes (about 1 km) resolution, is used for 1 year (from Apr. 1998 to Mar. 1999 ; 36 periods). Two vegetation indices are made from three sensor data (RED, NIR, SWIR).

1) NDVI(Normalized Difference vegetation index)
2) NDWI(Normalized Difference water index)

NDVI has been widely used for remote sensing of vegetation for many years. This index uses radiances or reflectance from red channel around 0.66μm and near-IR channel around 0.86μm. NDWI is proposed for remote sensing of vegetation liquid water (Gao [2]). That is defined as $(\rho(0.86\mu m)-\rho(1.24\mu m))/(\rho(0.86\mu m)+\rho(1.24\mu m))$, where ρ represents the radiance in reflectance units. In this study, SWIR (1.58-1.75μm) sensor data is used, instead of 1.24μm sensor. The features of spectral refrectance of them are dominated by water absorption.

Then the BISE (The best index slope extraction) method (Viovy and Arino [3]) is applied for reducing cloudy noise in NDVI and NDWI time-series (see Fig.1). This method is based on that plant growth is gradually for a certain period. In this study, 30 days is adopted as that period. On the other hand, crop rotation (harvest and planting) causes drastic change on the land surface for less than 30 days. For the above reason, that period is changed to 20 days for adjusting to the sudden surface change during crop rotation period.

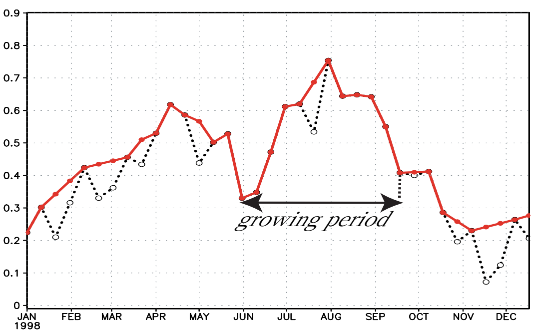

Fig. 1 : Time series of NDVI data at E116 deg, N33 deg (Dotted line ; raw data, Full line ; applied BISE method)

3. LANDUSE CLASSIFICATION

3.1. NDVI time series

Firstly, all mesh (1320 × 600, 30 seconds resolution) is categorized into three group (see Fig.2) using the accumulated NDVI value and pattern of NDVI time series.

1) nonvegetation area (city, soil, water)
2) natural vegetation area (evergreen forest, deciduous forest)
3) agricultural area (paddy field, farmland etc.)

If one year accumulated NDVI value of each mesh is less than 10.5, that mesh is determined to nonvegetation area. Then these meshes are classified into three categories. One is water area, which is easy to be separated from other two categories. If the minimum NDVI value of each mesh for one year is lower than 0, that mesh is classified into water area. On the other hand, the small water area and other two landuse (city, soil) are difficult to be classified. In that case, not only satellite data but also other landuse data (for example USGS global landuse/landcover) is used for detecting water area.

Natural vegetation area includes two categories. If one year accumulated NDVI value of each mesh is more than 19, that mesh is classified into evergreen forest. If one year accumlated NDVI value is less than 19 and vegetative period (whose NDVI value more than 0.4) are more than 21 periods, that mesh is classified into deciduous forest.

Table 1: Landcover/landuse type and classification index

landcover/use type	classification index
evergreen forest	1 year accumulated NDVI value is more than 19.0
deciduous forest	NDVI value of 21 period is more than 0.4
City	1year accumulated NDVI value is less than 10.5
Water area	1 year accumulated NDVI value is less than 10.5 more than 1 period NDVI is less than 0
Wheat + Rice	degree-days temperature is 1900∼2400 NDWI value is 0.2 from 13 to 17 period
Wheat + Maize	degree-days temperature is 1400∼1700, $0 < L1/L2 < 1.2$
Wheat + Soybean	degree-days temperature is 1400∼1700, $0.8 < L1/L2 < 3.0$
Wheat + Penuts	degree-days temperature is 1700∼1900
Wheat + Cotton	degree-days temperature is 1900∼2400
Wheat + Other crop	other condition

Above two groups are determined easily. On the contrary, other area which includes many kinds of agricultural area is difficult. In this study, the characteristics of agricultural cycle are used for classification.

3.2. Cropland classification

Most of agricultural area is cropland, and many kinds of crop are grown in the Huaihe river basin. The dominant cropland in south part of the Huaihe river basin is paddy field, while that in other part is farmland. All agricultural area is classified broadly into 3 types of cropland, first is farmland (winter wheat + summer crop), second is paddy field (1 cropping rice) and third is farm + paddy field (winter wheat + rice). Winter wheat is the dominant crop in winter-spring season. For example, more than 98 % of agricultural area in the Hunan province is the winter wheat farm in winter-spring season.

