Thesis for the Degree of Master of Science

Estimation of groundwater recharge rate considering natural and artificial factors at a coastal area in the Busan City

by

Sung Il Yang

Department of Environmental Geosciences
The Graduate School
Pukyong National University

August 2010

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(부산 해안도시 지역에서 자연적·인위적 요인을 고려한 지하수 함양량 산정)

Advisor: Prof. Sang Yong Chung

by
Sung Il Yang

A thesis submitted in partial fulfillment of the requirements
for the degree of

Master of science

in the Department of Environmental Geosciences,
The Graduate School,
Pukyong National University

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Sung Il Yang

Approved by:

(Chairman) Jung Chan Choi

(Member) Sang Yong Chung (Member) Tae Seob Kang

August 25, 2010

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양 성 일

부 경 대 학 교 대 학 원 환경지질과학과

요 약

본 연구에서는 해안도시 지역에서 토지이용 및 기후 변화에 따른 실제증발산량을 산정하고, 실제증발산량과 기상인자들 간의 관계에 대해 분석하였으며, 지표유출량, 해안·기저유출량, 지하수 이용량(생활용, 공업용, 농업용, 기타), 상·하수도 누수량, 지하철 역사 및 전력구 터널 유출량을 고려하여 지하수 개발가능량을 산정하였다. 연구지역은 부산광역시 수영구이며, 서쪽은 금련산과 배산이 위치하고, 북쪽으로는 연제구와 접하고, 동북쪽으로는 수영강이 흐르고, 남쪽으로는 해안에 접하고 있다. 실제증발산량은 강수량, 잠재증발산량 및 증산작용계수를 구하여 산정하였다. 본 연구에서의 잠재증발산량 산정에 필요한 기상인자들은 대기온도, 이슬점온도, 대기압, 일조시간 및 평균풍속 등이다. 실제증발산량은 2002년에는 554.14 mm/yr, 2005년에는 427.91 mm/yr로 산정되었으며, 실제증발산량과 잠재증발산량의 변동양상은 유사하게 나타났다. 증발산량과 기상인자 간의 영향성을 분석하기 위해, 상관성분석이 수행되었다. 실제증발산량과 잠재증발산량 간의 상관계수는 0.98로서 매우 높았으며, 실제증발산량 및 잠재증발산량과 강수량의 상관성은 매우 낮은 것으로 나타났다. 실제증발산량 및 잠재증발산량과 평균풍속 간의 상관계수는 각각 0.73과 0.67로서 기상인자 중 가장 높은 것으로 나타났다. 이는 본 연구지역에서 증발산량의 변동에 가장 큰 영향을 미치는 기상인자가 평균풍속임을 의미한다. 연구지역은 도

시화로 인한 불투수층(대지, 도로 등)의 증가로 지표유출량이 강수량의 49.8% 로 매우 높은 값을 나타내었다. 연구 지역은 지하수에 영향을 미치는 요인으로서 주민의 지하수 공에서 직접 양수를 통한 이용, 상·하수도의 노후로 인한 누수, 지하철 역사에서의 지하수 유출, 전력구 터널 공사로 인한 지하수 등이 있다. 지하수개발가능량은 강수량, 지표유출량, 실제증발산량의 순으로 영향성을 나타내었다. 이는 도시화로 인해 강우가 불투수층(대지, 도로 등)에 의해 지표면 하로 침투를 하지 못하게 되기 때문이다. 물이 부족한 시대에 살고 있는 현재 지하수를 보전·관리하고 효율적으로 이용하기 위해서는 자연적인 요인(증발산, 기저유출, 해안유출)과 인위적인 요인(도시화에 의한 지표유출, 지하수 이용, 상·하수도 누수, 지하철 역사 및 전력구 터널 유출)을 고려하여야 하며 각 요인들의 정확한 값을 산정하는 것은 필수적이다.

Ⅰ. Introduction

The shortage of water resources resulting from reckless water use and industrial activity has become a serious problem to human. National policy as well as consciousness for lasting procures, management and stable use of water resources are preferentially necessary, for which a practical and quantitative research on water resources is essential.

Groundwater is being filled by precipitation. The groundwater recharge is estimated by precipitation, evapotranspiration, runoff and baseflow (Domenico and Schwartz, 1998; Fitts, 2002; Todd and Mays, 2005). Evapotranspiration caused by evaporation and transpiration is one of factors for estimation of the groundwater recharge (Arya, 2001). The quantitative estimation of evapotranspiration to separate evaporation and transpiration in the current study level is impossible. The calculation of evapotranspiration has been proposed by several researchers (Thornthwaite, 1944; Penman, 1948; Blaney and Criddle, 1950; Moneith, 1965; Allen et al., 1998).

The evaporation means the change from liquid or solid state of matter to the gas. The transpiration means inhaled water from the plant roots is a evaporated phenomenon through the pores of the leaves. Water vapor emission rate by evaporation and transpiration is estimated by aggregating total evapotranspiration (Arya, 2001). The actual evapotranspiration can be estimated by potential evapotranspiration, precipitation and the plant-available water coefficient (Zhang et al., 2001). The precipitation and plant-available water coefficient are easily obtained, but the potential evapotranspiration should be considered various weather factors (Allen et al., 1998). Thus, realistic and reliable estimation of potential evapotranspiration is very important and many studies related estimation of potential evapotranspiration were conducted (Thornthwaite, 1944; Penman, 1948; Blaney and Criddle, 1950; Moneith, 1965; Allen et al., 1998).

In domestic, water balance research according to change of land use was started in the mid-1990s. It was developed by a spatial and temporal heat flux technique or estimation technique of evapotranspiration using remote sensing data and geographic information systems (Ahn et al., 1995), relative evapotranspiration ratio in the urban areas was estimated by using high-resolution LANDSAT TM data applied to surface moisture status algorithm (Kim et al., 2006). Evaporanspiration is defined as the potential evapotranspiration, it is that soil surface type is suitable for water evaporation as well as soil layer is saturated (Arya, 2001). The researches on potential evapotranspiration were that a grid-based water balance method was proposed to analyze the spatial distribution of recharge, which was applied to Woedo catchment in the northern area of the Jefu Island (An et al., 2006), and the annual potential evapotranspiration in region having 56 climate observation was estimated to analyze the effect of climate change due to urbanization (Rim and Chae, 2007). Availability of climate change due to urbanization was analyzed for FAO Penman-Monteith evapotranspiration. The change degree of potential evapotranspiration had been influenced by urbanization, temperature increasing due to heat island phenomenon and reduces humidity and wind speed due to the effect of the increase of residential areas, especially wind speed (Rim, 2007).

Studies on evapotranspiration were starting in the 1940s from abroad. There were methods to estimate actual evapotranspiration; a method to estimate consumptive use considered the weather factor (Thornthwaite, 1944); a method using theoretical method according to conservation of energy (Penman, 1948); a method using relationship with monthly mean temperature, day length and comsumptive used on the assumption that water consumption by plants were only affected by the climate and the types of plants (Blaney and Criddle, 1950); Penman method became Penman-Monteith method by using the factors of weather conditions of day and night (Moneith, 1965). In the U.S. north-east area, the 6 estimation methods of potential evapotranspiration (Thornthwaite, 1944; Makkink, 1957; Turc, 1961; Hamon, 1963; Priestley and Taylor, 1972; Hargreaves and Samani, 1985) were compared as well as analyzed, and it was quantified. This was reported that Turc, Hamon and Priestley-Taylor methods were confidence (Lu et al., 2005). It performed the sensitivity analysis between potential evapotranspiration estimated by using FAO Penman-Monteith method and meteorological factors on seasonal and local changes in three separate Yangtze River Yangtze River basin(upper, middle, lower). The upper region was influence by relative humidity, the middle and lower regions were influence by mean wind speed (Gong et al., 2006).

Park (1996a) had made domestic groundwater recharge estimation conception and techniques, and then applied to Han River, Nakdong River, Geum River, and the Yongsan River basin. Unlike previous studies, it was performed a research related to optimum yield and water balance study by using wired networks analysis, water balance analysis and Hill law in a limited area; Keunchon Well Field (Hahn et al., 1988). Park et al. (2007) proposed a simple equation of groundwater recharge used at the basic planning step of groundwater optimal management in the coastal areas.

In this paper, changes of actual evapotranspiration according to changes in land use due to urbanization were compared and analyzed from 1999 to 2007 in a coastal area, Suyeong-gu, Busan. Furthermore, its influence was clarified through regression analysis and correlation between meteorological factors. Runoff, coastal runoff, baseflow, groundwater usage, leakage of water supply · sewage, groundwater discharge from subway station and electronic cable tunnel were considered to estimate groundwater recharge. In order to use, conservation and management of groundwater, this paper investigated the exact value of each factor because natural factors (evapotranspiration, baseflow, coastal flow) and artificial factors (runoff, groundwater use, leakage of water supply · sewage, groundwater discharge from subway and electronic cable tunnel) should have properly been considered.

Ⅱ. Study area

The study area, Suyeong-gu, Busan of the Metropolitan city is located in 129 ° 05′40 ″~ 129 ° 08′08″ in the longitude and 35 ° 07′59 ″~ 35 ° 11′01″ in the latitude. The width of the study area is 3.6 km, and its length is about 5.3 km (Fig. 1). The east of the study is located in the Sugyeong River and Mt. Kuumryun to the west is bounded. Suyeong Bay is formed to the south, and Mt. Bae is bounded to the north. The overall topography of the study area is formed a high to the west and north, because of this, precipitation outflows directly to the south Suyeong Bay or to the east of Suyeong River.

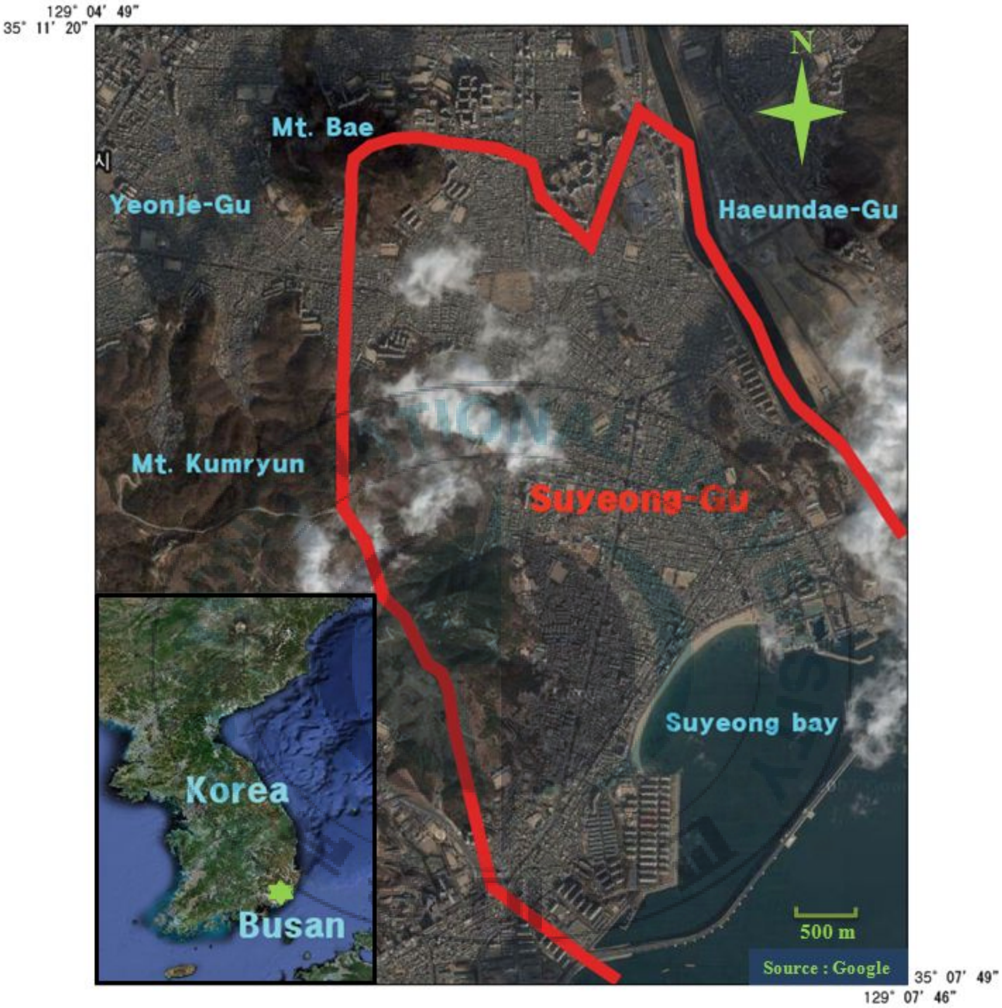

Fig. 1. Study area.

Land use data used in this study was surveyed from 1999 to 2007 years. It was classified as building, forest, roads, waters, dry, rice, park, grave and others (Table 1, Fig. 2). The total area of Suyeong-gu was increased of 0.055 km^2 in 2007 than 1999. The most of land use area in

Suyeong-gu was building increased of 0.06 % in 2007 than 1999. Forest and waters decreased by 0.97% and 0.05%, respectively, and the road was a 0.13% increase in 2007 than 1999. The total area of Suyeong-gu was growing, but forest and waters due to urbanization had being reduced (Suyeong-gu District Office, 2008). Others were factory, school, parking lot, gas station, warehouse, religion sit, and historical sites and so on. The most surface was covered with asphalt or concrete. Others were more than 5 % of Suyeong-gu and it increased of 5.60 % in 1999 and 6.37 % in 2007 due to urbanization.

Table 1. Area of land use in the Suyeong-gu

Year	Area (㎢)	Building (%)	Forest (%)	Road (%)	Waters (%)	Dry, Rice, Park, Grave (%)	Others (%)
1999	10.16	50.99	24.92	15.12	2.37	1.00	5.60
2000	10.16	51.28	24.62	15.11	2.36	0.99	5.64
2001	10.16	51.33	24.58	15.16	2.34	0.96	5.63
2002	10.16	51.21	24.57	15.18	2.34	0.95	5.75
2003	10.16	51.20	24.56	15.22	2.33	0.94	5.75
2004	10.21	51.08	24.47	15.29	2.36	0.96	5.84
2005	10.21	51.12	24.42	15.26	2.36	0.95	5.89
2006	10.21	51.14	24.36	15.29	2.35	0.95	5.91
2007	10.21	51.06	23.95	15.25	2.32	1.05	6.37
Avg.	10.18	51.16	24.49	15.21	2.35	0.97	5.82

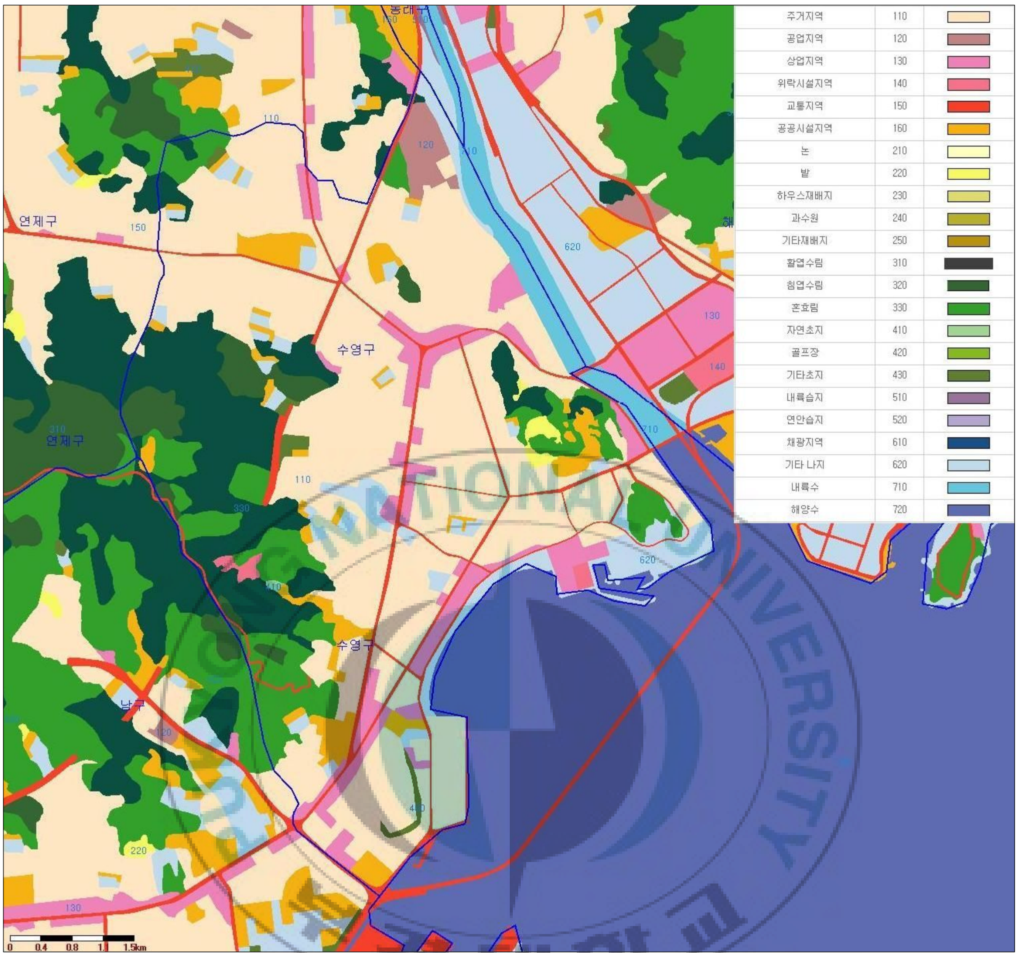

Fig. 2. Land cover map of the Suyeong-gu (EGIS, 2008).

Ⅲ. Sustainable development yield

The groundwater recharge is estimated with the most scientific method in the considered area, and then sustainable development yield defines as the optimal quantity without harmful influence of the underground environment in the currently available area. Therefore, the most important variable when estimating the sustainable development yield is the estimation of groundwater recharge.

The most commonly used method of sustainable development yield estimation is the water balance method. The water balance method is estimated the sustainable development yield if precipitation, evapotranspiration, runoff, baseflow (and coastal flow), groundwater recharge and inflow and outflow rate of groundwater from the outside basin is maintained (Hahn and Hahn, 1999).

$$OP = P - ET - RO - BF \pm IU \qquad (35)$$

,where OP : Sustainable development yield

P : Precipitation

ET : evapotranspiration

RO : Runoff

BF : Baseflow (and coastal flow (CF))

IU : Inflow and outflow rate of groundwater from the outside basin

Inflow and outflow rate of groundwater from the outside basin in the study area was applied to groundwater use, leakage of water supply · sewer, groundwater discahrge from subway and electronic cable tunnel.

1. Potential evapotranspiration

The evapotranspiration estimation is the sum of evaporation from the surface and transpiration from plants. It is affected by the climate factors, plant type, color concentration, plant density, growth rate, the size of the plant leaf surface as well as soil porosity, hydraulic conductivity, particle size, soil moisture content, etc. The methods for evapotranspiration estimation are the Blaney-Criddle, the Thornthwaite method, the Penman Method and the FAO Penman-Monteith (FAO P-M) method.

1.1. Blaney-Criddle Method

The relationship of monthly mean temperature, day length and plant consumptive use is expressed by the following equation assuming water consumption is only affected by the climate and plants type (Blaney and Criddle, 1950).

$$CU = \frac{KT_m P}{100} = Kf \qquad (1)$$

,where CU : Consumptive use (inch)

K : Crop factor

T_m : Mean temperature

P : Ratio between month and annual day length (%)

$f = \frac{T_m P}{100}$

From the upper equation, the plant consumptive use can be represented as a function of day length and temperature. Because the energy required to heat the air as well as the energy required for plant growth and transpiration always have a fixed rate in the upper equation. Therefore, the plant consumptive use can be estimated during the plant growth in the following equation.

$$CU = \sum Kf = K\sum f \qquad (2)$$

Where, $\sum f$ is the sum for growth term. K is different depending on the plant, but it is represented as the following table by Blaney-Criddle method.

Table 2. Ratio between month and annual day length (%)

Lat. \ Mon.	1	2	3	4	5	6	7	8	9	10	11	12
20	7.57	7.85	8.26	8.67	9.02	9.15	9.08	8.97	8.40	8.05	7.71	7.50
30	7.16	7.57	8.19	8.81	9.36	9.36	9.57	9.02	8.47	7.85	7.30	7.02
40	6.61	7.23	8.12	9.08	9.84	9.84	10.05	9.36	8.53	7.64	6.81	6.40

Table 3. Crop factor (K)

Plant type	Growth period	Crop factor
Alfalfa	1 year (with winter)	0.85
Corn	4 month	0.75
Bean	3 month	0.65
Orchard · Grass	1 year (with winter)	0.65~0.75
Wheat · Oat	3 month	0.75

1.2. Thornthwaite Method

This method is estimated the plant consumptive use such as the Blaney-Criddle method. However, the factors according to the plant type were not represented to the equation with the temperature and day length (Thornthwaite, 1948).

For a year, if mean temperatures are t_n℃ (n = 1, 2, 3, ..., 12 Mon), the monthly heat index, j can be represented as the following empirical equation.

$$j = (t_n/5)^{1.514} \tag{3}$$

Therefore, because the annual heat index is the sum to monthly heat index, so the annual heat index is the following equation.

$$J = \sum_{n=1}^{12} j_n \tag{4}$$

If the mean temperature is t_n℃, any monthly potential evapotranspiration PE_X (plant consumptive use) is the following equation.

$$PE_x = Ct_n^a \tag{5}$$

,where PE_X : Plant consumptive use or Potential evapotranspiration

t_n : Mean temperature (℃)

a : Annual heat index

a is estimated by the following equation.

$$a = (675 \times 10^{-9})J^3 - (771 \times 10^{-7})J^2 + (179 \times 10^{-4})J + 0.49239 \tag{6}$$

When PE_X is 30 days (1 month),and the duration of sunshine is 12 hours, the upper equation can be expressed by the following equation, That is

$$PE_x = 1.62(10t_n/J)^a \ cmd^{-1} \tag{7}$$

Because PE_X is the theoretical value of the monthly potential evapotranspiration, evapotranspiration for a particular month that is the average temperature t_n℃ is revised to the following equation.

$$PE = PE_x \frac{DT}{30 \times 12} \tag{8}$$

,where D : Number of day of the relative season

1.3. Penman Mothed

The theoretical methods of evapotranspiration were used to the air dynamical method and energy conservation law, but in the case of evapotranspiration the air dynamical method can be not used because of considered evaporation from the plants surface. In the theoretical method, the evaporation and transpiration must be estimated from the free water surface and plant surface. Therefore, estimation of the evapotranspiration is available to the theoretical method by the energy conservation law (Penman, 1948).

