Climatic Water Balance Analysis using NOAA/AVHRR Satellite Images

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Abstract: The purpose of this study was to analyze the climatic water balance of the Korean peninsula using meteorological data and the evapotranspiration (ET) derived from NOAA/AVHRR. Quantifying water balance components is important to understand the basic hydrology. In this study, a simple method to estimate the ET was proposed based on a regression approach between NDVI and Morton's actual ET using NOAA/AVHRR data. The Morton's actual ET for land surface conditions was evaluated using a daily meteorological data from 77 weather stations, and the monthly averaged Morton's ETs for each land cover was compared with the monthly NDVIs during the year 2001. According to the climatic water balance analysis, water deficit and surplus distributed maps were created from spatial rainfall, soil moisture, and actual and potential ETs map. The results clearly showed that the temporal and spatial characteristics of dryness and wetness may be detected and mapped based on the wetness index.

Keywords: climatic water balance, evapotranspiration, NDVI, NOAA/AVHRR

1. Introduction

It is necessary to quantify various hydrologic components for climatic water balance analysis. One of the most things of hydrologic components is evapotranspiration (ET).

Evapotranspiration (ET) is the process by which water is evaporated from wet surfaces and transpired by plants (Chow, 1984). There are many methods of estimating ET and potential ET such as soil-moisture sampling, lysimeter measurements, water balance, energy balance, groundwater fluctuations and ET equations, but it is very difficult to estimate ET by consideration of regional characteristics of topography or vegetation.

Most methods require various meteorological data and these equations are very complex. Also, these methods are not suitable for estimating of distributed ET.

Factors controlling ET from ground are air temperature, humidity, wind, radiation, soil-moisture and so on. These factors strongly influence the vegetation, and the vegetation influences the ET directly. Therefore, there is a high correlation between the vegetation and the ET. To grasp vegetation condition at any area, NDVI calculated from NOAA/AVHRR data is utilized.

Climatic water balance has been applied to obtain quantity of various hydrologic components. The purpose of this study was to analyze the climatic water balance of the Korean peninsula using meteorological data and the evapotranspiration (ET) derived from NOAA/AVHRR. Distributed wetness index was mapped for estimating drought stats using climatic water balance.

2. NDVI and land cover map

NDVI developed for estimating the state of the vegetation (Rouse et al., 1974), has been widely adopted and applied due to its effectiveness as a surrogate measure of biophysical parameters. NDVI can be represented as follow for application of NOAA/AVHRR data.

$$NDVI = (Ch.2 - Ch.1)/(Ch.2 + Ch.1) \quad (1)$$

where Ch.1, 2 are the reflectance in the visible red (channel 1) and near infrared channel (channel 2) of NOAA/AVHRR, respectively. At the cloud-covered areas, NDVI is underestimated as compared with non-cloud areas. Therefore, the maximum value composite (MVC) is calculated from a multi-temporal series of NDVI images. Also, imageries in the winter period are not suitable for obtaining ground surface information by reason of snow cover.

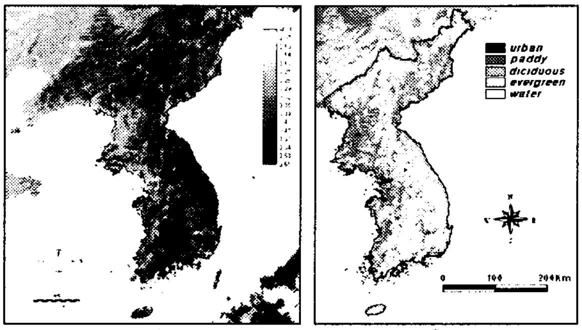
In this study, MVC values were calculated monthly from consecutive NDVI images with the exception of snowing season.

Also, iNDVI (integrated NDVI) can be used as representative NDVI within a given period of time.

$$\mathrm{iNDVI} = \Sigma(\mathrm{NDVI}_j \times d_j)/\Sigma d_j \quad (2)$$

where $NDVI_j$ is j^{th} NDVI and d_j is observed day of $NDVI_j$.

Land cover map was derived from iNDVI using histogram classification method. This method may categorize vegetation area, which takes similar ground characteristics into a land cover class. Land cover map can be used for estimating ET of each land cover classes.



(a) (b)

Fig. 1. (a) iNDVI during the period March-December 2001 (b) Land cover map from iNDVI

3. Actual ET from meteorological data

Morton (1978) suggested that actual ET can be estimated by the complementary relationship and it was represented by:

$$Ea = 2Ep - Epp \quad (3)$$

where Ea is actual ET (mm/day), Ep is potential ET by Priestly-Taylor's method (mm/day) and Epp is potential ET by Penman's method (mm/day).

Since, daily meteorological data are necessary to use the complementary relationship, weather elements (e.g., temperature, humidity, wind velocity, sunshine time) are acquired from the 73 meteorological stations in Korea.

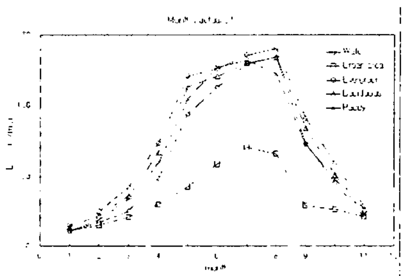


Fig. 2. Estimated actual ET for the Han River basin (2001)

4. Estimation of monthly ET using NDVI from NOAA/AVHRR data

Satellite-derived NDVI is very useful tool for the frequent monitoring of green vegetation cover. The state of vegetation has a relationship with meteorological condition, and meteorological condition also has high correlation with ET. Therefore, it can be considered that ET at a forest region such as the Korean peninsular is linearly proportional to the NDVI.