Paddy field is classified using NDWI data. The reflectance of SWIR sensor at water is low as well as other two sensors (RED and NIR), but it is higher than other at soil. Therefore, if the lowest NDWI value for crop rotation period is less than 0.2, that mesh is judged as paddy field.

3.3. Degree-days method

The summer growing period can be estimated from NDVI time series (see Fig.1). The definition of growing period is the difference between the planting season (when the NDVI time series begin to rise continuously at spring-summer season) and the harvesting season (when the NDVI time series drop more than 0.1 and the dropped value is less than 0.5 at autumn season).

The growing period is an useful index for crop classification, but it is different at each area and crop. In this study, the degree-days temperature, as defined Eq. (1), is calculated using daily mean air temperature. If the daily mean air temperature is more than 10 degree, it is integrated for the growing period (see Fig.1). The accumulated temperature of each crop is determined as Table1 from local agricultural manual (Chu. et al [4]).

The degree-days temperature : k day's air temperature; T_k, Standard temperature (10 degree); T_b, planting period; a, harvesting period; b

$$T_k > 10 \ \ degree, \qquad \sum_{k=a}^{b} (T_k - T_b) \qquad (1)$$

Rice and cotton, maize and soybean belong to the same temperature range. Rice and cotton are separated using

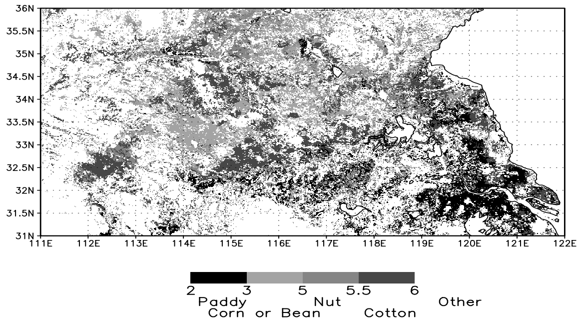

Fig. 2 : Cropland classification of Huaihe river basin

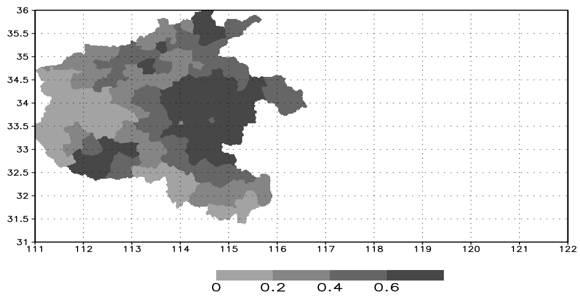

Fig. 3 : Percentage of cropland in Hunan province

NDWI index as above. Maize and soybean are separated using the curve of NDVI time series. The NDVI curve of maize is more rapidly than that of soybean. In this study, L1 is defined as the difference between the value of peak period and that of 40 days before from the peak, L2 is defined as the difference between that of 20 days before and that of 40 days before. If L1/L2 is lager than 1.2, that mesh is soybean farm. If L1/L2 is smaller than 0.8, that mesh is maize farm. If L1/L2 is between 0.8 and 1.2, that mesh is mixed farm.

4. VALIDATION

4.1. Agricultural statistics

There are many kinds of agricultural statistics data in this region. In particular, there is detailed data in Hunan province that located on the west part of the Huaihe river basin. There are 187 prefectures in Hunan province, and each prefecture has land area data (see Fig.3), cropland area data (e.g. rice, wheat, soybean, maze, cotton), crop yields data, irrigated cropland data and so on. In this study, statistics land area and cropland area data are used for validation. Firstly, the statistical land area data of

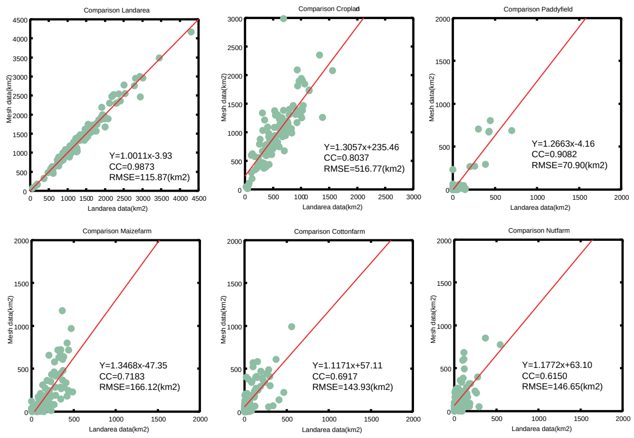

Fig. 4 : Scatterplot of statistics data and estimated mesh data at each prefectures (upper low ; land area, cropland, rice), (lower low ; maize, cotton, nuts)

prefectures with the land area estimated from 1km mesh data (which is made from 2km resolution digital map) are compared. The accuracy of estimated land area is relatively well, but other classified data tend to be over estimated (see Fig.4).