The energy conservation law can be represented the following equation considering the energy required for transpiration.

$$H = R_N = S + ET + K + N + \triangle S \quad (9)$$

,where $H = R_N$: Total amount of used solar energy

S : Energy conducted from plants to soil

ET : Energy used in evapotranspiration

K : Radiant energy emitted into the atmosphere

N : Energy spent on plant growth (carbon assimilation)

$\triangle S$: Changes in temperature of plants (change in the amount of storage)

However, more than 95% of the value of ET and K are occupied in the above expression for each factor. The following equation can be represented because factors of the remaining S, N, and $\triangle S$ are just 5 %.

$$H = K + ET \quad (10)$$

Penman assumed that ET can be estimated by the concept which is ET is the same as evaporation of the free water surface. So, ET is E, and E and K are represented like the following equation by applying to air dynamical method.

$$E = f(u)(e_0 - e_a) \quad (11)$$

$$K = rf^{'}(u)(T_0 - T_a) \tag{12}$$

,where $f(u)$: Function of wind speed

$f'(u)$: 1 gradient for u of $f(u)$

T_o, T_a : Temperature of the object surface and atmosphere(To: dew-point temperature)

e_o : Saturated vapor pressure of water on T_o

e_a : Vapor pressure of water on T_a

r : Constant humidity measurements (=0.486mmHg/℃)

In addition, gradient △ can be expressed as the following equation in the relationship between vapor pressure and temperature.

$$\triangle = \frac{e_o - e_s}{T_o - T_a} \tag{13}$$

When e_s is saturated vapor pressure on T_a and $f'(u) \fallingdotseq f(u)$, It can be organized to the following equation.

$$E = \frac{\triangle \cdot H + rE_a}{\triangle + r} \tag{14}$$

The following equation with E_a equation proposed by Penman is.

$$E_a = 0.35(1 + 0.149u_2)(e_0 - e_a) \quad (15)$$

Where, the unit of u_2 is km/hour, E_a is mm/day, e_o as well as e_a are mmHg. Penman proposed the following equation to estimate above H.

$$H = (1-\gamma)R_A(0.18 + 0.55_n/N) - \sigma T_A^4(0.56 - 0.09\sqrt{e_a})(0.10 + 0.910^n/N) \quad (16)$$

,where R_A : Solar energy reaching the Earth′s atmosphere

n : Duration of sunshine

N : Maximum length of the day

σ : Stephan-Btotzman Constant

T_A : Kelvin Temperature

e_a : Vapor pressure above 2 m from surface

The evapotranspiration estimated by Penman method is the maximum evapotranspiration in case of unlimited supplies of water, so there is different from the actual quantity consumed by plants. Moisture needed for plant growth has not the maximum value as well as actual amount of the water in the soil is limited, so the value of evapotranspiration by Penman method should be revised.

E value of Penman method and consumption of the plants have the following relationship.

$$CU = 0.95E \quad (17)$$

Also, because the consumption of plants is different to depending on the plants growth, Penman proposed multiplied by the E and coefficients of 0.8 in May ~ August; 0.7 in March, April, September and October; 0.6 in November ~ February.

1.4. FAO Penman-Monteith Method

The actual evapotranspiration is the sum of the evaporation from the surface into the atmosphere and plant transpiration to the atmosphere by the activity of the leaves. The actual evapotranspiration can be estimated by using potential evapotranspiration, precipitation and the plant-available water coefficient (Zhang et al., 2001), the equation is.

$$\frac{AET}{P} = \frac{1 + w\frac{PET}{P}}{1 + w\frac{PET}{P} + \frac{P}{PET}} \tag{18}$$

,where AET is the actual evapotranspiration, w is the plant-available water coefficient, PET is the potential evapotranspiration and P is the precipitation.

The potential evapotranspiration of the equation (18) is estimated by equation (19) (Allen et al., 1998).

$$PET = \frac{0.408\Delta(R_n - G) + \gamma\frac{900}{T+273}u_2(e_s - e_a)}{\Delta + \gamma(1+0.34u_2)} \quad (19)$$

,where Δ : Slope vapour pressure curve

R_n : Net radiation

G : Soil heat flux density

γ : Psychrometric constant

T : Mean daily air temperature at 2 m height

u_2 : Wind speed at 2 m height

e_s : Saturation vapour pressure

e_a : Actual vapour pressure

$(e_s - e_a)$: Saturation vapour pressure deficit

$$\Delta = \frac{4098 \times \left[0.6108 \times \exp\left(\frac{17.27 \times T}{T + 237.3}\right)\right]}{(T+237.3)^2} \quad (20)$$

$$R_n = R_{ns} - R_{nl} \quad (21)$$

,where R_{ns} : Net solar or shortwave radiation

R_{nl} : Net outgoing longwave radiation

$$R_{ns} = (1-\alpha)R_s \quad (22)$$

α : Albedo.

$$R_s = \left(a_s + b_s \times \frac{n}{N}\right) \times R_a \tag{23}$$

,where a_s : Regression constant, expressing the fraction of extraterrestrial radiation reaching the earth on overcast days

n : Actual duration of sunshine

N : Daylight hours

$a_s + b_s$: Fraction of extraterrestrial radiation reaching the earth on clear days ($n = N$)

$$R_a = \frac{24(60)}{\pi} G_{sc} d_r \left[w_s \sin(\varphi) \sin(\delta) + \cos(\varphi) \cos(\delta) \sin(w_s) \right] \tag{24}$$

,where R_a : Extraterrestrial radiation

G_{sc} : Solar constant =0.0820

d_r : Inverse relative distance Earth-Sun

w_s : Sunset hour angle

φ : Latitude

δ : Solar decimation

$$d_r = 1 + 0.033 \times \cos\left(\frac{2\pi}{365} J\right) \tag{25}$$

,where J is the number of the day in the year between I January and

365 or 366 (31 December).

$$w_s = \arccos[-\tan(\varphi)\tan(\delta)] \tag{26}$$

$$\delta = 0.409 \times \sin\left(\frac{2\pi}{365}J - 1.39\right) \tag{27}$$

$$R_{nl} = \sigma\left[\frac{T_{\max,K^4} + T_{\min,K^4}}{2}\right] \times (0.34 - 0.14\sqrt{e_a}) \times \left(1.35 \times \frac{R_s}{R_{so}} - 0.35\right) \tag{28}$$

,where σ : Stefan-Boltzmann constant

$T_{\max,K}$: Maximum absolute temperature during the 24-hour period

$T_{\min,K}$: Minimum absolute temperature during the 24-hour period

R_s : Measured or calculated solar radiation

R_{so} : Calculated clear-sky radiation

$$R_{so} = (a_s + b_s) \times R_a \tag{29}$$

$$u_2 = u_z \times \frac{4.87}{\ln(67.8 \times z - 5.42)} \tag{30}$$

,where u_z : Wind speed at 2m above ground surface

u_z : Measured wind speed at z m above ground surface

z : Height of measurement above ground surface

$$\gamma = 0.665 \times 10^{-3} \times P_a \tag{31}$$

P_a is the atmospheric pressure.

$$e_s = \frac{e^o(T_{\max}) + e^o(T_{\min})}{2} \tag{32}$$

$$e^o(T) = 0.6108 \times \exp\left[\frac{17.27 \times T}{T + 237.3}\right] \tag{33}$$

$e^o(T)$ is the saturation vapour pressure at the air temperature.

$$e_a = e^o(T_{dew}) = 0.6108 \times \exp\left[\frac{17.27 \times T_{dew}}{T_{dew}} + 237.3\right] \tag{34}$$

T_{dew} : Dewpoint temperature.

1.5. Comparison of potential evapotranspiration estimation

(1) Blaney-Criddle method and Thornthwaite method have almost the same quantity because those methods are using the similar results of the estimation. This method is designed to estimate the annual consumption plants. There are risks in a short-term value because of not considering the error of estimation of the wind and relative humidity. The crop factor K should be adjusted by depending to early,

middle and end period of plants growth. The crop factors applied by those methods also depended on the growth period of plants.

(2) Blaney-Criddle method has the correct value when comparing to Thornthwaite method in the case of the arid regions.

(3) Penman method is more correct than Blaney-Criddle method or Thornthwaite method, but there are limits to apply because it needs more accurate weather data. The energy in the critical area can cause errors, because Penman method ignores the energy exchange for the amount of in and out water of a reservoir (Sunwoo Jungho, 1983).

(4) Recently, a new method for the potential evapotranspiration estimation has been used FAO Penman-Monteith method with combination of the Penman-Monteith and various parameters. This method is assumed crop height of 0.12 m, a fixed surface resistance of 70 s m^{-1}. FAO P-M overcomes problems of the P-M and offers the values of the actual crops. The FAO Penman-Monteith method to estimate evapotranspiration can be derived from the original Penman-Menteith equation and the equations of the aerodynamic and surface resistance (Allen, 1998).

2. Actual evapotranspiration

Parameters for the potential evapotranspiration estimation are *T*, mean daily air temperature at 2 m height, T_{MAX}, mean maximum temperature, T_{MIN}, mean minimum temperature, AP, atmospheric pressure, DT, dewpoint temperature, DS, duration of sunshine and MWS, mean wind speed. The mean temperature, mean maximum temperature and dew point temperature were the highest in 2001, but was the lowest in 2005. The mean minimum temperature was the highest in 2007, but was the lowest in 2005. The duration of sunshine was the longest in 1999 and shortest in 2003. The mean wind speed was the lowest having the same value in 2004, 2005 and 2006, but was the highest in 2002 (Suyeong-gu District Office, 2008).

Table 4. Meteorological data used to estimate PET in the Suyeong-gu

Year	T (°C)	T_{MAX} (°C)	T_{MIN} (°C)	AP (kPa)	DT (°C)	DS (hr)	MWS (m/sec)
1999	15.0	19.2	11.8	101.53	7.8	6.73	3.58
2000	14.9	19.2	11.6	101.51	7.8	5.51	3.56
2001	15.3	20.0	12.0	101.53	8.2	5.66	3.61
2002	14.7	18.9	11.4	101.51	7.2	5.54	3.88
2003	14.3	18.5	11.2	101.58	7.5	5.06	3.17
2004	14.9	19.3	11.5	101.57	6.5	6.58	3.10
2005	13.8	18.1	10.5	101.54	5.4	6.62	3.05
2006	14.7	18.9	11.4	101.55	7.0	6.02	3.11
2007	15.3	19.1	12.4	101.53	7.5	6.00	3.26

The plant-available water coefficient was "0" in impermeable layer, "0.5" in Dry, Rice, Park, Grave, "2.0" in Forest and "1.076" in waters (Zhang et al., 1999). The plant-available water coefficient was classified according to land use. The areas of classified lands were in the Table 5. The area of Building, Road and others (w=0) in Suyeong-gu ranged between 71.7 to 72.7 %, and the area of forest (w=2.0) ranged between 24.0 to 24.9 %. The areas in progress urbanization like this study have a low plant-available water coefficient due to reducing of the transpiration by plants (Zhang et al., 2001).

Table 5. "w" values and areas with land use

Year	Building, Road, Others (w=0)	Dry, Rice, Park, Grave (w=0.5)	Forest (w=2.0)	Waters (w=1.076)
1999	0.717	0.010	0.249	0.024
2000	0.720	0.010	0.246	0.024
2001	0.721	0.010	0.246	0.023
2002	0.721	0.010	0.246	0.023
2003	0.722	0.009	0.246	0.023
2004	0.722	0.010	0.244	0.024
2005	0.723	0.010	0.2443	0.024
2006	0.723	0.010	0.243	0.024
2007	0.727	0.011	0.239	0.023

The potential evapotranspiration and actual evapotranspiration were summarized in Table 6, ratios of the difference between the potential evapotranspiration and actual evapotranspiration were estimated. The precipitation in 1999, 2002 and in 2003 were more than 2,000 mm/yr, and it was the lowest in 2001; 1171.3 mm/yr. The potential evapotranspiration in 2002 was the highest (564.45 mm/yr), and it was the lowest in 2003 (449.95 mm/yr). In 2002, the actual evapotranspiration was the highest (554.14 mm/yr), and it was the lowest in 2003 (427.91 mm/yr). The fluctuation of the potential evapotranspiration and actual evapotranspiration was similar, and the difference was between 10.31 ~ 39.94 mm/yr. It was the lowest in 2002, while the highest in 2000. The ratio of potential evapotranspiration and actual evapotranspiration was higher than 0.92, it was a 0.98, the highest in 2002 and 2006.

In this study, the difference of potential evapotranspiration and actual evapotranspiration was small and the relative ratio was high. It was because of increasing urbanization in the large areas having w=0 (building, road, others). The fluctuation of the potential evapotranspiration and actual evapotranspiration was similar, but changes in precipitation and actual evapotranspiration showed a different pattern (Fig. 2). The actual evapotranspiration in the study area was more sensitive to changes in actual evapotranspiration than precipitation.

Fig. 3 shows the relationship between the actual evapotranspiration and mean wind speed. The fluctuation of actual evapotranspiration, except in 2004, was shown the same as the changes in wind speed. In addition, the relationship between actual evapotranspiration and temperature is represented (Fig. 3). Change of actual evapotranspiration depending on the temperature, except in 2002, is showed the same pattern. In other words, the actual evapotranspiration is highly affected by the mean wind speed and temperature.

Table 6. Estimated PET and AET using meteorological data (mm/yr)

Year	P	PET	AET	PET-AET	AET/PET
1999	2396.7	516.71	489.45	27.26	0.95
2000	1248.5	499.95	460.00	39.94	0.92
2001	1171.3	540.98	523.43	17.55	0.97
2002	2085.2	564.45	554.14	10.31	0.98
2003	2328.3	449.95	427.91	22.05	0.95
2004	1386.5	521.37	497.42	23.96	0.95
2005	1383.9	482.07	467.21	14.86	0.97
2006	1528.3	484.74	473.21	11.54	0.98
2007	1276.5	515.18	480.52	34.66	0.93
Avg.	1645.0	508.38	485.92	22.46	0.96

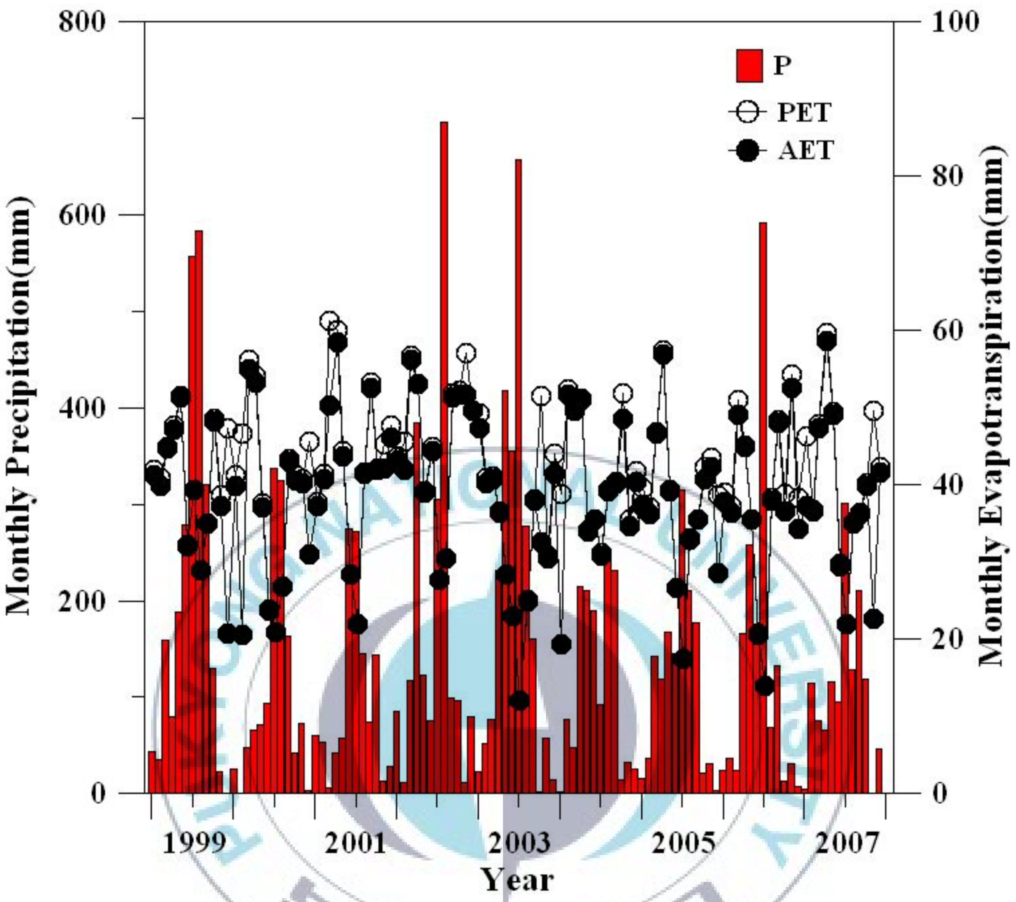

Fig. 3. Monthly variations of Precipitation, PET and AET.

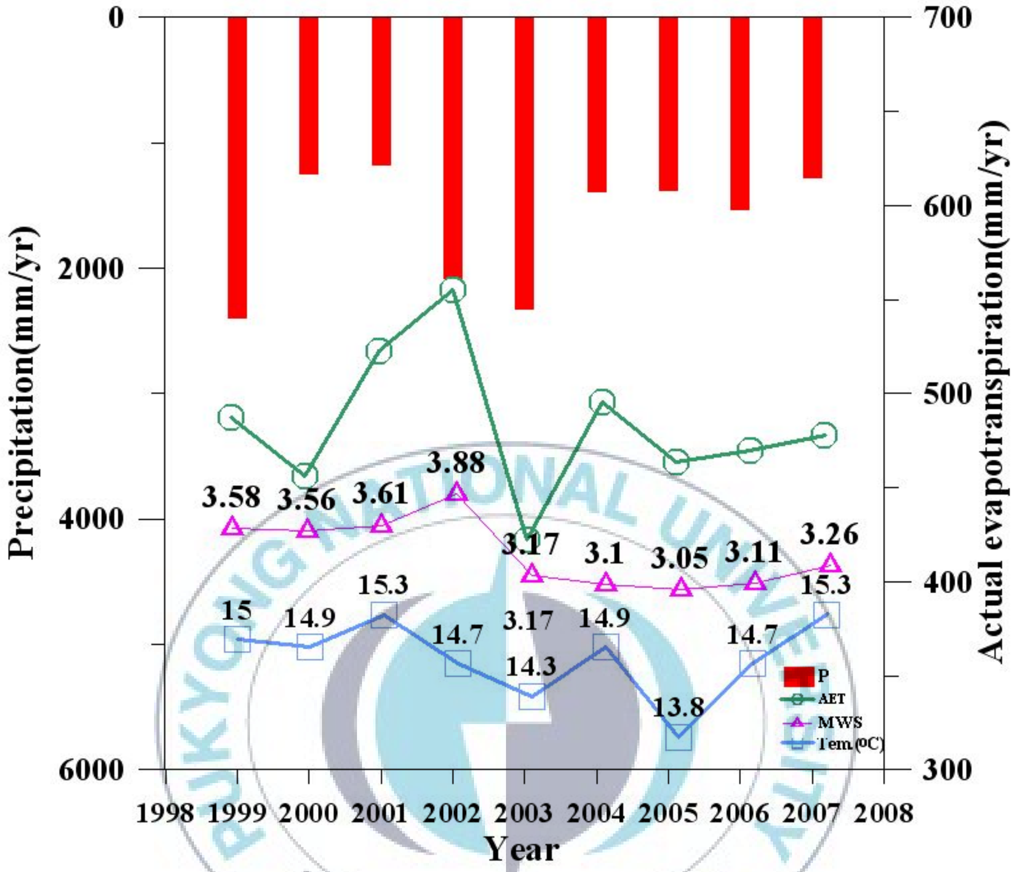

Fig. 4. Annual variations of Precipitation, AET, MWS and Temperature.

The actual evapotranspiration is a function for the potential evapotranspiration and precipitation (Zhang et al., 2001). In the study area, the actual evapotranspiration was dominated by the potential evapotranspiration rather than the precipitation. The linear regression functions for the actual evapotranspiration and the potential evapotranspiration was estimated (Fig. 4, 5).

The linear regression function for the actual evapotranspiration and the potential evapotranspiration using the monthly data was

$AET = 0.87 \times PET + 3.52$, and the coefficient of determination was 0.75, high. The linear regression function for the actual evapotranspiration and the potential evapotranspiration using the annual data was $AET = 1.04 \times PET - 42.50$, and the coefficient of determination was 0.92, very high.

In this study, the gradient for the actual evapotranspiration and the potential evapotranspiration was 0.87 in month and 1.04 in year. It is because data used in the regression analysis were different. The function for the actual evapotranspiration and the potential evapotranspiration in the study area was shown that the linear model was suitable to the monthly and annual scale, and the coefficient of determination was high because of the low variation of the evapotranspiration in annual scale.