The histogram of NDVI reflects seasonal changes of vegetation very well. NDVI was divided into specific ranges and pixel number of specific ranges was regarded as parameter. Using this parameter, linear regression analysis was performed on each land cover.

The results of this procedure may offer the method for estimating directly actual ET using NDVI at any point. Regression equations, $Ea=aNDVI+b$ type, of each land cover class were derived from linear regression analysis.

Table 1. Linear regression equations

Land cover class	Regression eq.	R^2
Urban area	Eau=441.8×NDVI+4.82	0.46
Paddy	Eap=294.3×NDVI+24.2	0.41
Deciduous	Ead=413.4×NDVI-13.2	0.65
Evergreen	Eae=381.7×NDVI-39.8	0.62
Etc.	Eaw=229.8×NDVI+19.6	0.54

The actual ET can be estimated simply using these regression equations with only one parameter, NDVI, at any points.

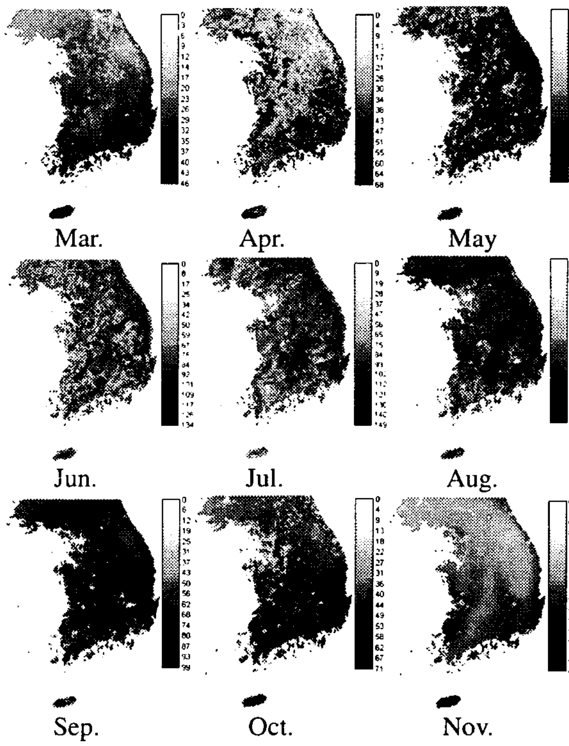


Fig. 3. Monthly ET (mm/day) obtained by NDVI (2001)

5. Climatic water balance analysis

Climatic water balance has been applied to obtain quantity of various hydrologic components. Hydrologic information is estimated by comparison between rainfall and ET under complex terrain condition. Water deficit is defined that subtraction actual supply from climatic demand. Water surplus is defined that surplus water after demand by plants. Water deficit and surplus was represented by.

P<Ea $\quad AWL = P - Ea$

$$Sm_i = Sm_{i-1} \times \exp(AWL/Sm_{i-1})$$
$$D = (Ea + Wc - Sm_i) - P$$

P>Ea $\quad AWL = 0$

$$Sm_i = Sm_i - 1 + (P - Ep)$$
$$S = P - (Ea + Wc - Sm_i)$$

where S is water surplus (mm/month), D is water deficit (mm/month), Ep is potential ET (mm/month), Ea is actual ET (mm/month), Sm_i is soil moisture at any month (mm/month), Sm_{i-1} is soil moisture of previous month at any month, AWL is soil moisture capacity.

AWL was assumed 200mm, because soil moisture of beginning month must be saturated sufficiently.

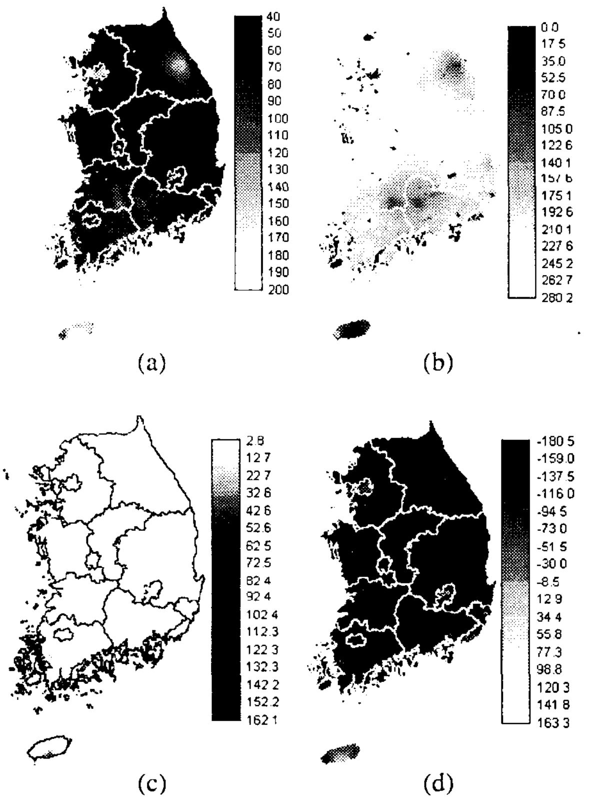


Fig. 4. (a) soil moisture map, (b) water deficit map, (c) water surplus map, (d) wetness index map of May 2001

6. Conclusions

Developed method in this study is based on high correlation between NDVI from NOAA/AVHRR data and ET from meteorological data. Using this method, areal distribution data set of actual ET can be produced simply using NDVI calculated from NOAA/AVHRR data. This method is applicable to another countries on suitable calibration of relationships between NDVI and ET. This method makes possible to estimate ET of any areas where enough meteorological and hydrological data are unavailable. Areal distribution of drought based on NDVI could be estimated using climatic water balance analysis.

Acknowledgement

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