The most considerable reason of over estimate is that 1 km is not enough in resolution for cropland categorise and crop pattern estimation. In other words, the whole area of each mesh classified into cropland do not correspond to the actual one. In this study, VSW index is used for calculation of the cropland occupied ratio of each mesh.

4.2. Cropland occupied ratio

Vegetation-Soil-Water (VSW) index is devised for monitoring land cover conditions (Yamagata et al. [5]). The VSW index is defined as a natural extension of PV1 (see Fig.5) for monitoring not only vegetation but also soil and water conditions as well. The definition of VSW index is shown in Fig.7, which shows the relationship between VSW indices and the end member triangle on a NIR-Red Scatter Plot.

The vegetation ratio is estimated using the triangle and Eq. (2), PV means vegetation index, PW means water index and PS means soil index in Fig.7. The R of Eq. (2) indicates the vegetation ratio, which include natural and agricultural vegetation. Natural vegetation changes little for summer season, on the other hand agricultural vegetation drops rapidly at crop rotation period. The crop rotation period in this area is around May or June.

Consequently, the maximum and minimum V ratio are searched from may to august for separating agricultural from natural vegetation. The maximum ratio indicates both of them, and the minimum ratio indicates only natural vegetation. Therefore using the difference between R_{max} and R_{min} (see Eq. (2)), the agricultural V ratio (R_{agr}) of each mesh is estimated. The value of 'α' in Eq. (2) is determined as 1.298 for maximizing the correlation coefficient around regression line of scatter plot (see Fig.6). Then, the 'β' in Eq. (3) value is determined to 1.160 as equalizing the amount of estimated cropland area to the statistical one. In case of farmland and paddy area, 'α' is used as the same value of cropland (1.298), and 'β' is calculated individually as equalizing the amount of estimated area to the statistical one (see Fig.6). The 'β' of farmland is 0.766 and that of paddy field is 1.545, that results indicate the decreasing effect of paddy field is lager than that of farmland.

$$R = \frac{\alpha V}{\alpha V + S + W} \tag{2}$$

$$R_{agr} = (R_{max} - R_{min}) \times \beta \tag{3}$$

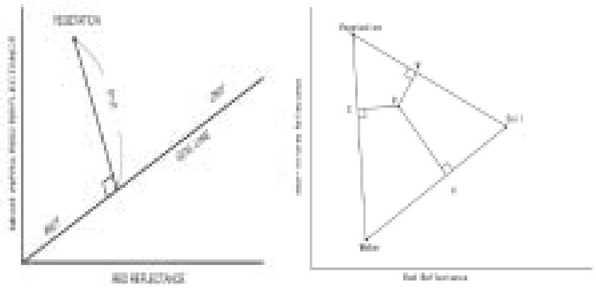

Fig. 5 : Relationship in a NIR-Red scatter plot (left Fig.; PV1 and the soil line, right Fig.; VSW index and the end member traingle)

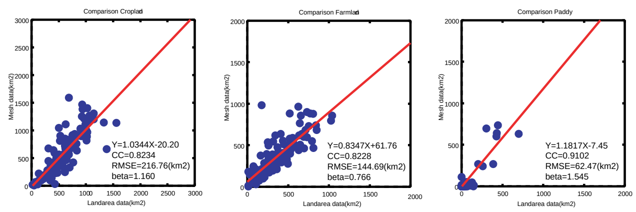

Fig. 6 : Scatterplot of statistics and degital-mesh data (cropland, farmland, paddy field)

5. Water budget analysis

5.1. Shiguan river basin

Shiguan river basin is composed of 3 areas. 2 areas are located on the upstream of 2 water reservoirs (Meishan, Nianyushan), and another area is located on the downstream. Since all irrigation data exists in the downstream region, it is defined as the target area for this analysis.

Landuse data was validated from agricultural statistics data, then estimated water usage are validated from the water budget analysis in Shiguan river basin that located on the south part of HUBEX (shaded area of Fig.7). There are many kinds of hydrological data (e.g. discharge, irrigation and rain) in this basin and its catchment area is $5930km^2$. Using landuse and cropland occupied ratio data (see Fig.8, Fig.9), land surface scheme is applied to this basin.