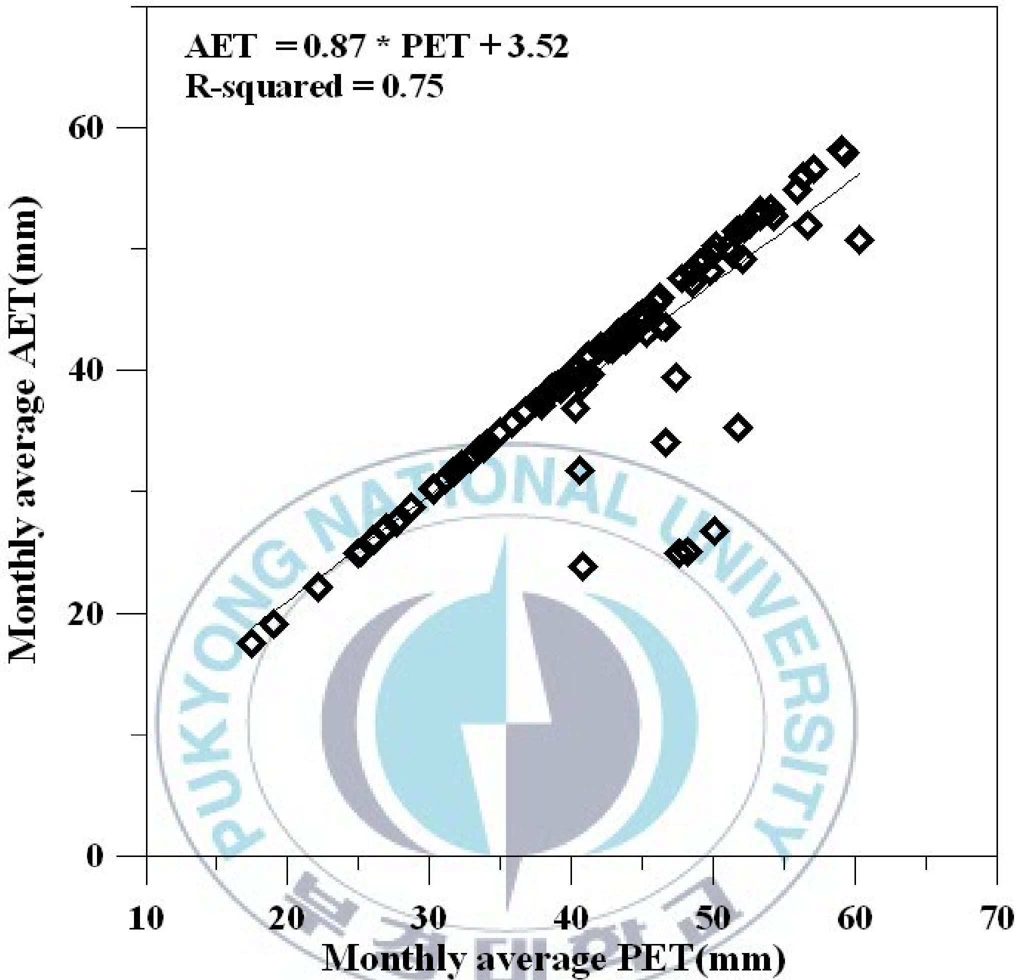

Fig. 5. The linear regression functions for monthly average of AET and PET.

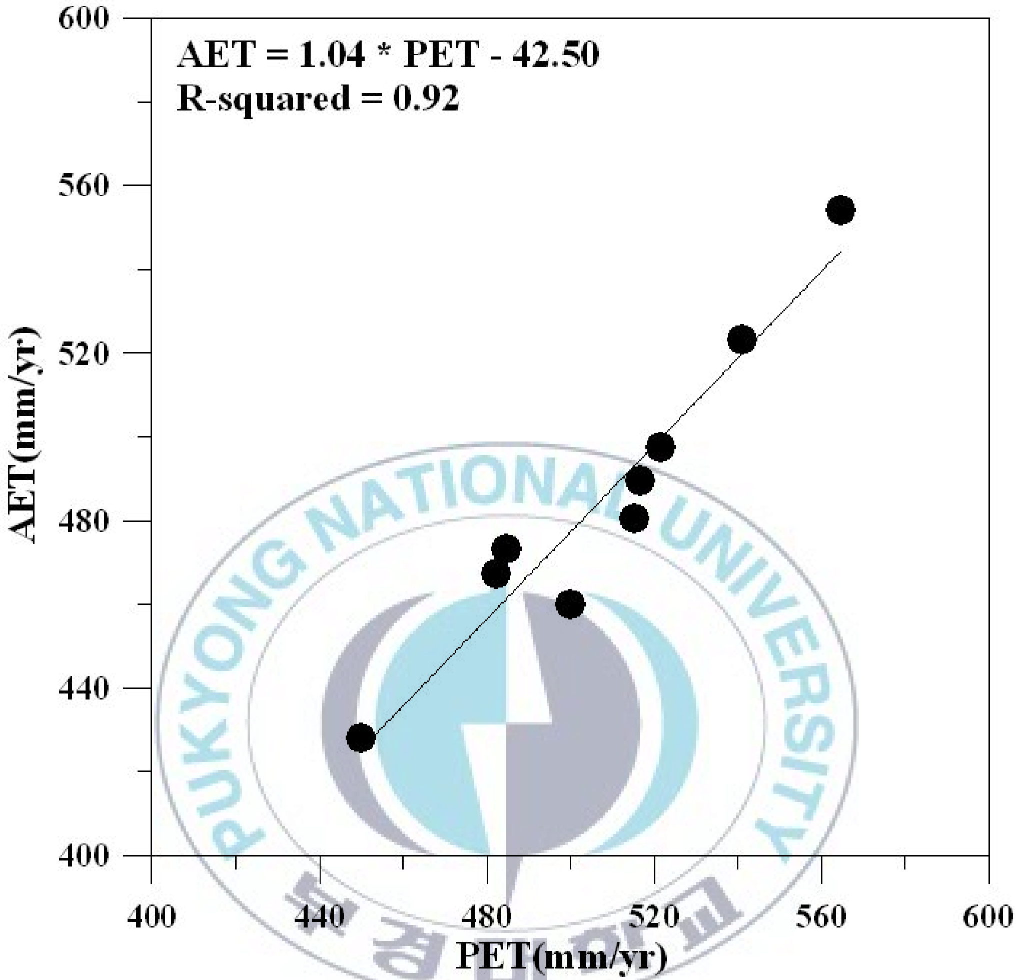

Fig. 6. The linear regression functions for annul average of AET and PET.

2.1. Correlation analysis

Correlations analysis between the evapotranspiration and the meteorological factors were performed and the estimated correlation coefficients were summarized in Table 7.

The correlation coefficient of the actual evapotranspiration and potential evapotranspiration was 0.96, high, but the correlation coefficient of 1) the precipitation and actual evapotranspiration; 2) the precipitation and potential evapotranspiration were very low, respectively. In Suyeong-gu, the coastal urban areas, the influence for the potential and actual evapotranspiration and the mean wind speed was higher than others, and the correlation coefficients were 0.73 and 0.67. And then the relationship of the atmospheric pressure was higher, the correlation coefficients for the actual evapotranspiration and potential evapotranspiration were -0.52 and -0.62. It is because more saturated vapor pressure is increasing more evapotranspiration is decreasing. The influence of the mean maximum temperature was higher than the mean daily temperature on evapotranspiration, the correlation between the mean minimum temperature and evapotranspiration was relatively low. The evapotranspiration in the coastal urban areas is caused predominantly by the mean wind speed than the other meteorological factors such as precipitation and temperature. Gong et al. (2006) reported that the most significant meteorological factors for estimating the evapotranspiration variation was the relative humidity in China Yangtze River basin, alpine (average altitude 3000 m), but the same area of the Yangtze River close to the lowlands (average altitude 100 m) was mean wind speed.

The linear regression analysis of the wind speed, temperature and saturated vapor pressure and the potential evapotranspiration and actual evapotranspiration were performed to estimate the regression functions.

The linear regression function gradient for the mean wind speed and the potential evapotranspiration and actual evapotranspiration in Sugyeong-gu, respectively, was about 85 and 84, the coefficients of determination between the raw data and the estimated functions were 0.54 and 0.45, respectively (Fig. 9, 10). According to the estimated linear function, the evapotranspiration was increasing over 84 mm/yr, if the mean wind speed was 1 m/sec higher.

The linear regressions for the evapotranspiration and mean daily temperature and mean maximum temperature in this study were increasing (Fig. 11, 12, 13, 14). The change in evapotranspiration according to changes in the temperature was higher to the potential evapotranspiration than the actual evapotranspiration, showed 17 % by mean maximum temperature and 12 % by mean daily temperature difference, respectively. In Rajasthan, India during 32 years (1971-2002), the fluctuation of evapotranspiration by temperature was the highest. In addition, it was predicted that evapotranspiration due to global warming would be increased to continue (Goyal, 2004).

In the Studies in the general, atmospheric pressure (AP) had inverse relationship to the evapotranspiration (Singh and Xu, 1997). The linear decreases of the potential evapotranspiration and actual evapotranspiration due to the increase of atmospheric pressure in Suyeong-gu were occurred (Fig. 15, 16). The vaporized moisture from the soil surface and water surface is more evaporated if the atmospheric pressure is lower. Therefore, evapotranspiration will be reduced if having the same conditions of other factors related to the evapotranspiration at the high atmospheric pressure region. In this study, the decrease of the potential evapotranspiration according to the atmospheric pressure was higher than the actual evapotranspiration. It is means that the potential evapotranspiration to changes in the atmospheric pressure was more sensitive.

Table 7. Correlation coefficients between ET and meteorological factors

	P	PET	AET	T	AP	T_{MAX}	T_{MIN}	DT	MWS	DS	E_S	Ea
P	1.00	-0.13	-0.06	-0.24	0.19	-0.34	-0.18	0.14	0.25	-0.11	-0.68	-0.21
PET		1.00	**0.96**	**0.57**	**-0.62**	**0.60**	0.47	0.29	**0.73**	0.14	0.47	0.22
AET			1.00	0.40	-0.52	0.48	0.30	0.15	**0.67**	0.13	0.37	0.09
T				1.00	-0.34	0.91	0.97	0.78	0.45	-0.04	0.75	0.61
AP					1.00	-0.27	-0.31	-0.31	-0.76	0.03	-0.33	-0.47
T_{MAX}						1.00	0.79	0.72	0.46	-0.03	0.88	0.69
T_{MIN}							1.00	0.77	0.39	-0.10	0.65	0.54
DT								1.00	0.62	-0.51	0.54	0.83
MWS									1.00	-0.30	0.29	0.56
DS										1.00	-0.10	-0.45
E_S											1.00	0.73
Ea												1.00

Es : Mean saturation vapour pressure; Ea : Actual vapour pressue

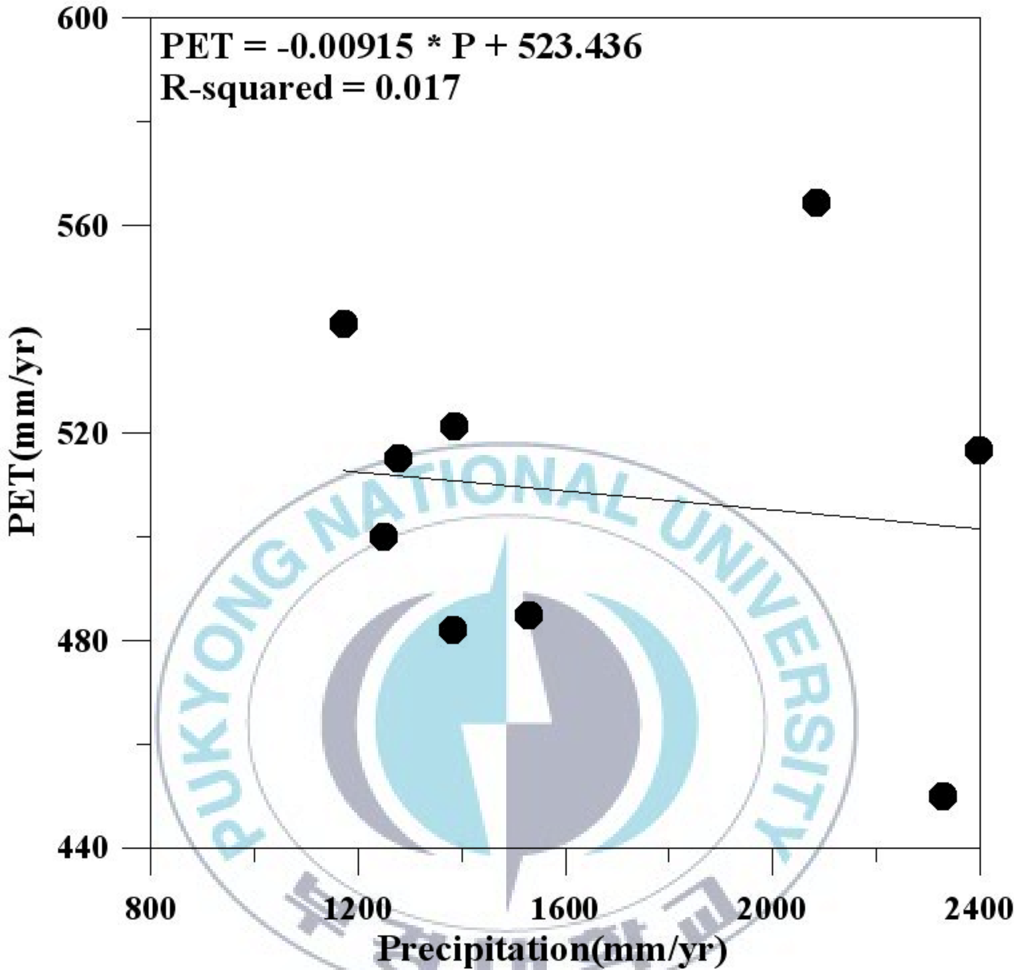

Fig. 7. The linear regression functions for PET and Precipitation.

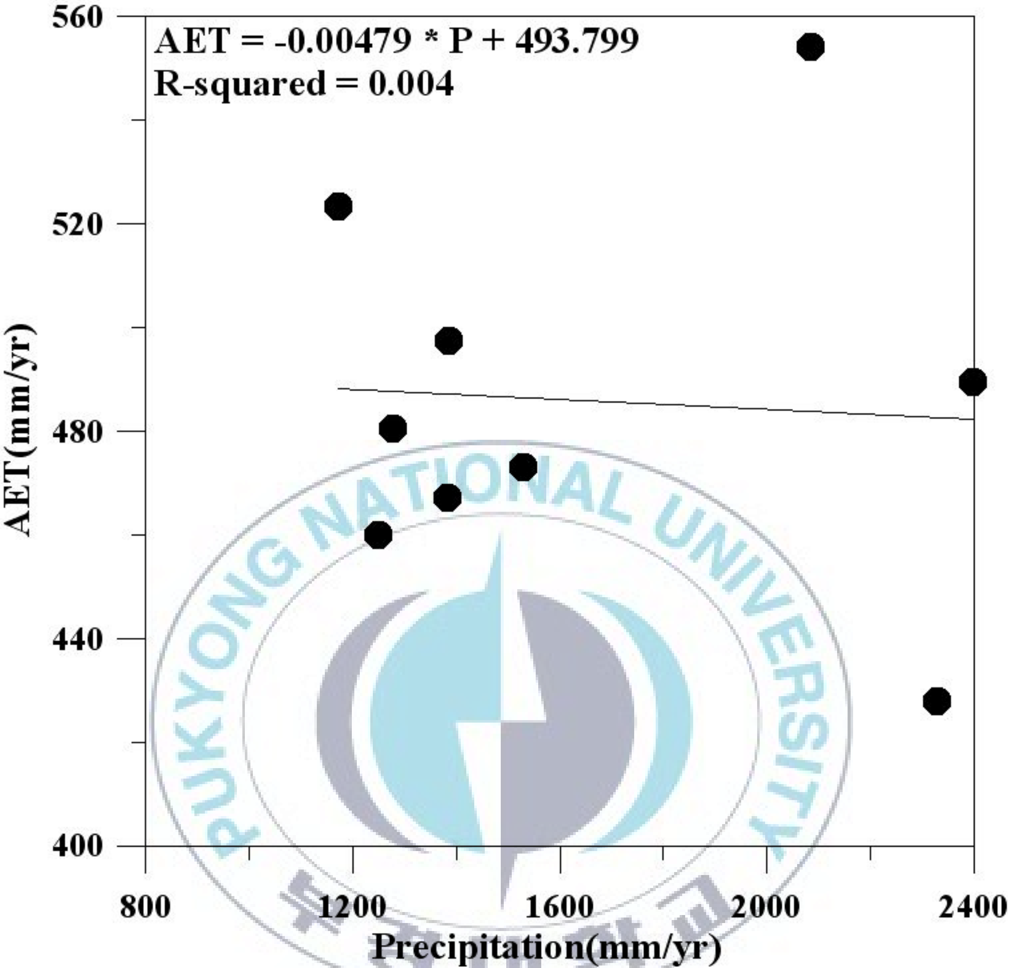

Fig. 8. The linear regression functions for AET and Precipitation.

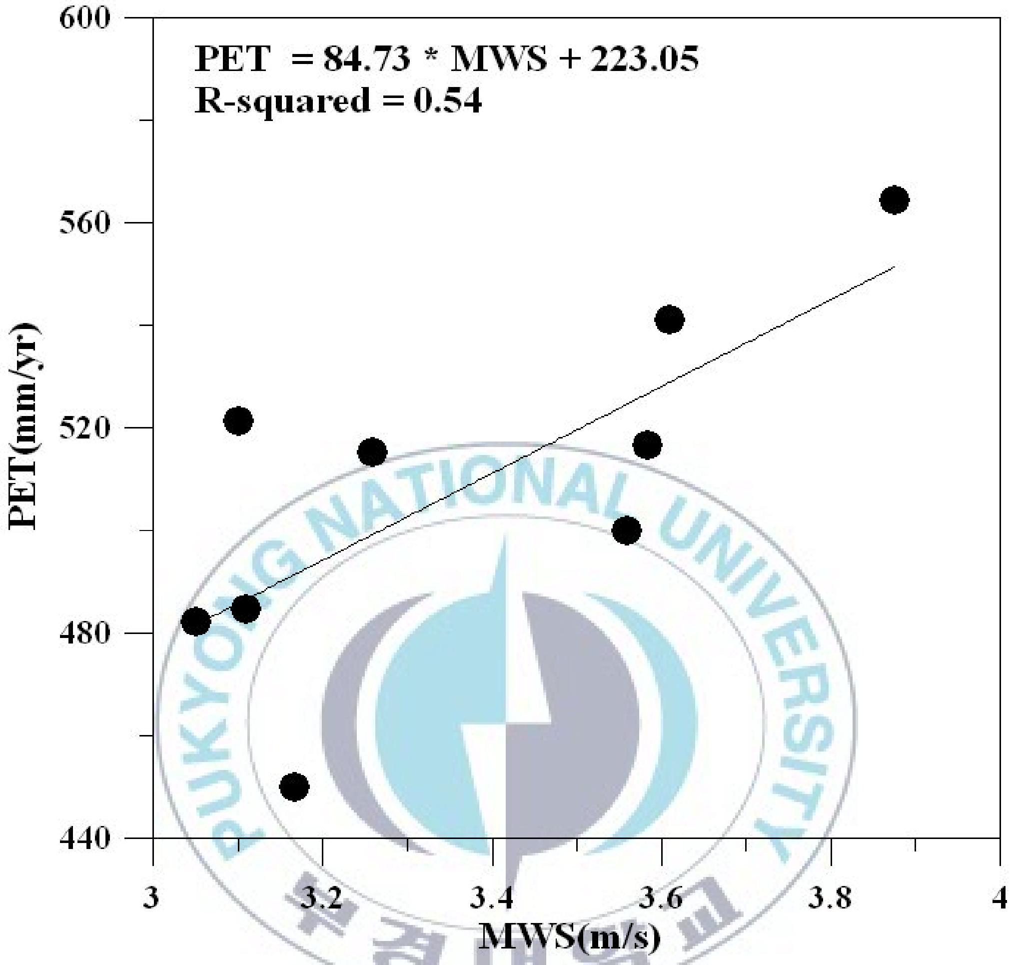

Fig. 9. The linear regression functions for PET and MWS..

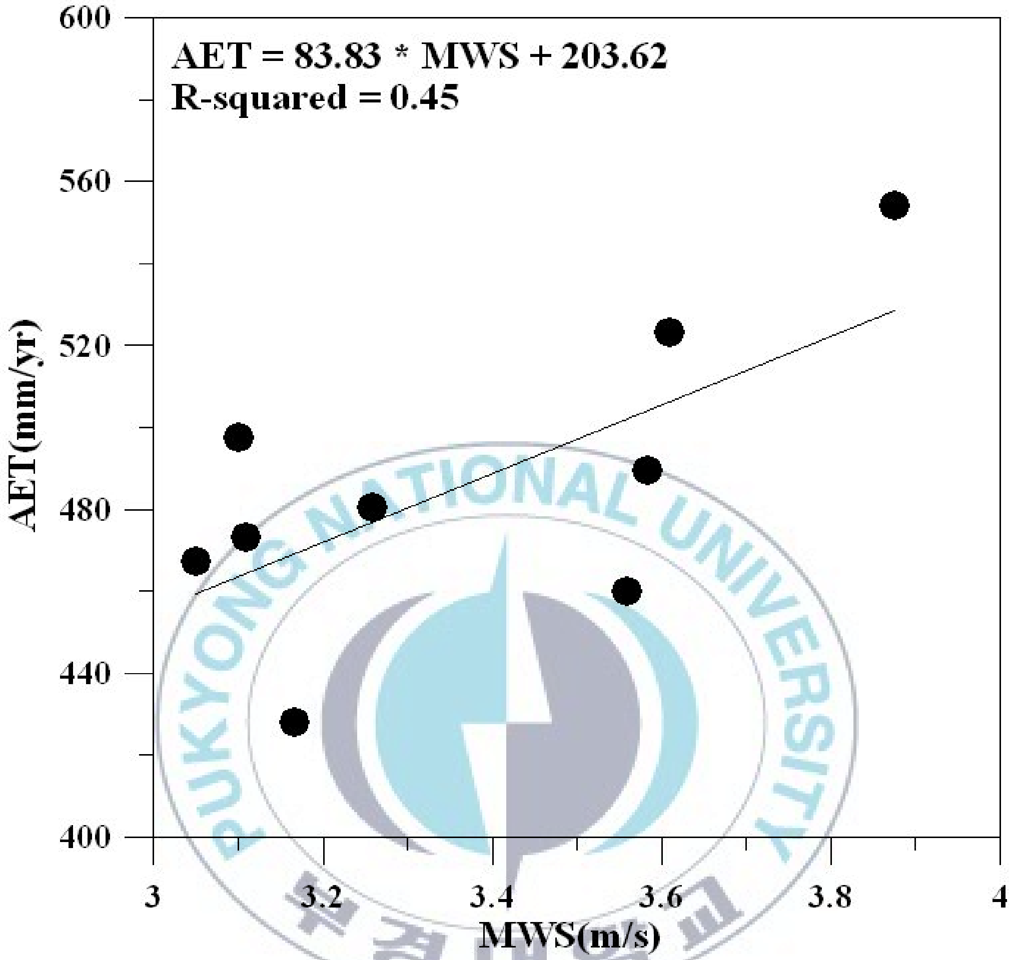

Fig. 10. The linear regression functions for AET and MWS.

