Biological Forum – An International Journal **8**(2): 196-202(2016)

ISSN No. (Print): 0975-1130
ISSN No. (Online): 2249-3239

Estimating Groundwater Recharge, Evapotranspiration and Surface Runoff using Land-use data: A Case Study in Northeast Iran

Mehdi Zarei*, Reza Ghazavi**, Abbasali Vli and Khodayar Abdollahi*******

**Ph.D. Student, Faculty of Natural Resource and Earth Sciences, University of Kashan, Iran*
***Associated Professor, Department of Watershed Management, Faculty of Natural Resources and Earth Sciences, University of Kashan, Kashan, Iran*
**** Associated Professor, Department of Desert Studies, Faculty of Natural Resources and Earth Sciences, University of Kashan, Kashan, Iran*
*****Assistant Professor, Faculty of Earth Sciences, Shahrekord University, Iran*

(Corresponding author: Mehdi Zarei)
(Received 05 September, 2016, Accepted 27 September, 2016)
(Published by Research Trend, Website: www.researchtrend.net)

ABSTRACT: Estimation of temporal and spatial distribution of recharge is a key factor for a long-term water resource planning, especially in semi-arid regions. The main objective of this is to assess the groundwater recharge, surface runoff and evapotranspiration in the Mashhad basin using a spatially distributed water balance model (WetSpass-M) in different land-use types. Distributed land-use map, groundwater depth, monthly climatological data (e.g. precipitation, temperature…..), monthly LAI, slope and soil texture maps are the basic relevant input data for the model. All inputs were prepared in the form of digital maps using GIS and remote sensing tools. Results of the model indicate that the long-term temporal and spatial average monthly rainfall of 22 mm was distributed as 14% of surface runoff, 29 % groundwater recharge and 57% of evapotranspiration. Resulting to the high evapotranspiration rate, high surface runoff and temperature, agricultural regions (including rain-fed and irrigation farming) has the lowest groundwater recharge. Analysis of the simulated results indicate that WetSpass-M model is good enough to simulate the components of water balance for the Mashhad basin.

Keywords: Groundwater recharge, land-use, Water balance, GIS, Remote Sensing, Mashhad basin

INTRODUCTION

Extraction of groundwater for irrigation using in many area is faster than nature replenishing it, causing water level decline continuously (Anuraga *et al*, 2006). Around 12% of the total area of Iran (i.e. 19 million ha) is agricultural land. The average water use in agricultural sector of the world is70 %, and in developing countries it is 82%, however in Iran more than 90% of the water is used in terms of irrigation (Rafiei Emam, 2015). In semi-arid regions of Iran especially in the Mashhad basin groundwater is the main source of water for irrigation. Ground water is an important source of fresh drinking and irrigated water across the world and plays a vital role in mitigating the environmental values especially in arid and semi-arid regions (UN/WWAP, 2006; Holger *et al*, 2012). Therefore, assessment of groundwater resources condition and its recharge in arid and semi-arid regions is an important challenge in determining the aquifer's sustainable yield (Yongxin and Beekman, 2003; Crosbie *et al*, 2010). So, groundwater recharge is a key factor in water balance researches, its temporal and special information is necessary for a long-term water resources planning.

Estimation of water balance components is useful for water and land management for instance, calculation of sustainable amount of groundwater depletion, evaluation of water availability or prevention of land degradation and desertification. Abu-Saleem *et al* (2010) evaluate the water balance components using WetSpass model for the Hasa basin in Jordan. According to the results, mean annual groundwater recharge and surface runoff are respectively 0.98 mm and 23.64 mm per year. In the other words, about 0.64% and 15.4% of the annual precipitation convert to groundwater recharge and surface runoff respectively, and the major part of the precipitation (83.96%) is lost as evapotranspiration. In Northern Ethiopia, Arefaine *et al* (2012) simulate the water balance components including groundwater recharge, evapotranspiration and surface runoff using WetSpass model. Results show that the mean annual groundwater recharge, evapotranspiration and surface runoff were found to be 66, 440 and 40mm respectively. Therefore, 12% of the precipitation becomes recharge while evapotranspiration and surface runoff are 81% and 7% of the precipitation respectively. Al-Kuisi and El-Naqa (2013) estimating the groundwater recharge in jafr basin (an arid region) using WetSpass model.

They found that the long-term temporal and spatial average annual rainfall of 53.5 mm was distributed as 2.61 mm (4.9%) of surface runoff, 50.6 mm (94.6%) of evapotranspiration, and 0.27 mm (0.5%) of recharge. This recharge corresponds to 3.67 mm^3 for the Jafr basin. Results show that WetSpass is a suitable model to simulate the water balance components for this basin. Gebreyohannes *et al* (2013) using WetSpass model to estimate the availability of surface and groundwater water resources in the Geba basin. According to the results of WetSpass 76% of the precipitation is lost by evapotranspiration, 18% and 6% of the precipitation becomes surface runoff and groundwater recharge respectively. Aish (2014) using WetSpass model in the Gaza Strip to estimate the water balance components. Results of the study show that 77 percent of precipitation is lost through evapotranspiration, 11 percent becomes surface runoff and 12 percent of precipitation recharges the groundwater system.