Fig. 7 : Location of Shiguan river basin in HUBEX

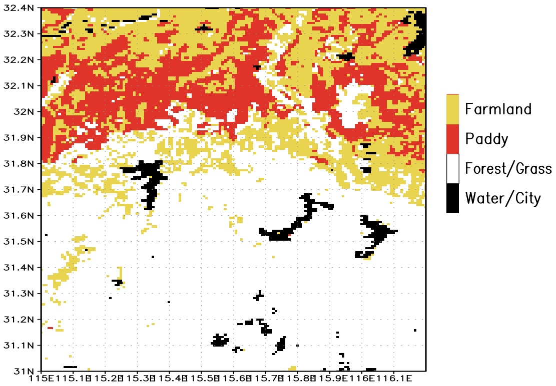

Fig. 8 : Landuse of Shiguan river basin

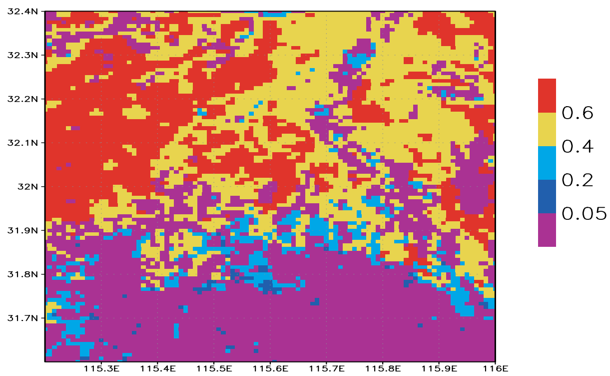

Fig. 9 : Cropland occupied ratio in the north Shiguan

5.2. Water budget calculation

In this study, hourly meteorological mesh data (sphere: E115.0-116.2, N31.0-32.4) is created in 30 seconds (about 1.1km) resolution using the same method of previous study (Kozan. et al [1]). Using irrigation rule (see [1]), hourly water and energy flux are calculated by land surface scheme (SiBUC) for 123 days (1/5/1998-31/8/1998).

Fig.10 shows an accumulated value of water budget components (rainfall, evapotranspiration, and runoff) in the downstream region (catchment area is 2.525 thousand km^2). Accumlated rainfall of this region for 123 days is 738mm (in average unit), evapotranspiration is 408.9mm, runoff is 238.2mm and irrigation water is 84.7mm.

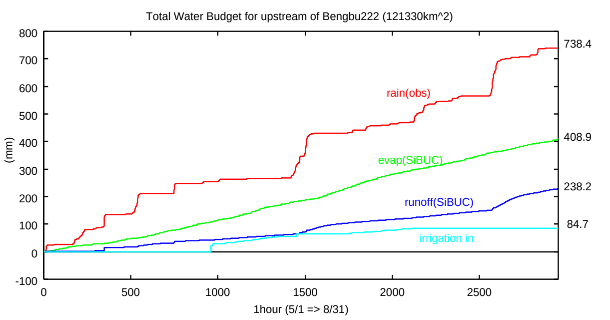

Fig. 10 : Time series of water budget in the downstream area of Shiguan river basin (accumulated rainfall, evapotranspiration, runoff)

5.3. Irrigation water validation

There are 9 irrigation canals in the Shiguan river basin. All of 2 canals' water (0.01828 billion t) is used in the downstream region and most of other 2 canals' water (0.32899 billion t) is also used.

84.7mm (in average unit) irrigation water is estimated in this simulation, and this value equivalent to 0.2139 billion t water. Judging from irrigation data, estimated irrigation water is considered reasonable and proper.

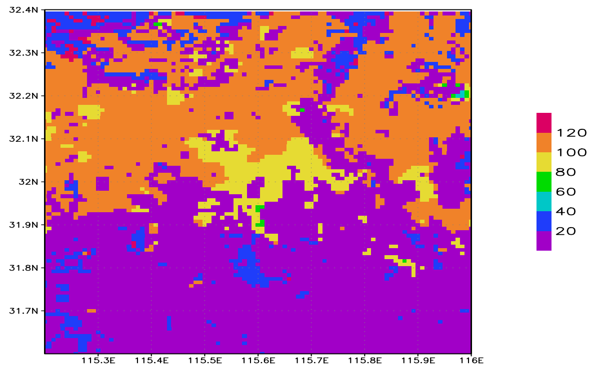

Fig. 11 : Estimated irrigation water in the north Shiguan

6. CONCLUSION

In this study, new landuse data is produced from satellite and surface meteorological data, and it is validated using agricultural statistic data. Then VSW method is applied for improvement of over estimation. It is confirmed that this classification and VSW method are available. Furthermore, this landuse data is applied to the land surface scheme, and it is performed for water budget calculation in the Shiguan river basin. Availability of this data for the hydrological study is also confirmed.

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