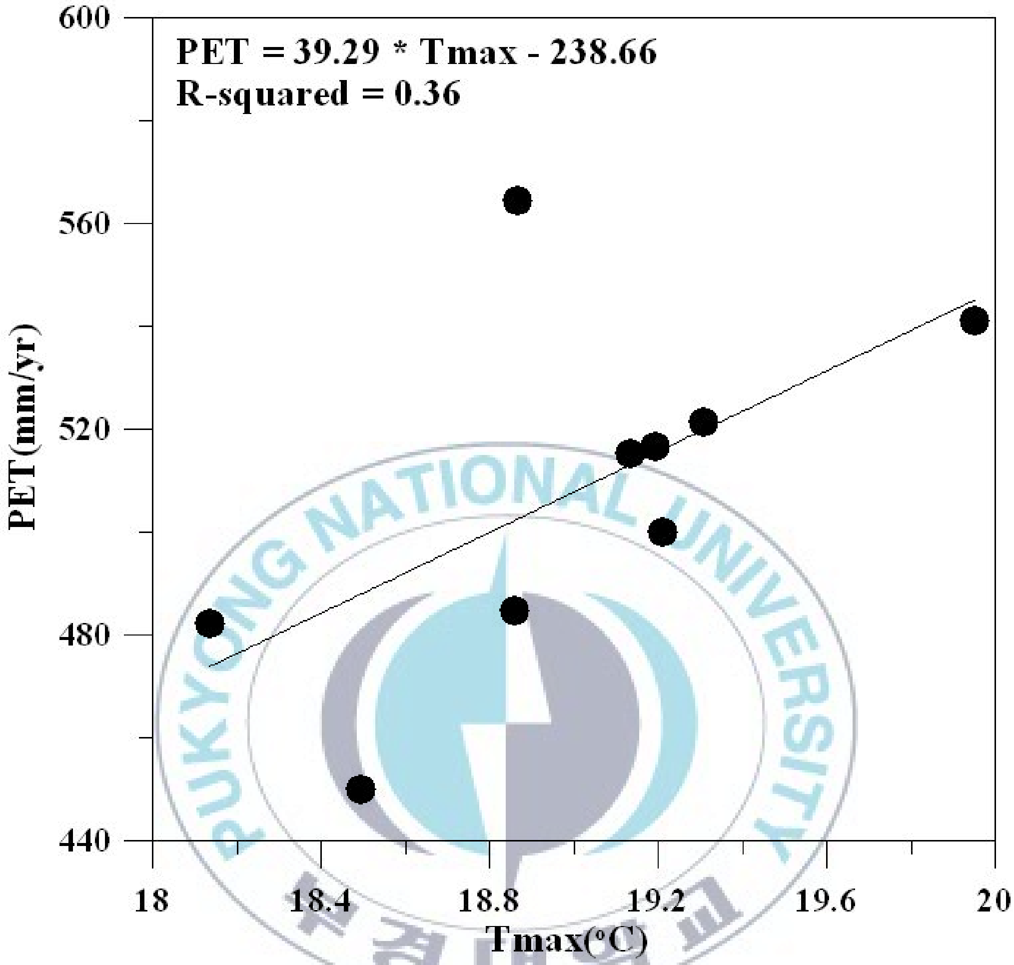

Fig. 11. The linear regression functions for PET and Tmax.

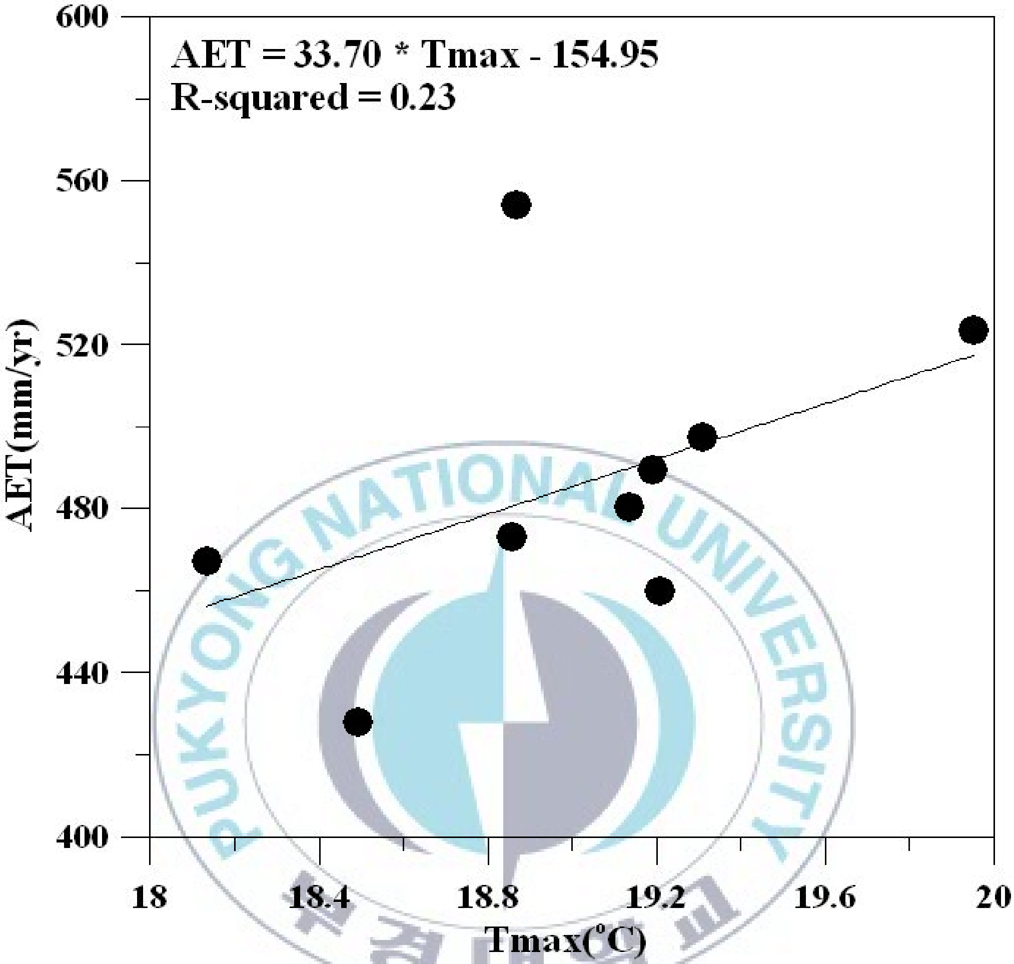

Fig. 12. The linear regression functions for AET and Tmax.

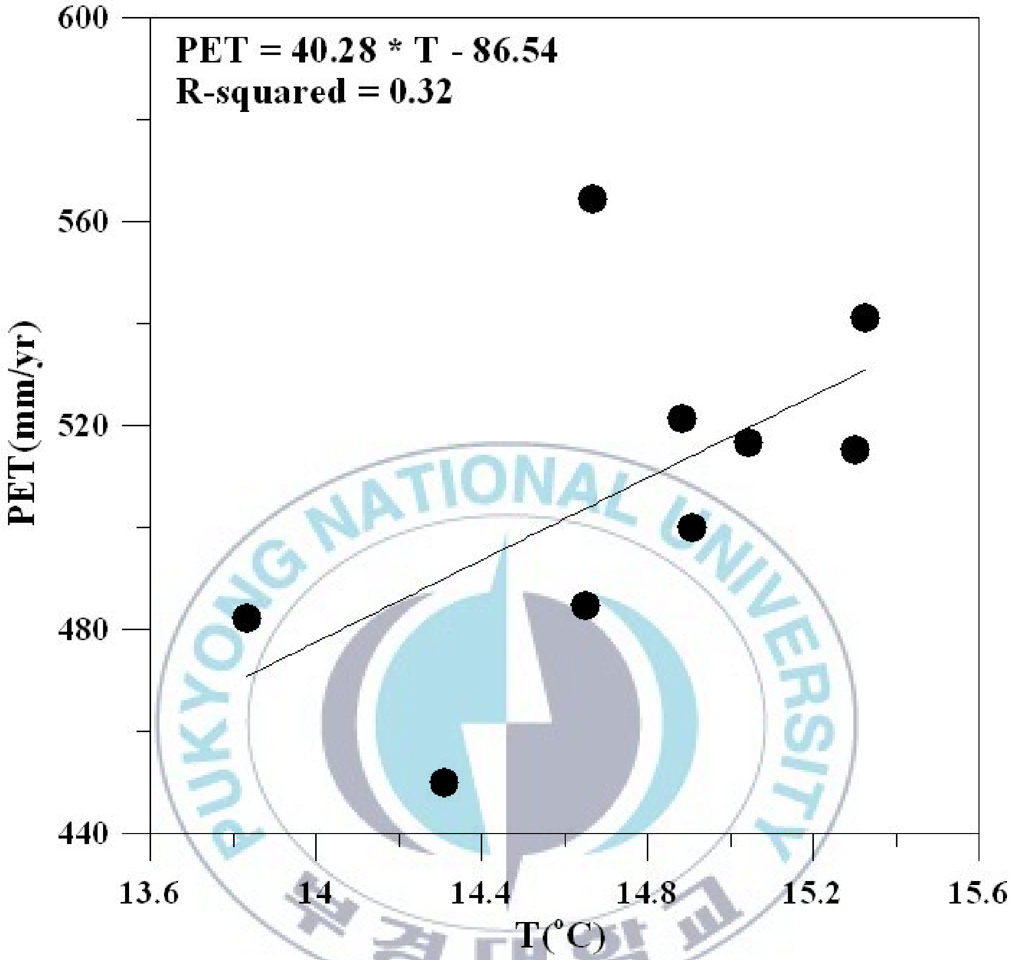

Fig. 13. The linear regression functions for PET and T.

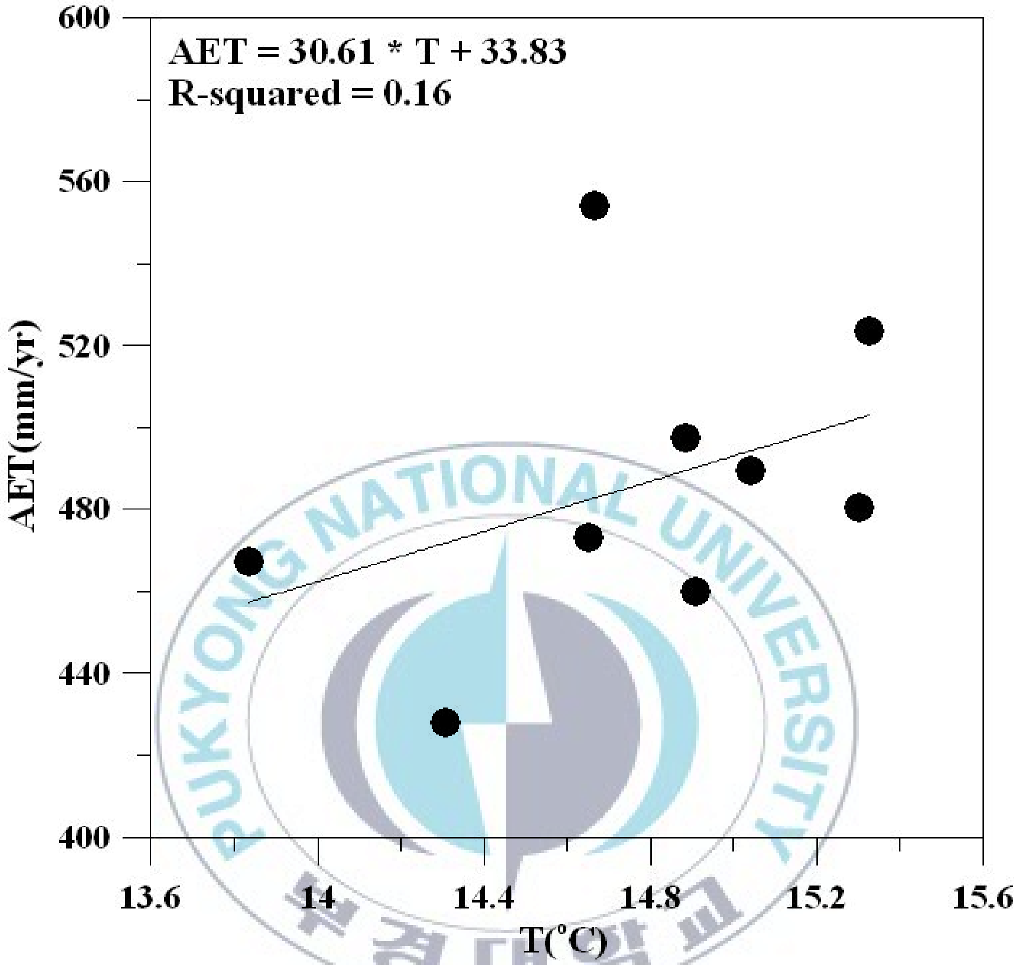

Fig. 14. The linear regression functions for AET and T.

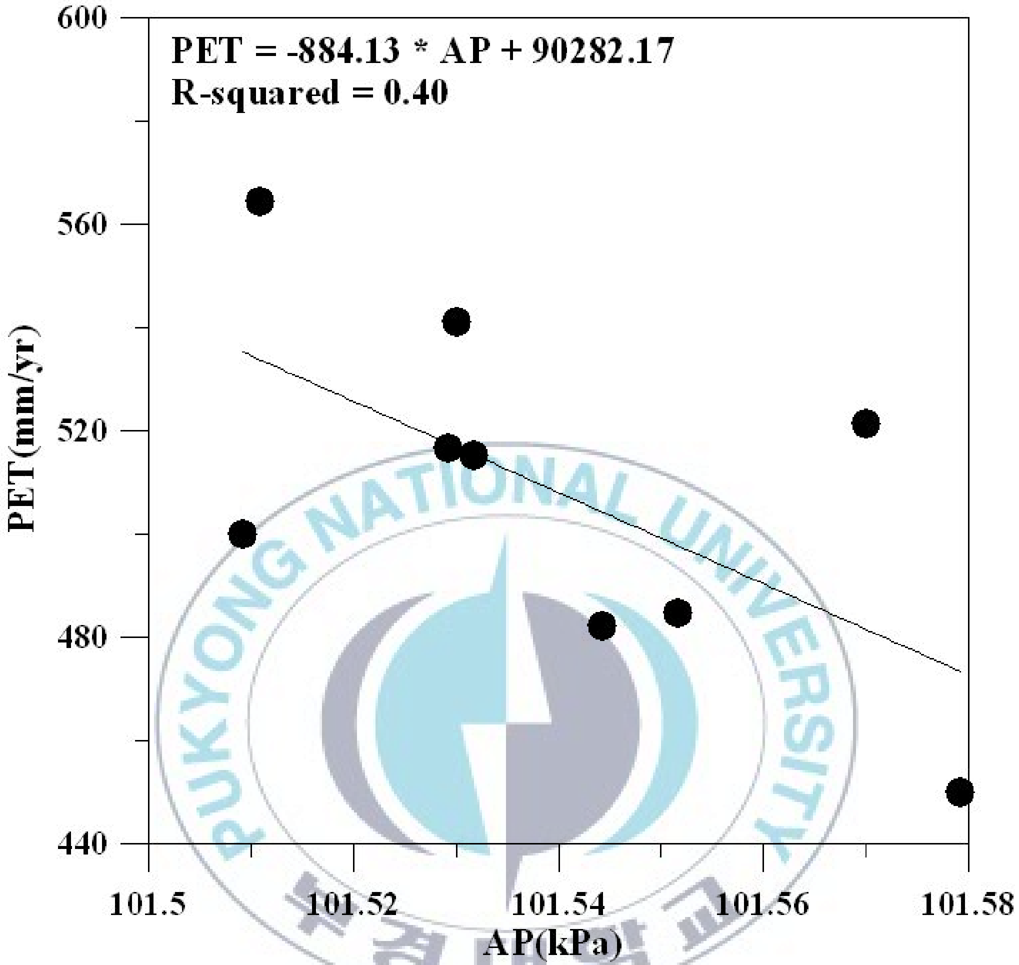

Fig. 15. The linear regression functions for PET and AP.

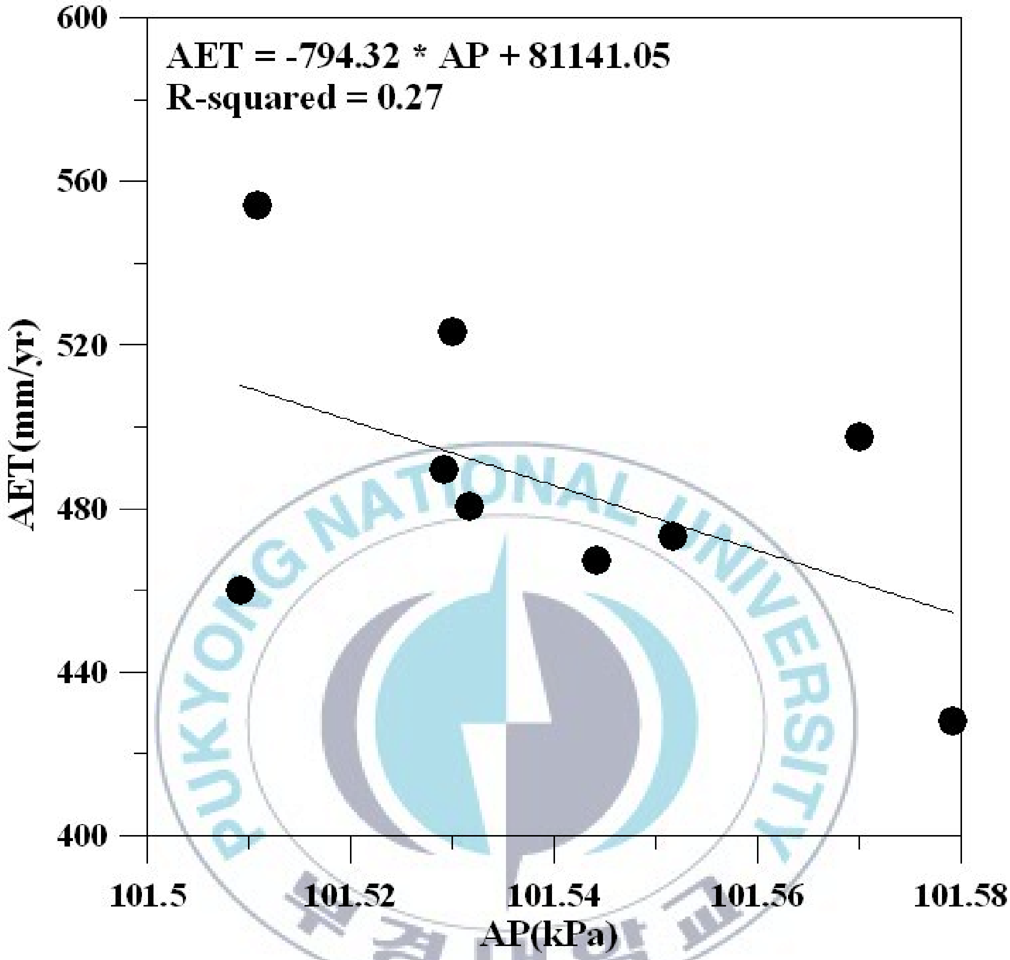

Fig. 16. The linear regression functions for AET and AP.

3. Runoff

The some precipitation after infiltration below the surface and evaporation is discharged along the surface of the ground. In other words, the runoff depends on the evaporation and infiltration, and infiltration depends on the state of the soil. If the soil is saturated, the infiltration does not occur while runoff occurs.

That precipitation minus the evaporation and infiltration is called excess precipitation or surface runoff. SCS-CN method was developed by U.S. Soil Conservation Service that is to estimate excess precipitation using only vegetation cover and soil characteristics in the absence of runoff data, and is using to estimate the excess precipitation (Hahn and Hahn, 1999).

3.1. Basic concept

SCS-CN method is a direct factor affected the size of the available quantity. It is considered the soil type, land use or plants cover type, cover treatment and hydrologic condition (Soil Conservation Service, 1969, 1971).

SCS-CN was presented the equation (36) in order for estimating the runoff.

$$\frac{F}{S} = \frac{Q}{P} \tag{36}$$

,where F : Storage of the soil in time [mm]

S : Storage when a fully saturated [mm]

Q : Effective yield corresponds to surface runoff [mm]

P : Cumulative rainfall [mm]

The runoff from the precipitation is presented a function of S and F. It is $F = P - Q$.

Thus, equation (36) can be expressed as the following.

$$Q = \frac{P^2}{P+S} \tag{37}$$

The equation means that runoff occurs as soon as precipitation occurs. However, most of early precipitation is infiltrated, and runoff depends on precipitation. Runoff occurs after several time. So, initial loss of precipitation is considered if initial runoff is considered.

The initial loss was determined $0.2S$ by experience. If this relationship was substituted to the equation (37), it became the equation (38). It is a relationship between the precipitation and available quantity. Here, Q and P should be bigger than 0 and 0.2, respectively.

$$Q = \frac{(P - 0.2S)^2}{P + 0.8S} \tag{38}$$

In equation (38), S will have different values depending on the antecedent soil moisture condition, A.M.C. The S on the AMC-Ⅰ which has a small antecedent precipitation is greater than the AMC-Ⅱ which is usual, but is smaller than the AMC-Ⅲ which is a lot of precipitation. The S what is presented the potential water quantity of the basin states represent the nature of hydrologic soil-cover complexes - soil, land use and cover treatment. CN (runoff curve number) is defined by a function of S - equation (39) which is considered indirectly the effects of runoff.

$$CN = \frac{25,400}{S + 254} \quad \text{or} \quad S = \frac{25,400}{CN} - 254 \tag{39}$$

Where, CN is a indicator according to soil type and state in the SCS.

The important matters when runoff is estimated by using the equation (38) and (39) in SCS should be considered the soil type, antecedent soil moisture condition and land uses.

These three elements are reflected to the runoff estimation by the equation (39), and is divided accordingly. SCS can be classified into four. A type is the lowest runoff potential mud. B type is the moderately low runoff potential sand with mud and silt that the penetration rate is high than the average value. C type is the moderately high runoff potential soil with mud and silt that the penetration rate is less than the average value. D type is the highest runoff potential soil with mud and silt that is close to the direct impermeable layer.

To analyse the relationship between total precipitation and effective precipitation, 5 days or 30 days of the antecedent precipitation is commonly used as index represented the antecedent soil moisture condition. In other words, if the antecedent precipitation is high in case that there is the same precipitation, the soil moisture in the basin is high. The runoff, the effective yield, will be reduced.

The antecedent soil moisture condition of SCS is divided into the growing season and dormant season in year. Three kinds of conditions are classified as the following.

A.M.C-Ⅰ : Lowest runoff potential
A.M.C-Ⅱ : Average runoff potential
A.M.C-Ⅲ : Highest runoff potential

The three antecedent soil moisture conditions are the criteria for classifying the degree of wetting in the basin by the size of the 5 days antecedent precipitation. AMC group is the following Table 8 according to the size of the 5 days antecedent precipitation.

Table 8. Classification of AMC Group according to 5 days antecedent precipitation.

A.M.C Group	5 days antecedent precipitation, P_5(mm)	
	dormant season	growing season
I	$P_5 < 12.7$	$P_5 < 35.56$
II	$12.7 < P_5 < 28.0$	$35.56 < P_5 < 53.34$
III	$P_5 > 28.0$	$P_5 > 53.34$

The initial condition of the soil is determined by the antecedent precipitation, and the CN value (runoff curve numbers) is estimated by using Table 9 and 10 depended on the land use and cover treatment. The runoff is dependent on the land use and cover treatment. U. S. Soil Conservation Service had a regulation depending on the soil cover treatment and soil type divided by the natural grassland areas and the city.

Table 9. Runoff curve numbers for hydrologic soil-cover complexes

Land use or cover	Treatment or practice	Hydrologic condition	Hydrologic soil group			
			A	B	C	D
Fallow	Straight row	-	77	86	91	94
Row crops	Straight row	Poor	72	81	88	91
	Straight row	Good	67	78	85	89
	Contoured	Poor	70	79	84	88
	Contoured	Good	65	75	82	86
	Contoured and terraced	Poor	66	74	80	82
	Contoured and terraced	Good	62	71	78	81
Small grain	Straight row	Poor	65	76	84	88
		Good	63	75	83	87
	Contoured	Poor	63	74	82	85
		Good	61	73	81	84
	Contoured and terraced	Poor	61	72	79	82
		Good	59	70	78	81
Close-seeded lefumes	Straight row	Poor	66	77	85	89
or rotation meadow	Straight row	Good	58	72	81	85
	Contoured	Poor	64	75	83	85
	Contoured	Good	55	69	78	83
	Contoured and terraced	Poor	63	73	80	83
	Contoured and terraced	Good	51	67	76	80
Pasture or range		Poor	68	79	86	89
		Fair	49	69	79	84
		Good	39	61	74	80
	Contoured	Poor	47	67	81	88
	Contoured	Fair	25	59	75	83
	Contoured	Good	6	35	70	79
Meadow		Good	30	58	71	78
Woods		Poor	45	66	77	83
		Fair	36	60	73	79
		Good	25	55	70	77
Farmsteads		-	59	74	82	86
Roads (dirt)		-	72	82	87	89
(hard surface)		-	74	84	90	92

Table 10. Runoff curve numbers for urban areas

Cover description		Curve numbers for hydrologic soil group			
Cover type and hydrologic condition	Average percent impervious area	A	B	C	D
Fully developed urban areas (vegetation established)					
Open space (lawns, golf courses, cemeteries, etc.)					
Poor condition (grass cover <50%)		68	79	86	89
Fair condition (grass cover 50-75%)		49	69	79	84
Good condition (grass cover >75%)		39	61	74	80
Impervious areas					
Paved parking lots, roofs, driveway, etc.					
(excluding right-of-way)		98	98	98	98
Streets and roads					
Paved; cubs and storm sewers					
(excluding right-of-way)		98	98	98	98
Paved; open dirches (including right-of-way)		83	89	92	93
Gravel (including right-of-way)		76	85	89	91
Dirt (including right-of-way)		72	82	87	89
Western desert urban areas					
Natural desert landscaping (pervious areas only)		63	77	85	88
Artificial desert landscaping (impervious weed barrier, desert shrub sith 1-2 in. sand or gravel mulch and basin borders)		96	96	96	96
Urban districts					
Commercial and business	85	89	92	94	95
Industrial	72	81	88	91	93
Residential districts by average lot size					
1/8 acre or less (town houses)	65	77	85	90	92
1/4 acre	38	61	75	83	87
1/3 acre	30	57	72	81	86
1/2 acre	25	54	70	80	85
1 acre	20	51	68	79	84
2 acres	12	46	65	77	82
Developing urban areas					
Newly graded areas (pervious areas only, no vegetation)					
		77	86	91	94
Idle lands (CNs are determined using cover types similar to those in Table 18)					

Table 10 represents the soil- plants covered runoff curve number (CN) under the conditions of the AMC-Ⅱ. If the antecedent soil moisture condition is A.M.C-Ⅰor A.M.C-Ⅲ, these values become a change in the runoff cover number.

AMC-Ⅰ is less the 5 days antecedent precipitation than the AMC-Ⅲ, so the runoff is smaller because the infiltration rate is high, but A.M.C-Ⅲ is bigger. Therefore, SCS is estimated the CN (Ⅰ) and CN (Ⅲ) using the following equation (40) and (41).

$$CN(\text{I}) = \frac{4.2 * CN(\text{II})}{10 - 0.058CN(\text{II})} \tag{40}$$

$$CN(\text{III}) = \frac{23 * CN(\text{II})}{10 + 0.13CN(\text{II})} \tag{41}$$

Where, CN (Ⅰ), CN (Ⅱ) and CN (Ⅲ) are the runoff curve number under each AMC-Ⅰ, Ⅱ, Ⅲ. Estimated AMC-Ⅰ and AMC-Ⅲ by using the above equation are the following Table 11.

Table 11. Adjustment of runoff curve numbers according to AMC

A.M.C - CN			S (A.M.C-Ⅱ) (mm)	Curve Point (mm)	A.M.C - CN			S (A.M.C-Ⅱ) (mm)	Curve Point (mm)
Ⅱ	Ⅰ	Ⅲ			Ⅱ	Ⅰ	Ⅲ		
100	100	100	0.00	0.0	60	40	78	169	33.8
99	97	100	2.57	0.5	59	39	77	177	35.3
98	94	99	5.18	1.0	58	38	76	184	36.8
97	91	99	7.85	1.5	57	37	75	192	38.4
96	89	99	10.6	2.0	56	36	75	200	39.9
95	87	98	13.4	2.8	55	35	74	208	41.6
94	85	98	16.2	3.3	54	34	73	216	43.2
93	83	98	19.1	3.8	53	33	72	225	45.0
92	81	97	22.1	4.3	52	32	71	234	47.0
91	80	97	25.1	5.1	51	31	70	244	48.8
90	78	96	28.2	5.6	50	31	70	254	50.8
89	76	96	31.5	6.4	49	30	69	264	52.8
88	75	95	34.5	6.9	48	29	68	276	54.9
87	73	95	37.8	7.6	47	28	67	287	57.4
86	72	94	41.4	8.4	46	27	66	297	59.4
85	70	94	44.7	8.9	45	26	65	310	62.0
84	68	93	48.3	9.6	44	25	64	323	64.5
83	67	93	52.1	10.4	43	25	63	335	67.1
82	66	92	55.9	11.2	42	24	62	351	70.1
81	64	92	59.4	11.9	41	23	61	366	73.2
80	63	91	63.5	12.7	40	22	60	381	76.2
79	62	91	67.6	13.5	39	21	59	396	79.2
78	60	90	71.6	14.2	38	21	56	414	82.8
77	59	89	76.0	15.2	37	20	57	432	86.4
76	58	89	80.3	16.0	36	19	56	452	90.4
75	57	88	84.6	17.0	35	18	55	472	94.5
74	55	88	89.2	17.8	34	18	54	493	98.6
73	54	87	94.0	18.8	33	17	53	516	103.0
72	53	86	98.8	19.8	32	16	52	538	108.0
71	52	86	104.0	20.8	31	16	51	564	113.0
70	51	85	109.0	21.8	30	15	50	592	118.0
69	50	84	114.0	22.9	…	…	…	…	…
68	48	84	119.0	23.9	25	12	43	762	152.0
67	47	83	125.0	24.9	20	9	37	1016	203.0
66	46	82	131.0	26.2	15	6	30	1440	288.0
65	45	82	137.0	27.4	10	4	22	2286	457.0
64	44	91	143.0	28.4	5	2	13	4826	965.0
63	43	80	149.0	29.7	0	0	0	∞	∞
62	42	79	156.0	31.2					
61	41	78	162.0	32.5					

3.2. Runoff estimation

The plant cover and land use of the study area are shown Fig. 2 and Table 12. The land use of the study area was divided row crops, small grain, forest business area, office area, manufacturing are, paved load, curved load; storm sewer, paved load; train, dirt load and open area. The soil type through the data analyzed is represented in Table 12.

The row crops, small grain dirt load and open area were included to B soil type that the capacity of runoff is low. Others were D soil type that the capacity of runoff is high. There were no A and C soil type.

Table 12. SCS curve number in the study area (AMC-Ⅱ)

Condition of Vegetation and Land use	Soil type	CN
Row crops	B	75
Small grain	B	72
Forest	D	77
Business and office area	D	95
manufacturing area	D	93
Paved and curved load; storm sewer	D	98
Paved load; drain	D	93
Dirt load	B	82
Open area	B	61

To estimate the runoff, 5 days antecedent soil moisture condition was divided by Ⅱ, Ⅰ, Ⅲ from 1999 to 2007 year. CN(Ⅱ) was 89.98 in 1999.

The same year CN(Ⅰ) and CN(Ⅲ) were 79.04 and 95.38, respectively. Estimated CN(Ⅱ) was applied to Table 13. The results AMC-Ⅱ was 28.29, and then AMC-Ⅰ and AMC-Ⅲ were 67.37 and 12.30, respectively. CN and S estimated using same ways are shown in Table 13.

Table 13. CN and S in the study area

AMC - CN				S (mm)			Curve Point
Year	Ⅱ	Ⅰ	Ⅲ	AMC-Ⅱ	AMC-Ⅰ	AMC-Ⅲ	(mm)
1999	89.98	79.04	95.38	28.29	67.37	12.30	12.7
2000	90.03	79.14	95.41	28.11	66.94	12.22	12.7
2001	90.05	79.18	95.42	28.06	66.80	12.20	12.7
2002	90.06	79.19	95.42	28.04	66.76	12.19	12.7
2003	90.06	79.20	95.42	28.02	66.72	12.18	12.7
2004	90.08	79.22	95.43	27.98	66.63	12.17	12.7
2005	90.09	79.24	95.44	27.94	66.53	12.15	12.7
2006	90.10	79.27	95.44	27.90	66.43	12.13	12.7
2007	90.13	79.33	95.46	27.80	66.19	12.09	12.7

The runoff estimated by using CN and S values is arranged to Table 14. The mean precipitation and runoff were 1,645.02 mm and 843.75 mm, and the runoff was 49.80 % of the precipitation. In 1999, the precipitation was the highest (2,396.70 mm). The runoff was also the highest (1,381.97 mm) in 1999. On the other hand, the precipitation was the lowest (1,171.30 mm) in 2001, like the preceding, the runoff was the lowest (561.93 mm) in the 2001. The linear function for the runoff and the precipitation was $RO = 0.75 \times P - 342.57$ and coefficient of determination was 0.98, very high. Therefore, the runoff was mainly influenced by the precipitation in the study area. The building and road that are the impermeable layer were more than 65 % in the study are, and then slope also developed in the study are. So, the precipitation was not infiltrated under the surface, on the other hand, most of precipitation was discharged.

Table 14. Precipitation and runoff in the study area

	Precipitation		Runoff	
Year	mm	%	mm	%
1999	2,396.70	100	1,381.97	57.66
2000	1,248.50	100	569.20	45.59
2001	1,171.30	100	561.93	47.98
2002	2,085.20	100	1,174.12	56.31
2003	2,328.30	100	1,325.26	56.92
2004	1,386.50	100	585.83	42.25
2005	1,383.90	100	638.71	46.15
2006	1,528.30	100	846.69	55.40
2007	1,276.50	100	510.01	39.95
Avg.	1,645.02	100	843.75	49.80

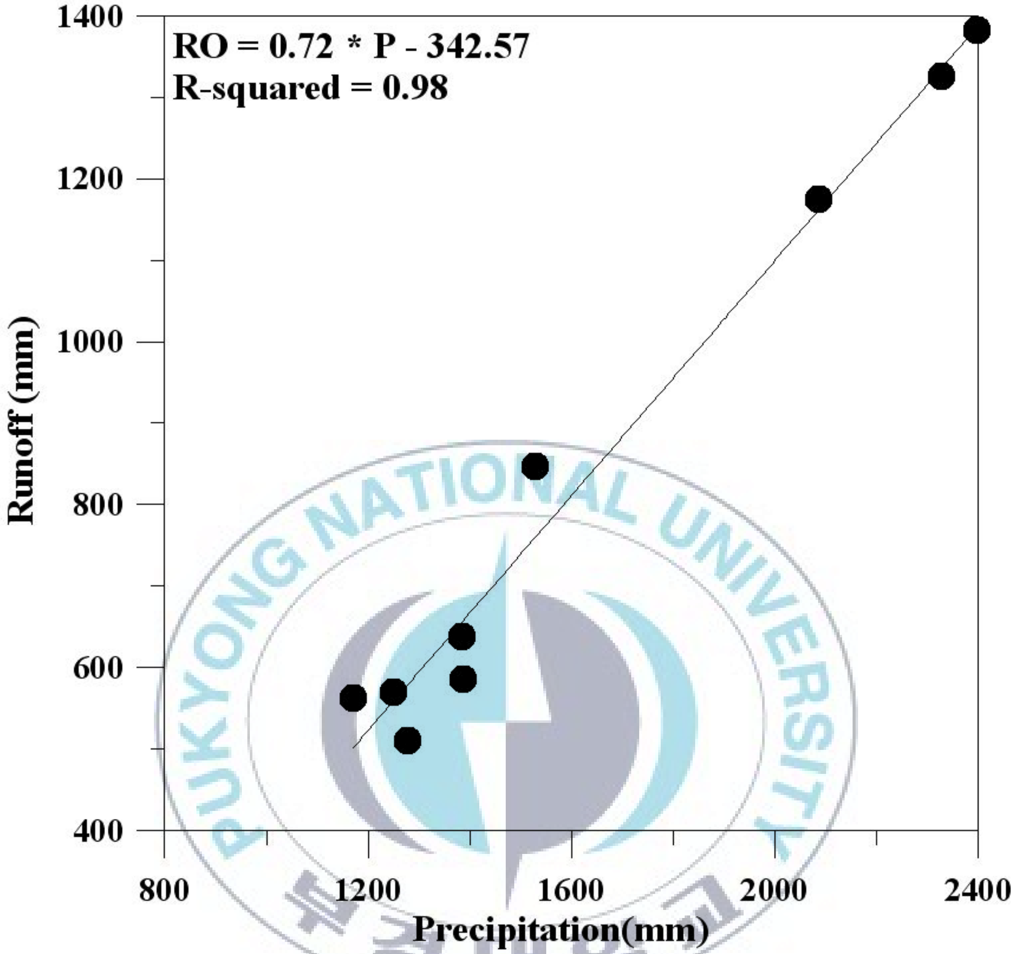

Fig. 17. The linear regression functions for runoff and precipitation.

4. Coastal flow

Coastal flow (CF) is the sustainable development development and management skill to evaluate the sustainable development yield in the coastal area. It is still developing in U.S.A and Europe and preliminary research. The estimation of the sustainable development yield should be preceded to applied to the optimal development and management skill. The researches about the estimation of the sustainable development yield are progressing, but researches considering the character of the coastal area are not progressing in Korea.

4.1. Basic concept of coastal flow estimation

4.1.1. Method using Darcy law

The flow rate using Darcy's law can be estimated by the multiplication of the hydraulic conductivity (K), hydraulic gradient (i=dh/dx) and cross-sectional area (A).

4.1.2. Direct measurement

Direct measurement uses the infiltration system. The infiltration system is a simple mechanism to measure the amount of groundwater through the seabed. A plastic bag is installed at the top of a drum. The bottom of the drum is cut and opened. The bottom of the drum is to be buried to the seabed. Inflow of groundwater in the drum is estimated that is the coastal flow.

4.1.3. Tracer method

Tracer method uses the natural or artificial soluble moving to groundwater.

4.1.4. Acoustic Scintillation Thermography (AST)

It is a method using sound waves occurring when heat fluid is erupted. The eruption of the heat fluid is the similar to the coastal flow of the groundwater because density is different to seawater. AST method is to detect the wave refraction occurring when water having different water around water mixes with surrounding water. In case wave refraction occurs, AST method can be used to the coastal flow.

4.2. Field survey and coastal flow estimation

The coastal flow in this study paper was estimated using the Darcy's law. In the Agency (Sustainable Water Resources Research Center, 2009) calculated the data necessary for calculating the standard materials were used (Table 15). The hydraulic conductivity was $4.50 \times e^{-07}$ m/sec, and then the depth due to the weathering and alluvial aquifer was applied to 9 m. Coastline of the study area was 4,850 m from Suyeong 1 bridge to the west end of Gwanganri beach. The hydraulic gradient of the study area was calculated considering Mt. Kumryun (425 m) and Mt. Baen (255 m) and Gwangalli. Based on upper data, the coastal flow was approximately 29,001 m^3/yr. There was not a significant impact to estimate the groundwater recharge.

Table 15. The standard data for estimation of the coastal flow

Location	Hydraulic conductivity	Depth	Porosity	Coastline	hydraulic gradient	Coastal flow	
	(m/sec)	(m)	-	(m)	-	(m^3/yr)	(mm/yr)
Suyeong-gu	4.50E-07	9.0	0.306	4,850	0.153	29,001	2.85

A field study was conducted at Gwanganri beach to confirm the coastal flow outflowing at higher alluvial aquifer than sea level. There was no the coastal flow by results of the field study (Fig. 18).

Fig. 18. The field study for the coastal flow.

5. Baseflow

Baseflow (BF) is a component of the runoff. Baseflow in local groundwater flow system is the same as the groundwater runoff. Infiltrated precipitation from a recharge area to deep underground becomes a part of the regional groundwater flow system, so it not becomes baseflow. From local groundwater flow system, the source of baseflow is water from surface, so baseflow defines groundwater recharge by precipitation.

River runoff is a function of time. Hourly river discharge curve is called river hydrograph recession curves. River hydrograph recession curves of the dry season are depletion curve. At that time, runoff consists of local groundwater discharge in the near river (Hahn and Hahn, 1999).

5.1. Basic concept

If groundwater from an underground reservoir discharges to near the river, groundwater is dropped. Therefore, if there is no precipitation, groundwater to near the river is reduced. If discharge of groundwater from a aquifer that is a reservoir is stopped, the river will be dry river when the baseflow is 0. Baseflow recession curve is a function of morphology of the terrain, basin shape, soil geology and vegetation.

River runoff in the dry season has a direct correlation with water level of near groundwater system. It calls 3 boundary conditions in

Hydraulics. The amount of drainage (baseflow) is getting decreased in a bucket if water level gradually falls in case of draining the water from a hole of the bucket. That is, the amount of drainage (baseflow) is not increased unless water poured out again or water level rises in the bucket (water level rise).

$$Q = Q_o e^{-at} \qquad (42)$$

,where Q : Baseflow after T from starting recession phenomenon

Q_o : Initial baseflow when recession phenomenon

t : Elapsed time after recession phenomenon

a : Coefficient of flood recession of basin

5.2. Baseflow estimation

Discharge in the study area has not been measured to estimate baseflow until now. Therefore, baseflow was estimated by applying the method of the coastal flow estimation (Table 16). The baseflow was just occurred in the southeastern region of the study area (Fig. 19, 20, 21). The groundwater level of the study area is higher than Suyeong River in the dry and wet season, so the baseflow is always occurred. The depth of the aquifer was applied to mean Suyeong River level, hydraulic gradient was estimated considering the height of the terrain. The estimated baseflow was 284.28 m^3/yr, 10.56 % of the coastal flow. The Baseflow was just compared with the precipitation. Therefore, the baseflow was not a significant impact to estimate the groundwater recharge like the coastal flow.

Table 16. The standard data for estimation of the baseflow

Location	Hydraulic conductvity	Depth	Porosity	Lenth of shoreline	hydraulic gradient	Baseflow	
	(m/sec)	(m)	-	(m)	-	(m^3/yr)	(mm/yr)
Suyeong-River	4.50E-03	1.58	0.306	3,390	0.132	3,070	0.3

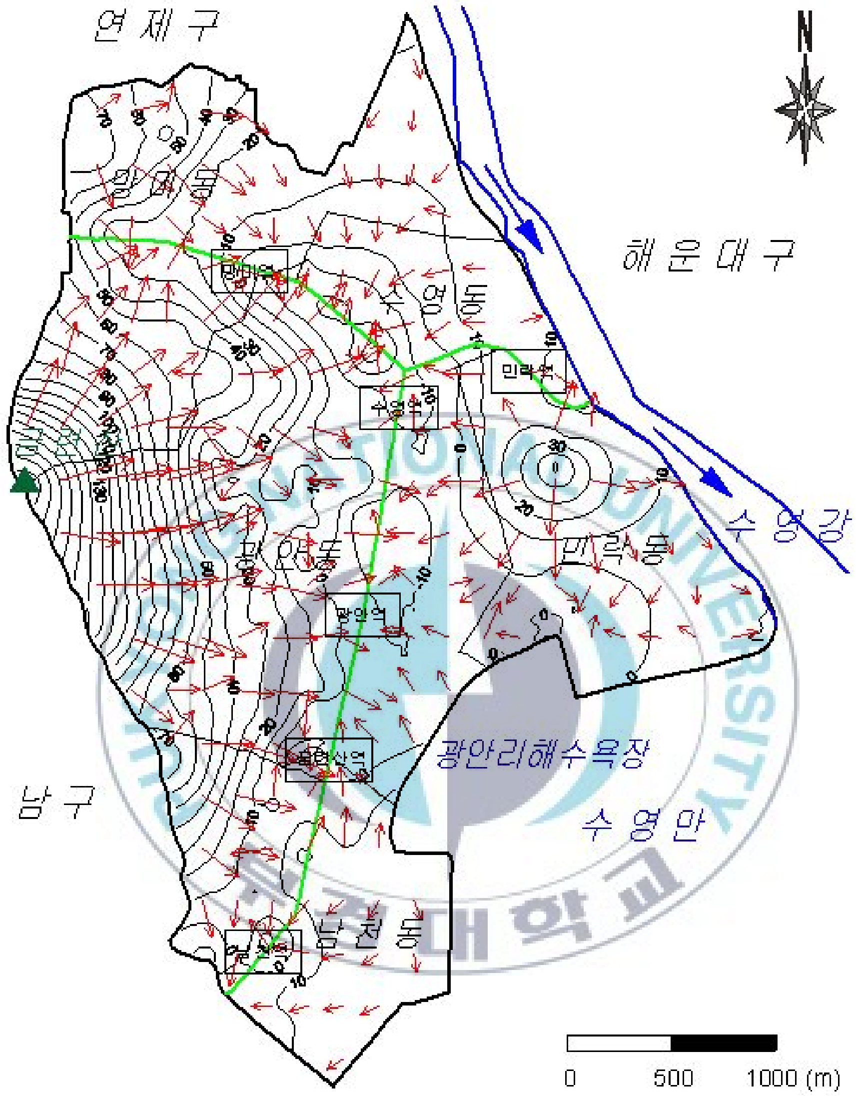

Fig. 19. The groundwater level in the study area at the dry season in 2007.

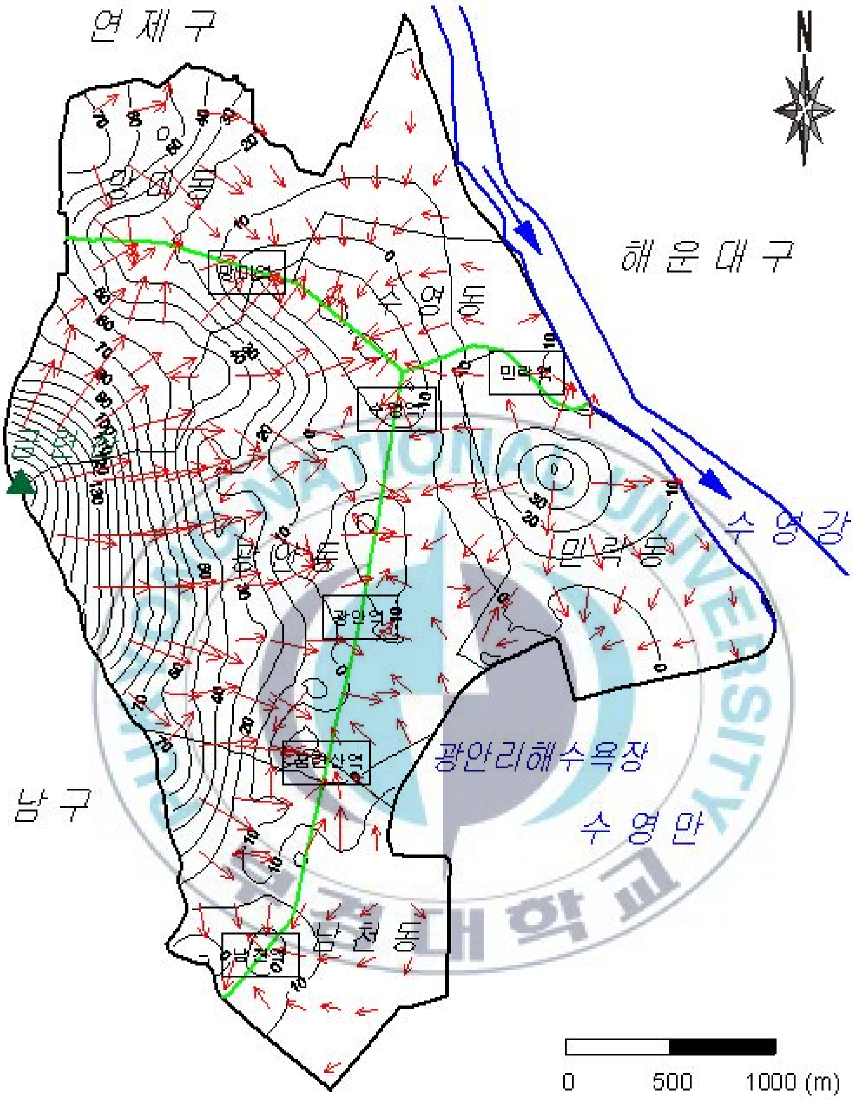

Fig. 20. The groundwater level of the study area at the wet season in 2008.

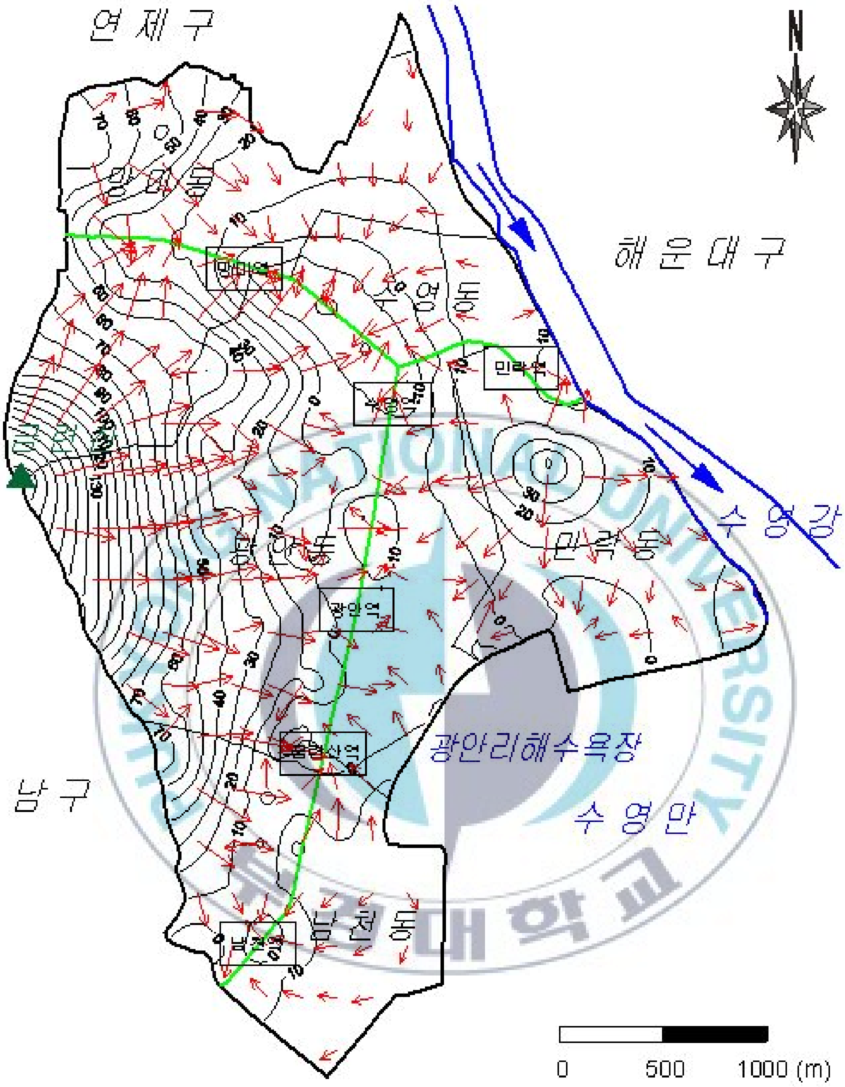

Fig. 21. The groundwater level of the study area at the wet season in 2009.

6. Groundwater recharge

Groundwater recharge typically can express as sustainable development yield.

$$GR = P - AET - RO - BF \tag{43}$$

The precipitation, AET, runoff, runoff, coastal · baseflow and groundwater recharge are shown in Table 17. During that period, the highest groundwater recharge was 640.38 mm/yr in 2003, and 27.5 % of the precipitation in 2003. The lowest groundwater recharge was 78.99 mm/yr in 2001, and 6.74 % of the precipitation in 2001. The mean groundwater recharge was 19.58 % comparing the precipitation in the study area. The linear regression function for groundwater recharge and precipitation was $GR = 0.36 \times P - 263.56$, and the coefficient of determination was 0.878 (Fig. 23). Therefore, more the precipitation is more the groundwater recharge.

Table 17. Estimation of groundwater recharge with precipitation, AET and runoff

	Precipitation		AET		Runoff		Coastal · Baseflow		Groundwater Recharge	
Year	mm	%	mm	%	mm	%	mm	%	mm	%
1999	2,396.70	100	489.45	20.42	1,381.97	57.66	3.15	0.13	593.47	24.76
2000	1,248.50	100	460.00	36.84	569.20	45.59	3.15	0.25	205.74	16.48
2001	1,171.30	100	523.43	44.69	561.93	47.98	3.15	0.27	78.99	6.74
2002	2,085.20	100	554.14	26.57	1,174.12	56.31	3.15	0.15	401.9	19.27
2003	2,328.30	100	427.91	18.38	1,325.26	56.92	3.15	0.14	640.38	27.5
2004	1,386.50	100	497.42	35.88	585.83	42.25	3.15	0.23	316.28	22.81
2005	1,383.90	100	467.21	33.76	638.71	46.15	3.15	0.23	290.92	21.02
2006	1,528.30	100	473.21	30.96	846.69	55.40	3.15	0.21	208.5	13.64
2007	1,276.50	100	480.52	37.64	510.01	39.95	3.15	0.25	281.98	22.09
Avg.	1,645.02	100	485.92	31.68	843.75	49.80	3.15	0.21	335.35	19.37

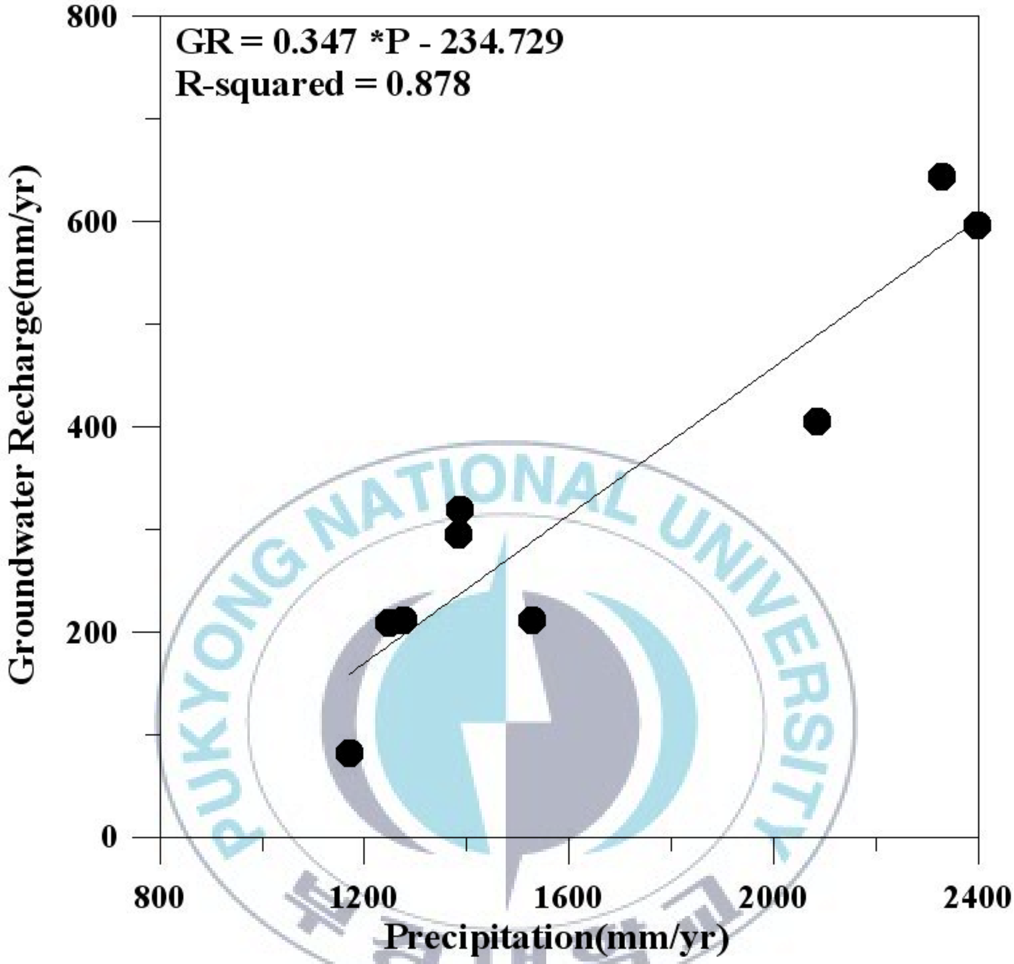

Fig. 22. The linear regression functions for GR and P.

6.1. Estimation of groundwater recharge using different method methods

6.1.1. Utilization of national water resources statistic data

Water resources was 12.76 billion ㎥/yr, and runoff was 7.31 billon, loss was 5.45 billon ㎥/yr by Groundwater Management Plan Report (MCT and Kwater, 2002). Evapotranspiration was 376.6 ㎥/yr that was 29.9 % of loss, groundwater recharge was 1.684 billon (Fig. 23).

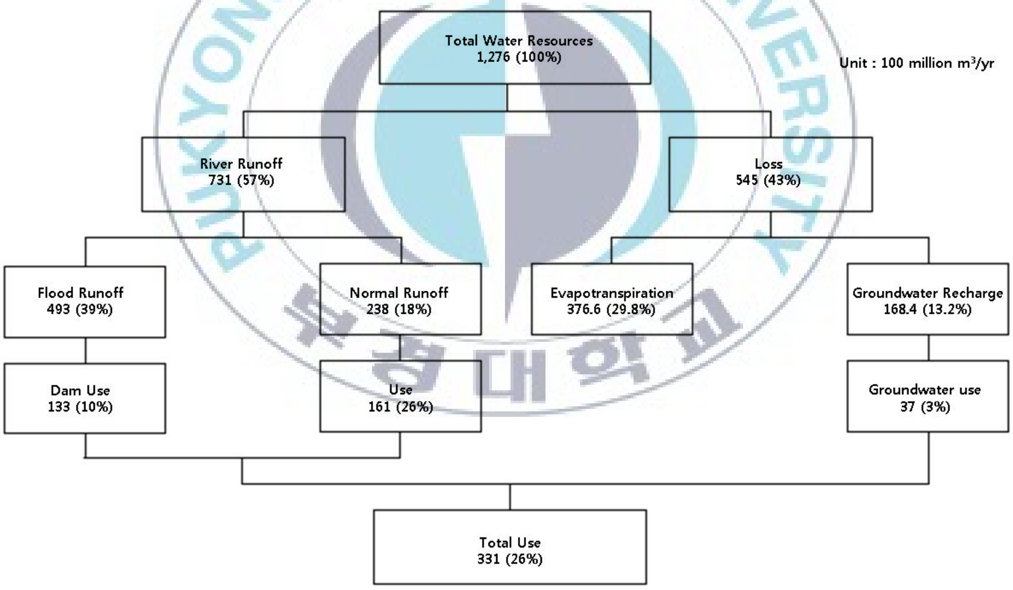

Fig. 23. Water resources in Korea.

The mean groundwater recharge in Korea was 13.2 % by Groundwater Management Plan Report (MCT and Kwater, 2002). It was used to estimate the groundwater recharge in study area. The groundwater recharge estimated by National water resource statistic data utilization was 217.14 which is smaller 118.21 mm/yr than the groundwater recharge estimated by the water balance. This was caused by differences in precipitation. It will vary depending on regional characteristics.

Groundwater recharge estimation by national water resource statistic data utilization (mm/yr)

= Annual mean precipitation (mm/yr) × 0.132

= 1,645.02 mm/yr × 0.132

= 217.14 mm/yr

6.1.2. Utilization of loss quantity

Water balance method uses under the assumption a equilibrium between outflow (and inflow) and storage, and then the groundwater recharge is estimated like the following.

$$GR = D - E \tag{44}$$

Where D is loss over a period in the region, E is evapotranspiration.

Loss is defined a value that precipitation minus runoff in the study area. If infiltrated water or outflow from a path of underground to surface is ignored, loss is the same with evapotranspiration. If it cannot ignore, however, actual evapotranspiration and loss are not same. The difference becomes groundwater recharge.

Turc and Coutange proposed the following empirical equation for the loss estimation in the 254 watershed of the world (Turc, 1963).

$$D = P - \lambda P^2, \qquad \lambda = \frac{1}{0.8 + 0.14T} \quad (Coutagne) \tag{45}$$

$$D = \frac{P}{\sqrt{0.9 + P^2/L^2}}, \qquad L = 300 + 25T + 0.05T^3 \quad (Turc) \tag{46}$$

,where P : Precipitation

λ and L : Function of temperature

D : Loss

The groundwater recharge was estimated by using the mean precipitation (1,645.02 mm/yr) and mean temperature (14.8 ℃) during 9 years (1999 to 2007). The results by applying Coutange and Turc empirical equation are the following. Losses using Coutange and Turc empirical equation were mean 627.95 mm/yr and 534.11 mm/yr, and 38.17% and 32.47 % compared to the precipitation, respectively. Therefore, the groundwater recharge using Coutagne and Turc loss 32.29 % (531.15 mm/yr) and 37.99 % (624.99 mm/yr) of the precipitation. Each method was higher 195.8 mm/yr and 289.64 mm/yr than 335.35 mm/yr by the water balance.

Table 18. Loss Estimation by using Turc empirical formulae Turc

Year	P (mm)	T (℃)	Coutange (mm)	Turc (mm)
1999	2,396.70	15.0	415.95	1245.00
2000	1,248.50	14.9	708.39	181.86
2001	1,171.30	15.3	704.97	42.76
2002	2,085.20	14.7	563.84	882.92
2003	2,328.30	14.3	393.62	1,256.09
2004	1,386.50	14.9	720.39	269.87
2005	1,383.90	13.8	682.88	319.52
2006	1,528.30	14.7	711.05	429.94
2007	1,276.50	15.3	722.64	179.04
Avg.	1,645.02	14.8	627.95	534.11

6.1.3. Utilization of long-term groundwater level data

This method is to estimate the groundwater recharge using long-term groundwater level data utilization. If Precipitation infiltrated into the top of the aquifer is ignored transpiration by plants and discharge by slope gradient at the downstream part, groundwater recharge can be estimated using specific yield of a top of aquifer multiplying the difference between the highest groundwater level during 1 year and the lowest groundwater level during dry season (Korea Resources Corporation, 1998).

$$I = \triangle H \cdot S_y \qquad (47)$$

,where I : Groundwater recharge by precipitation (LT^{-1})

ΔH : Annual variation of groundwater level (L)

S_y : Specific yield of a top of aquifer

The upper equation is considering water level variation of a aquifer that there is no inflow or outflow in the horizontal direction, on the other hand, there is just inflow in the vertical direction.

But in general, groundwater occurs the horizontal flow, groundwater level widths estimated by the fluctuation curve of groundwater level does not only represent the groundwater recharge. It comprehensively represents fluctuation of the groundwater stored in the aquifer. The fluctuation of groundwater resources is composed of groundwater recharge and discharge in case of ignoring artificial factors and plant's use. Therefore, if groundwater level is higher than any standard groundwater level, there is groundwater recharge, the opposite is discharge.

The fluctuation of annual groundwater resources, recharge and discharge can be expressed as follows based on the standard groundwater level using the long-term groundwater level data.

$$q_{ct} = q_{\in} + q_{out} = (H_{\max} - H_{\min}) \cdot S_y \tag{48}$$

$$q_{\in} = (H_{\max} - H_{avg}) \cdot S_y \tag{49}$$

$$q_{out} = (H_{avg} - H_{\min}) \cdot S_y \tag{50}$$

,where q_{ct} : Fluctuation of annual groundwater resources

q_{in} : Annual groundwater recharge

q_{out} : Annual groundwater discharge

$H_{\max}$: Annual maximum groundwater

H_{avg} : Annual average groundwater

$H_{\min}$: Annual minimum groundwater

The groundwater recharge using long-term groundwater level data was estimated at 30 m and 60 m during 1 year - 1 January to 31 December, 2009. The estimated maximum groundwater level was 6.38 m, minimum groundwater level was 2.27 m, mean groundwater level was 4.18 m. Specific yield estimated by Tae Young Kim (2009) was applying.

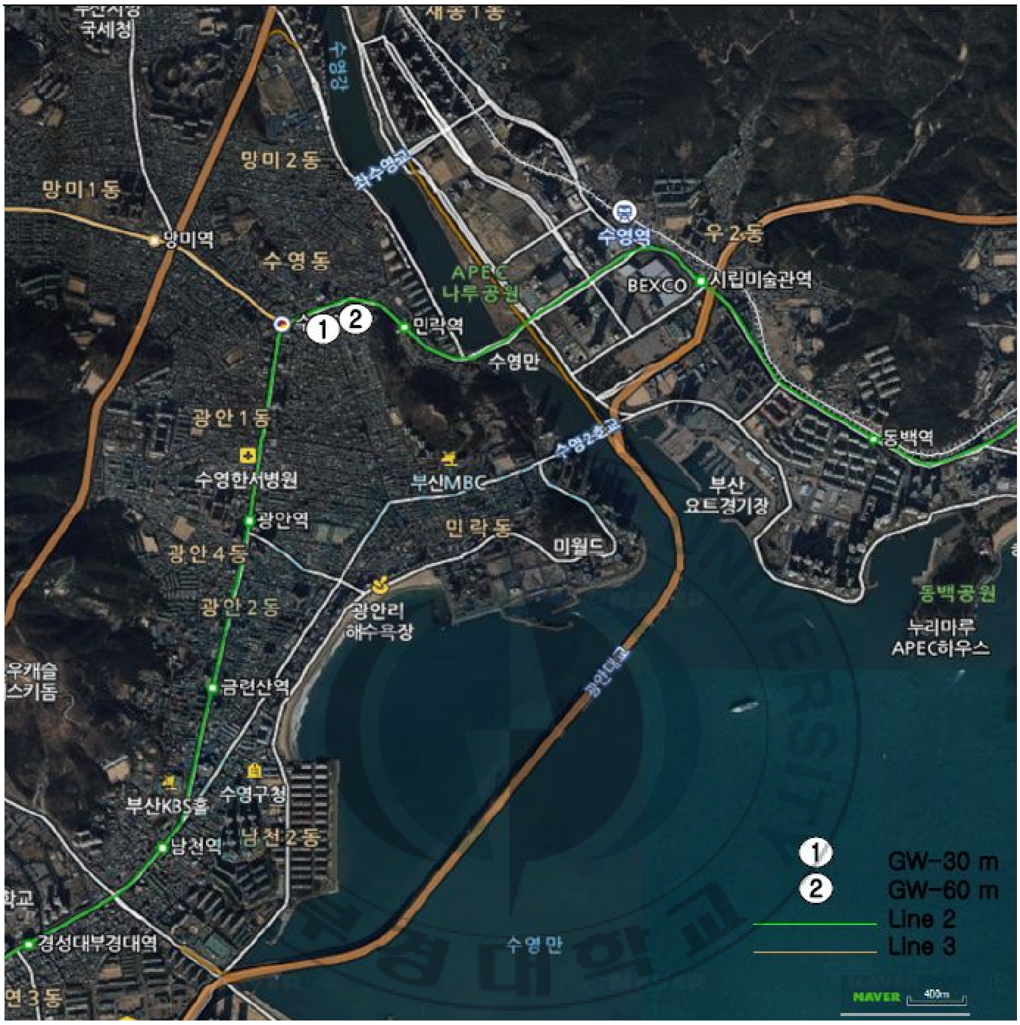

Fig. 24. The subway location of the study area.

Table 19. Groundwater data and specific yield in the study area

Year	Maximum value	Minimum value	Average	Maximum value − Average	Specific yield
2009	6.38 m	2.2744 m	4.18 m	2.20 m	0.05

Annual groundwater recharge was estimated using equation (51). The estimated groundwater recharge was 110 mm/yr, 32.5 % of the groundwater recharge estimated by the water balance.

$$I = \Delta H \cdot S_y \qquad (51)$$

= (Maximum value - Average) × specific yield

= (6.38 m - 2.27 m) × 0.05

= 110 mm/yr

Table 20 has shown the estimation of groundwater recharge using a variety of methods. The loss method of groundwater recharge was higher value than the others; on the other hand, the method using long-term groundwater level data was the lowest value. The groundwate recharges have differences depending on each method. Therefore, this paper was used the water balance method to estimate the groundwater recharge.

Table 20. Comparison of each groundwater recharge estimation method

Groundwater recharge estimation method		mm/yr	GR/P (%)
Water balance		335.35	19.37
National water resource statistic data		217.14	13.2
Loss	Coutange Empirical formulae	627.95	37.99
	Turc Empirical formulae	534.11	32.29
Long-term groundwater level data		110	6.69
Avg.		364.91	21.91

7. Inflow and outflow rates of groundwater from the outside basin

Inflow and outflow rate of groundwater from the outside basin is usually not applied to estimate the groundwater recharge. Natural environment is rapidly changing by anthropogenic activities in the modern. Groundwater usage, leakage of water supply · sewage, groundwater discahrge from subway and electronic cable tunnel were considered to estimate groundwater recharge.

7.1. Groundwater use

Table 21 is shown the groundwater used in the study area (MLTM and Kwater, 2008a). The groundwater use was divided into livelihood, industry, agriculture and others. There were 409 sites (1,505,741 m^3/yr) using groundwater, livelihood sites were 339 (1,179,700 m^3/yr), industry sites were 19 (56,659 m^3/yr), agriculture sites were 9 (36,720 m^3/yr), others were 42 (232,663 m^3/yr).

Table 21. Groundwater use data in study area [m^3/yr]

Year	Total		Livelihood		Industry		Agriculture		Others	
	Site	Utilization	Site	Utilization	Site	Utilization	Site	Utilization	Site	Utilization
1999	390	1,666,058	254	863,817	24	24,933	7	11,296	105	766,013
2000	391	1,608,403	256	815,981	22	20,048	7	11,296	106	761,079
2001	517	1,264,573	363	793,694	38	21,511	10	17,275	106	432,093
2002	469	1,736,870	422	1,533,720	22	142,010	5	12,260	20	48,880
2003	388	1,516,016	357	1,408,328	15	66,784	12	33,988	4	6,916
2004	395	1,496,739	365	1,353,829	15	66,784	11	69,210	4	6,916
2005	390	1,487,487	361	1,348,200	14	63,161	11	69,210	4	6,916
2006	385	1,455,863	348	1,304,767	12	54,162	11	59,360	14	37,575
2007	360	1,319,659	327	1,194,960	11	50,538	10	46,585	12	27,576
avg.	409	1,505,741	339	1,179,700	19	56,659	9	36,720	42	232,663

7.2. Leakage of water supply · sewage

Water supply leakage was estimated using data of Busan Water Authority (2007) and Ministry of Environment (2007a). Sewer leakage was estimated using data of Busan Sewerage master plan changes and Ministry of Environment (2007b). Population of the study area was 179,100. The water supply leakage was 6514.9 m^3/day (2,377,939 m^3/yr), and sewer leakage was 4,688.82 m^3/day (1,711,419 m^3/yr) (Table 22).

Table 22. Water supply · sewage leakage data

Water supply		Sewer	
m^3/day	m^3/yr	m^3/day	m^3/yr
6,514.9	2,377,939	4,688.82	1,711,419

7.3. Groundwater discharge from subway and electronic cable tunnel

There were 6 stations in the Line 2 and 2 stations in the Line 3 (Fig. 24). Grounwater was inflowing into the subway stations, and then that groundwater is discharging to the Suyeong River. The most discharged station in the study area was Millak (201,115 m^3/yr) in the Line 2, and Mangmi2 (302,950 m^3/yr) in the Line 3 (MLTM and Kwater, 2008b). The total groundwater discharge from the subway was 750,805 m^3/yr (Table 23), electronic cable tunnel was estimated using a flow meter from 2005 to 2007. Groundwater discharge from electronic cable tunnel was 547,500 m^3/yr during 3 year (Table 24).

Table 23. Groundwater discharge from subway

	Subway name	Groundwater outfow in subway	
		m^3/day	m^3/yr
2 Line	Namcheon	0	0
	Geumnyeonsan	281	102,565
	Gwangan A	148	54,020
	Gwangan B	27	9,855
	Suyeong	50	18,250
	Millak	551	201,115
3 Line	Mangmi1	170	62,050
	Mangmi2	830	302,950
Total		2,057	750,805

Table 24. Groundwater discharge from electronic cable tunnel

Groundwater discharge from electronic cable tunnel	
m^3/day	m^3/yr
1,500	547,500

8. Sustainable development yield

The sustainable development yield was estimated considering natural factors (evapotranspiration, baseflow, coastal flow) and artificial factors (runoff, groundwater use, leakage of water supply · sewage, groundwater discharge from subway and electronic cable tunnel). The water supply · sewer leakage was increasing the sustainable development yield, on the other hand, the others were contrary to the water supply · sewer leakage.

The sustainable development yield was mean 889,925 m^3/yr during the study period. The most sustainable development yield was 1,921,582 m^3/yr in 2003, while the least sustainable development yield was 212,595 m^3/yr in 2001 (Table 25). The groundwater recharge, groundwater use, leakage of water supply · sewer and groundwater discharge from subway and electronic cable tunnel were 387.17, 169.20, 74.90, 84.37 % of the sustainable development yield, respectively. Therefore, the sustainable development yield was mainly affected by the groundwater recharge and groundwater use.

The linear regression function for the sustainable development yield and the groundwater recharge was $SDY = 0.998 \times GR - 59232.10$, the coefficient of determination was 0.81, high. The groundwater recharge, leakage of water supply · sewer and groundwater discharge from subway and electronic cable tunnelhad a nearly constant value, so the sustainable development yield was changed by the groundwater recharge (Fig. 25).

The linear regression function for the groundwater use and the groundwater recharge was $GU = 1.953 \times GR - 1989117.415$, the coefficient of determination was 0.34 (Fig. 26). The linear regression function for the sustainable development yield and the groundwater use was $SDY = 0.118 \times GU + 1400909.654$, the coefficient of determination was 0.201

(Fig. 27).

To analyze influence of the sustainable development yield by the precipitation, evapotranspiration and runoff, there were conducted linear recession function analysis for the sustainable development yield and each factor.

The linear regression functions for the sustainable development yield and the precipitation was $SDY = 0.351 \times P - 264.592$, the coefficient of determination was 0.709, high (Fig. 28). The linear regression function for the sustainable development yield and the evapotranspiration was $SDY = -1.430 \times AET + 864.950$, the coefficient of determination was 0.034, high (Fig. 29). The linear regression functions for the sustainable development yield and the runoff was $SDY = 0.452 \times RO - 67.408$, the coefficient of determination was 0.622, high (Fig. 30). Therefore, influence for the sustainable development yield came next with the precipitation (0.709), runoff (0.622) and evapotranspiration (0.034).

After all, influence of the natural factor in the sustainable development yield estimation was the precipitation, and artificial factor was the runoff.

Table 25. Optimal yield data in study area

Year	Area	Used area	Groundwater recharge (A)	Groundwater use (B)	Water supply and sewer (D)	Subway (E)	Electronic cable tunnel (F)	Sustainable development yield (A-B-C+D-E-F)
	km^2	km^2	m^3	m^3	m^3	m^3	m^3	m^3
1999	10.159	2.874	6,061,512	1,666,058	666,519	750,805		1,666,825
2000	10.160	2.842	2,122,538	1,608,403	666,519	750,805		603,453
2001	10.158	2.832	834,425	1,264,573	666,519	750,805		586,278
2002	10.158	2.830	4,114,841	1,736,870	666,519	750,805		1,027,744
2003	10.158	2.827	6,537,439	1,516,016	666,519	750,805		1,921,582
2004	10.212	2.838	3,262,186	1,496,739	666,519	750,805		1,028,017
2005	10.211	2.831	3,003,023	1,487,487	666,519	750,805	109,500	415,966
2006	10.210	2.824	2,160,951	1,455,863	666,519	750,805	547,500	212,595
2007	10.214	2.790	2,912,454	1,319,659	666,519	750,805	547,500	546,868
Ave.	10.182	2.832	3,445,486	1,505,741	666,519	750,805		889,925
	/SDO (%)		387.17	169.20	74.90	84.37		

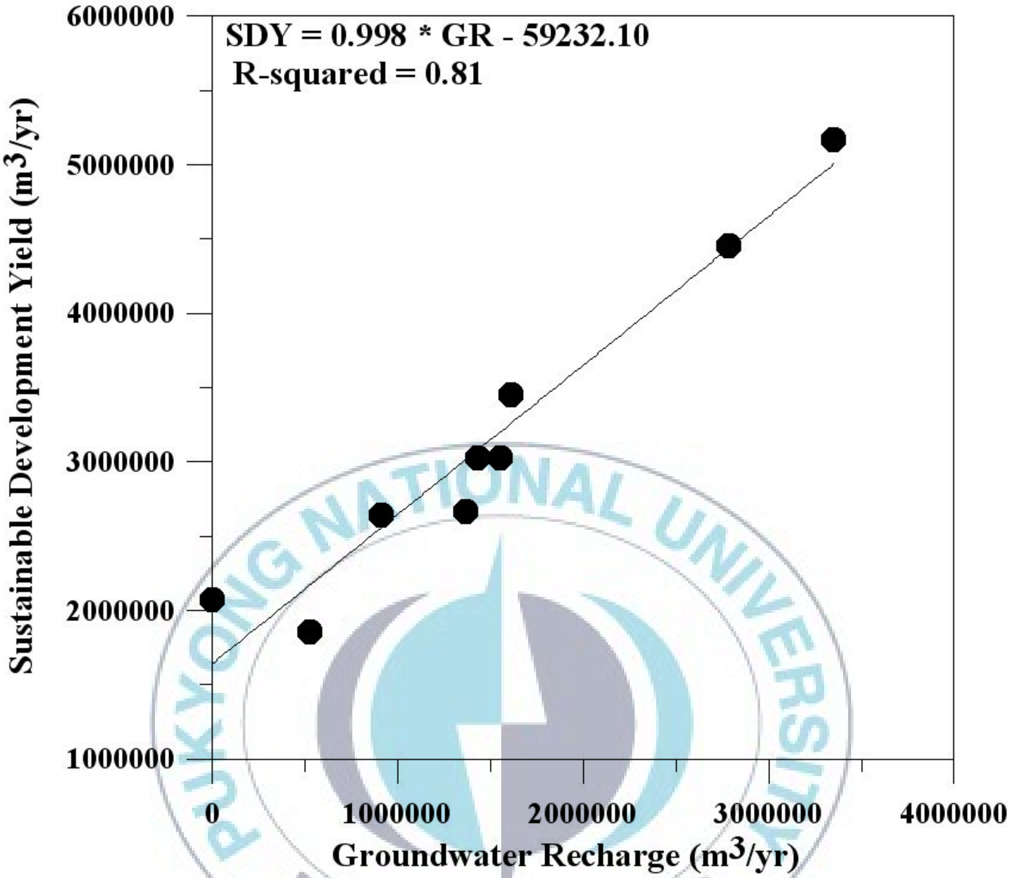

Fig. 25. The linear regression functions for sustainable development yield and groundwater recharge.

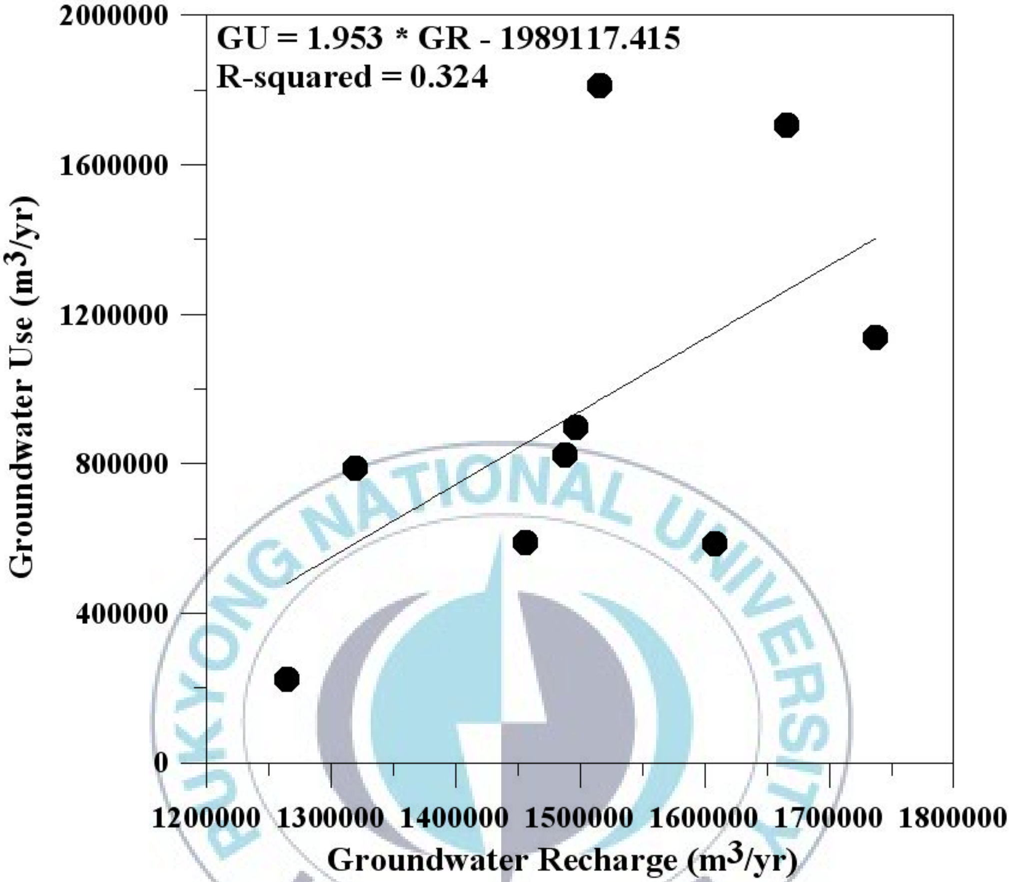

Fig. 26. The linear regression functions for groundwater use and groundwater recharge.

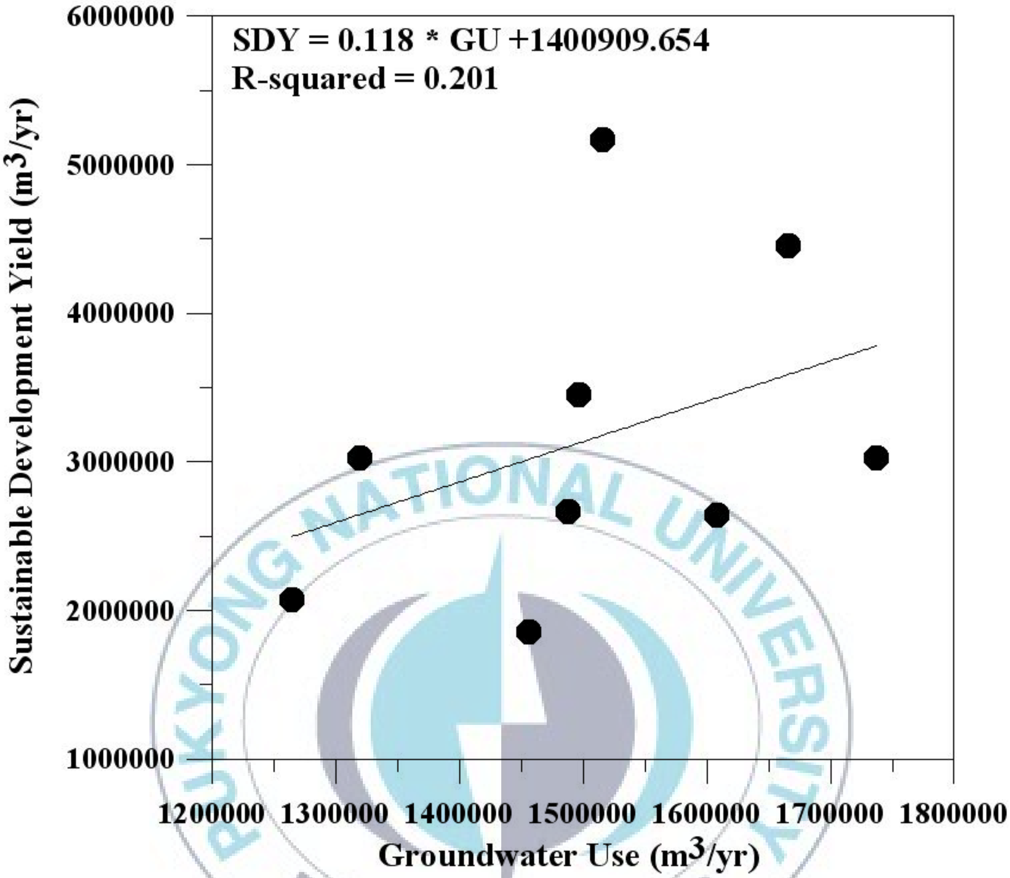

Fig. 27. The linear regression functions for sustainable development yield and groundwater use.

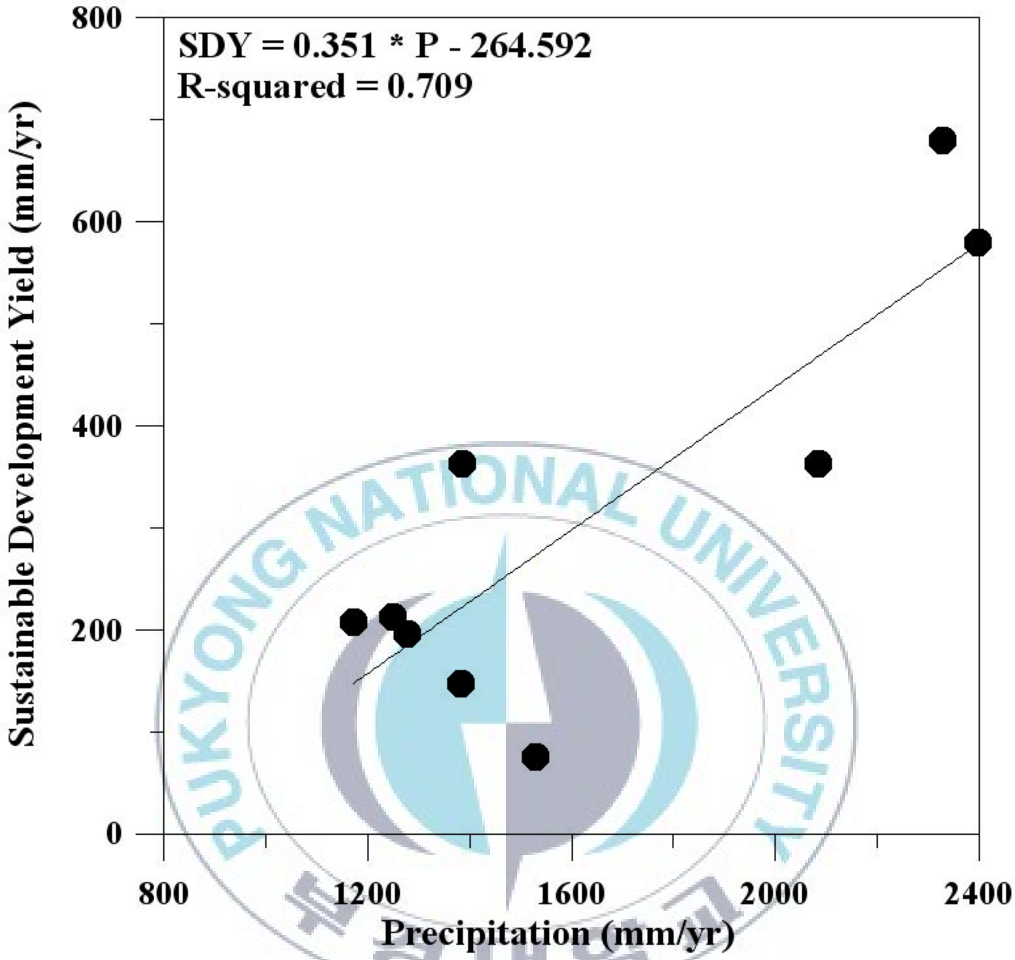

Fig. 28. The linear regression functions for sustainable development yield and precipitation.

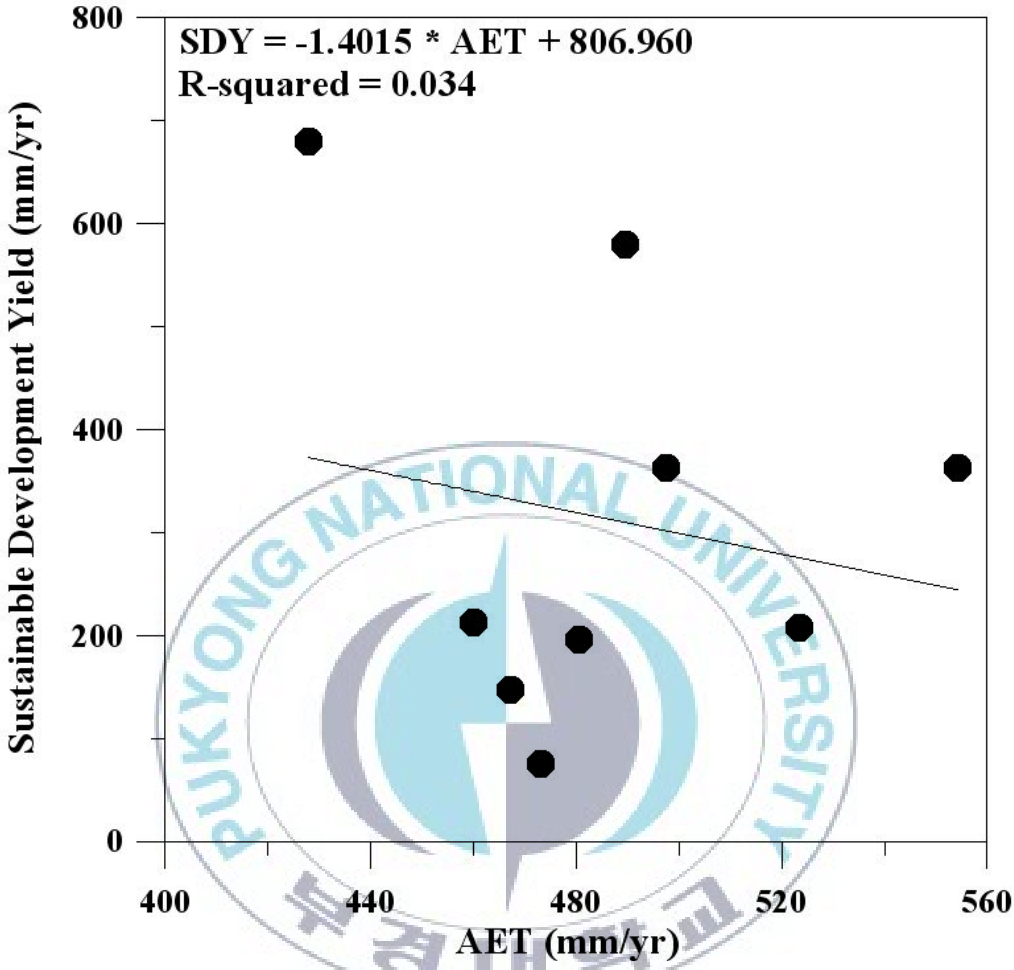

Fig. 29. The linear regression functions for sustainable development yield and runoff.

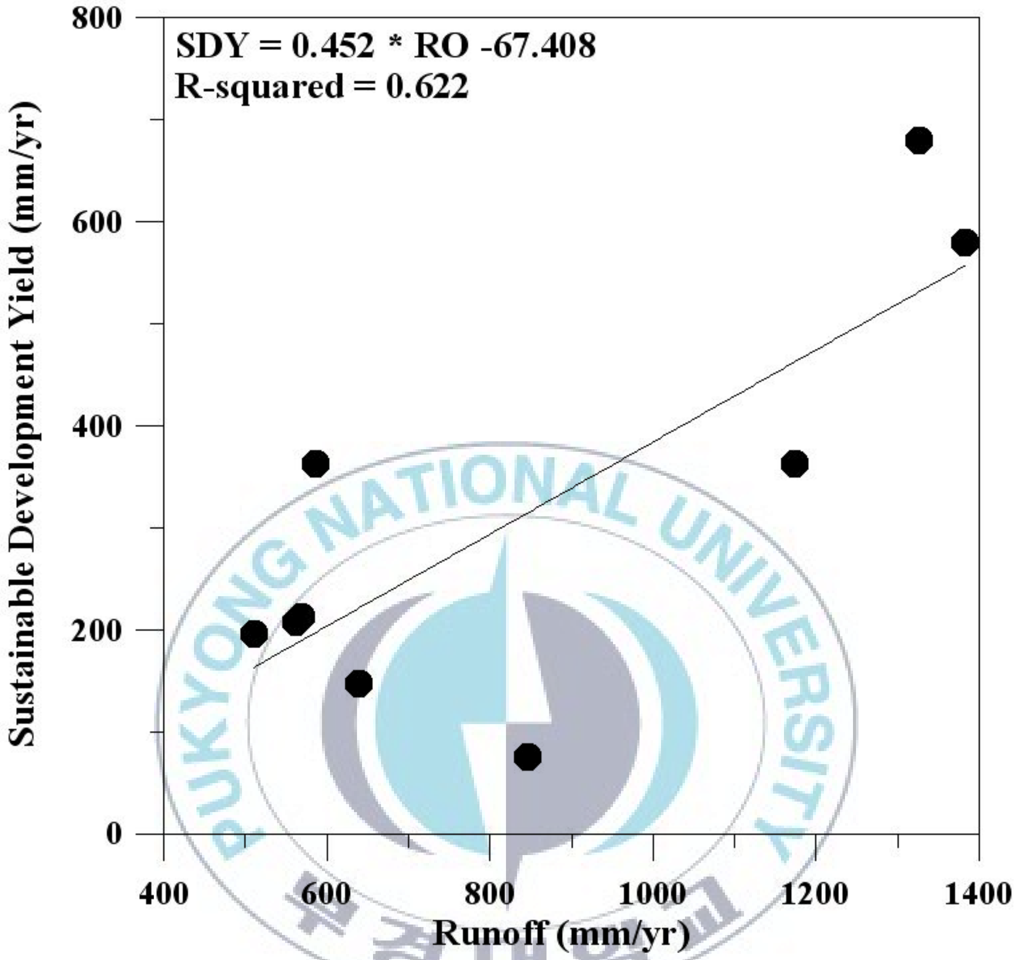

Fig. 30. The linear regression functions for sustainable development yield and runoff.

Ⅳ. Conclusions

The change of actual evapotranspiration according to land use was analyzed using meteorological data from 1999 to 2007 and compared by several estimation methods at a coastal area of the Suyeong-gu, the Busan city. Furthermore, its influence was clarified through regression analysis and correlation among meteorological factors. Runoff, coastal flow, baseflow, groundwater use, leakage of water supply · sewage, groundwater discharge from subway and electronic cable tunnel were considered to estimate sustainable development yield. Therefore, natural and artificial factors that were considered to estimate sustainable development yield were analyzed.

1. The actual evapotranspiration can be estimated by using potential evapotranspiration, precipitation and the plant-available water coefficient. The potential evapotranspiration was considered the mean daily air temperature at 2 m high, atmospheric pressure, dewpoint temperature, duration of sunshine and mean wind speed. The potential evapotranspiration was ranged from 449.95 to 564.45 mm/yr, and then the actual evapotranspiration was ranged from 427.91 to 554.14 mm/yr. In this study, the difference of potential evapotranspiration and actual evapotranspiration was small and the relative ratio was high. It was because of increasing urbanization in the large areas with w=0 (building, road, others).

2. Correlations analysis between the evapotranspiration and the

meteorological factors were performed. In Suyeong-gu, the coastal urban areas, the influence of to the mean wind speed, the potential and actual evapotranspirations was higher than other factors, and the correlation coefficients were 0.73 and 0.67.

3. The runoff was estimated by using plant coverage and land use. The mean precipitation and runoff were 1,645.02 mm and 843.75 mm, and the runoff was 49.80 % of the precipitation. Therefore, the runoff was influenced mainly by the precipitation in the study area. The building and road with the impermeable layer were more than 65 % and slope also was developed. So, the precipitation was not infiltrated under the ground, and most of precipitation was discharged.

4. The coastal flow and baseflow about paper were estimated using Darcy's law. The coastal flow was about 29,001 m^3/yr, and baseflow was about 3,070 m^3/yr in 10.56 % of the coastal flow. The coastal flow and baseflow were not significant impact in estimating the groundwater recharge.

5. The groundwater recharge was estimated using precipitation, AET, runoff, coastal flow and baseflow. During 9 years the highest groundwater recharge was 640.38 mm/yr, and 27.5 % of the precipitation in 2003. The linear regression functions for groundwater recharge and precipitation was $GR = 0.36 \times P - 263.56$, and the coefficient of determination was 0.878.

6. Inflow and outflow rate of groundwater from the outside basin is usually not used to estimate the groundwater recharge. Groundwater utilization, leakage of water supply · sewage, groundwater discharge

from subway and electronic cable tunnel were considered to estimate groundwater recharge. Leakage of water supply · sewer increased the sustainable development yield, on the other hand, the others were contrary to leakage of water supply · sewer. To analyze influence of the sustainable development yield by the precipitation, evapotranspiration and runoff, there were conducted linear recession function analysis for the sustainable development yield and each factor. Therefore, influence for the sustainable development yield came next with the precipitation, runoff and evapotranspiration. After all, influence of the natural factor in the sustainable development yield estimation was the precipitation, and artificial factor was the runoff. The sustainable development yield was estimated just using natural factors (precipitation, mean wind speed, temperature) in the past, but it should be estimated considering artificial factors (groundwater use, subway, tunnel etc.) in the modern.

8. For the optimal utilization of groundwater, groundwater should be properly conserved and managed. The main way to precure the sustainable development yield is to reduce runoff. We should find out effective ways that precipitation can infiltrates the impermeable roads and buildings. Also, groundwater discharge from subway and electronic cable tunnels needs to be recharged to the underground instead of the discharge to the river or sea.

References

Ahn Chung Hyun, Oh Sung Nam, Park Jong Hyun (1995), Mapping of Areal Evapotranspiration by Remote Sensing and GIS Techniques, Journal of the Korean Society of Remote Sensing, 11(1), 65-80.

Allen R. G., Pereira L. S., Raes D., Smith M. (1998), Crop evapotranspiration-guidelines for computing crop water requirements, FAO irrigation and dirainage paper 56, FAO, ISBN 92-5-104219-5.

An Hung Gi, Lee Yong Doo, Hwang Jong Hwan (2006), Estimation of the Spatial Distribution of Groundwater Recharge by Grid-based Soil Water Balance Method, Journal of Korean Society of Soil and Groundwater Environment, 11(1), 65-76.

Arya. S. P. (2001), Introduction to Micrometeorology, Academic Press, 420p.

Blaney H. F., Criddle W. D. (1950), Determining water requirements in irrigated areas from climatological and irrigation data, USDA (SCS) TP-96, 48p.

Busan Metropolitan (2005), Sewerage master plan changes, Ministry of Environment, 1617p.

Busan Water Authority (2007), 2007 Statistical Yearbook of Busan Water Supply, Busan Metropolitan, 142p.

Domenico P.A., Schwartz F.W. (1998), Physical and Chemical Hydrogelogy, 2nd ed., John Wiley and Sons, Inc., 506p.

EGIS (2008), www.egis.me.go.kr, Environmental Geographic Information System.

Fitts C. R. (2002), Groundwater science, Academic press, 45p.

Gong L., Xu C. Y., Chen D., Halldin S., Chen Y. D. (2006), Sensitivity of the Penman-Monteith reference evapotranspiration to key climatic variables in the Changjiang (Yangtze River) basin, J. of Hydrology, 329, 620-629.

Goyal R. K. (2004), Sensitivity of evapotranspiration to global warming: a case study of arid zone of Rajasthan (India), Agricultural Water Management, 69, 1-11.

Hahn Jeong Sang and Hahn Chan (1999), 3-D Groundwater Models and Applications, Pakyoungsa, 1390p.

Hahn Jeong Sang, Hahn Kyu Sang, Lee Yong Dong (1988), Determination of Optimal Yield and Water Budget Analysis on

Keumchon Well Field, Journal of the Geological Society of Koea, 24(2), 140-172.

Hamon W. R. (1963), Computation of Direct Runoff Amounts From Storm Rainfall, Int. Assoc. Sci. Hydrol. Pub., 63, 52-62.

Hargreaves G. H., Samani Z. A. (1985), Reference Crop Evapotranspiration From Temperature, Applied Engrg. in Agric., 1(2), 96-99.

Kim Hea Dong, Im Jin Wook, Lee Soon Hwan (2006), Distribution of Relative Evapotranspiration Availability using Satellite Data in Daegu Metropolitan, Journal of Korean Earth Science Society, 27(6), 677-686.

Kim Tae Yeong (2009), A Study on Groundwater Characteristics using Kriking Method and Numerical Modeling at a Coastal Urban Area in Busan, KOREA, Pukyong National University, 104p.

Korea Resources Corporation (1998), Study of Groundwater Recharge and pollution vulnerability assessment, 27-90.

Lu J., Sun G., McNulty S. G., Amatya D. M. (2005), A comparison of six potential evapotranspiration methods for regional use in the southeastern United States, J. of the American Water Resources Association, 41(3), 621-633.

Makkink G. F. (1957), Testing the Penman Formula by Means of Lysimeters, J. Inst. of Water Eng., 11, 277-288.

Ministry of Construction and Transportation · Korea Water Resources Corporation (2002), Groundwater Management Plan Report, Korea Institute of Consructuion Technology, 520p.

Ministry of Construction and Transportation · Korea Water Resources Corporation (2008a), Groundwater Survey Annual Report, Minister of Lan, Transport and Maritime Affairs Water Policy, 604p.

Ministry of Construction and Transportation · Korea Water Resources Corporation (2008b), Groundwater Runoff Reduction and Utilization Research, Korea Water Resources Corporation.

Ministry of Environment (2007a), 2006 Water supply Statistics, Water supply and sewerage Policy office Water supply and sewerage Policy office Division, 1825p.

Ministry of Environment (2007b), 2006 Sewerage Statistics, Water supply and sewerage Policy office Sewerage Division, 1131p.

Monteith J. L. (1965), Evaporation and environment, In Fogg, G.E., ed., symposium of the Society for Experimental Biology, The State and

Movement of Water in Living Organic, 19, Academic Press, Inc., NY, 205-234.

Park Chang Kun (1996), Estimation of the Available Amount of Groundwater in South Korea: 1. Development of the Method, Journal of the Korean Society of Groundwater Environment, 3(1), 15-20.

Park Nam Sik, Hong Sung Hun, Seo Kyung Soo (2007), Assessment of Potential Groundwater Resources for Optimal Management of Coastal Groundwater, Korea Water Resources Association, 665-675.

Penman H. L. (1948), Natural evapotranspiration from open water, bare soil, and grass, Proc. Roy. Soc. London, Ser. A, Mathematical and Physical Sciences, 193, 120-145.

Priestley C. H. B., Taylor R. J. (1972), On the assessment of surface heat flux and evaporation using large-scale parameters, Monthly Weather Review, 100, 81-82.

Rim Chang Soo (2007), Urbanization Effects on Reference Evapotranspiration, Journal of Korea Water Resources Association, 40(7), 571-583.

Rim Chang Soo, Chae Hyo Seok (2007), Evaluation of Urbanization Effects on Water Balance, Journal of Korea Water Resources

Association, 40(7), 555-570.

Singh V. P., Xu C. -Y. (1997), Sensitivity of mass transfer-based evaporation equations to errors in daily and monthly input data, Hydrological Processes, 11, 1465-1473.

Soil Conservation Service (1969, 1971), Hydrology in SCS National Engineering Handbook, Section4.

Sunwoo Jungho (1983), Hydrology, Dongmyungsa, 35-207.

Sustainable Water Resources Research Center (2009), Construction and Application of Optimal Management System for groundwater, Dong-A University, 116p.

Suyeong District of Busan Metropolitan city (2008), Statistical Yearbook of Land and Climate, Suyeong District of Busan Metropolitan city.

Thornthwaite C. W. (1944), Report of the committee on transpiration and evaporation, Am. Geophy. Union Trans., 25, 683-693.

Todd D. K., Mays L.W. (2005), Groundwater Hydrology, 3rd Ed., John Wiley and Sons, Inc., 636p.

Turc L. (1961), Evaluation de besoins en eau d'irrigation, ET potentielle, Ann. Agron., 12, 13-49.

Zhang, L., Dawes, W. R., and Walker, G. R. (1999), Prediction the effect of vegetation changes on catchment average water balance, Technical Report, 99/12, Coop. Res. Cent. for Catch. Hydrol., Canberra, ACT.

Zhang L., Dawes W. R., Walker G.R. (2001), Response of mean annual evapotranspiration to vegetation changes at catchment scale, Water Resour. Res., 37(3), 701-708.

Estimation of groundwater recharge rate considering natural and artificial factors at a coastal area in the Busan City

Sung Il Yang

Department of Environmental Geosciences, The Graduate School,
Pukyong National University

Abstract

In this study, the actual evapotranspiration was estimated according to use and climate change in a coastal area, and the relationship between actual evapotranspiration meteorological factors was analyzed. The groundwater recharge was estimated by considering the runoff, water supply · sewer rate, groundwater use (livelihood, industry, agriculture and others) and subway and electronic cable tunnel outflow rate. Sugyeong River to the east is located and Mt. Kuumryun to the west is bounded. Sugyeong Bay is formed to the south, and Mt. Bae is bounded to the north. The actual evapotranspiration was estimated by using potential evapotranspiration, precipitation and the plant-available water coefficient. Parameters to estimating the potential evapotranspiarion are the mean daily air temperature, dewpoint temperature, atmospheric pressure and mean wind speed. In 2002, the actual evapotranspiration was the highest (554.14 mm/yr), and it was the lowest in 2003 (427.91 mm/yr). The fluctuation of the potential evapotranspiration and actual evapotranspiration was similar. Correlations analysis between the evapotranspiration and the meteorological factors were performed. The correlation coefficient of the actual evapotranspiration and potential evapotranspiration was 0.96, high, but the correlation coefficient of 1) the precipitation and actual evapotranspiration; 2) the precipitation and potential

evapotranspiration were very low, respectively. The influence of the potential and actual evapotranspiration and the mean wind speed was higher than others, and the correlation coefficients were 0.73 and 0.67. The evapotranspiration in the coastal urban areas is caused predominantly by wind speed than meteorological factors such as precipitation and temperature. Runoff was 49.80 % of the precipitation because increasing impermeable layer (building, road and so on) according to urbanization. Groundwater usage, leakage of water supply · sewage, groundwater discharge from subway and electronic cable tunnel were considered to estimate groundwater recharge. Influence for the sustainable development yield came next with the precipitation, runoff and evapotranspiration. It is because precipitation cannot infiltrated into underground in the large areas having w=0 (building, road, others). In order to use, conservation and management of groundwater, they should be considered the exact value of each factor because natural factors (evapotranspiration, baseflow, coastal flow) and artificial factors (runoff, groundwater use, leakage of water supply · sewage, groundwater discharge from subway and electronic cable tunnel) to estimate accurate values.

감사의 글

2000년에 부경대학교에 입학하여 지금까지 학생으로서 열심히 보냈습니다. 대부분은 즐거운 일들로 가득했었으며, 이제는 그 결실로 석사학위논문을 완성하였습니다. 논문 작성과 대학생활에 도움을 주신 모든 분께 감사의 말씀을 전하려고 합니다.

먼저, 초등학교 6학년부터 부산에 살면서 몸 건강히 지낼 수 있도록 항상 보살펴주신 부모님, 형, 누나에게 항상 고맙게 생각합니다.

대학교 3학년 때 지하수환경연구실에 들어가면서 지금까지 열심히 지도해주신 정상용 교수님께 감사의 말씀을 전하며 처음 연구실에 들어가면서부터 지금까지 생활하는데 불편 없도록 도와주신 연구실 가족에게도 감사의 말씀을 전합니다. 또한, 2000년에 만나서 지금까지 함께 학교생활하면서 공부도 열심히 하고 당구도 많이 치러 다닌 동기들도 항상 건강하게 지냈으면 합니다.

석사 논문에 심사위원을 맡아주시고 지도해주신 강태섭 교수님과 최정찬 교수님께 감사의 말씀을 전합니다.

처음 입학해서부터 졸업할 때까지 항상 열정을 가지고 지도해주신 김영석 교수님, 박계헌 교수님, 박맹언 교수님, 백인성 교수님, 송용선 교수님, 이민희 교수님께도 감사의 말씀을 전합니다.

지금까지 겪었던 많은 일들을 바탕으로 보다 열심히 하도록 노력하겠습니다.