Water demand exceeds the internal renewable water availability in the most area of Iran. However, extraction from groundwater resources to meet the water demand is enormous volume (Faramarzi, 2010), which led to some desertification symptoms such as depletion of aquifers, reduced in stream flow, water quality reduction and land subsidence in most of the arid regions. Therefore, the sustainability of the current and future water resource extraction is the main concern for water resources of Iran. Understanding of the spatial and temporal variability of various water balance components especially groundwater recharge and surface runoff is required for an effective and sustainable management of water resources in Mashhad basin. The main objective of this study is to estimate the groundwater recharge, surface runoff and evapotranspirationin the Mashhad Basin, Iran. To achieve this objective we applied different techniques e.g. GIS and remote sensing for data preparing, and application of WetSpass-M model (Abdollahi *et al*, 2012) for assessment of groundwater recharge, surface runoff, evapotranspiration in different land-use types.

MATERIAL AND METHOD

A. Study area

Mashhad catchment (is suited between 58°29´ to 59°56? east longitude and 35°58´ to 37°3´ north latitude)is a sub basin of Kashafrud and Qaraqum catchment and is located in the northeast of Iran (Fig. 1). It has an area of 9909 km^2 where 3351 km^2 is plain and 6558 km^2 is the highlands. The elevation of mountainous regions ranging from 903.8 m to 3248 m and mean slopes are around 9.56%. In terms of weather conditions is characterized by a semi-arid climate.

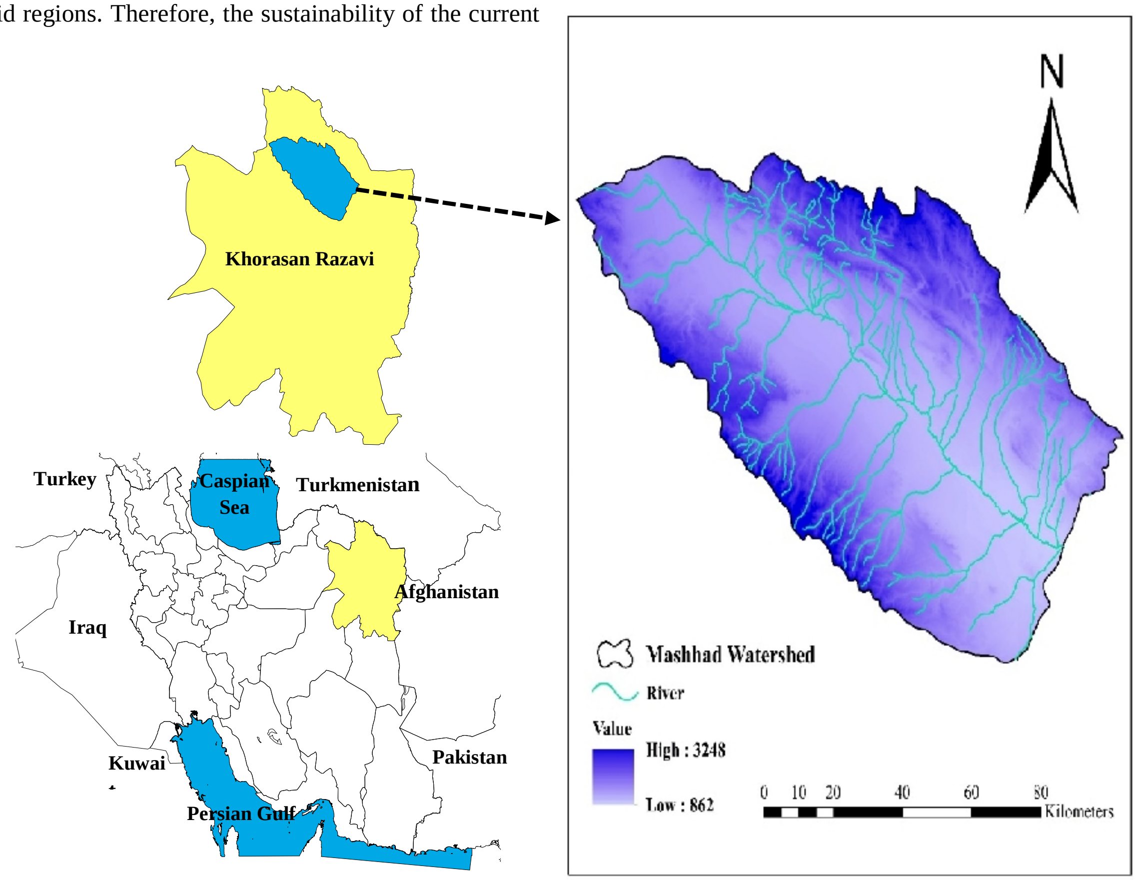

Fig. 1. Location of Mashhad Catchment in Khorasan Razavi Province, Iran.

Mean annual precipitation of Mashhad catchment is 247.5 mm/year, however its mean yearly pan-evaporation is 2300 mm/year (Shaabani *et al*, 2013, in Persian).Mashhad plain is the major industrial and agricultural center and the important social-political center in Khorassan-Razavi province. Nowadays, the study area is in critical condition in terms of ground water resources, land subsidence due to groundwater depletion appears in some parts of plain.

Since 1968, due to the extreme decline in water level, Mashhad plain was known as a prohibited plain (Akbari *et al*, 2009, in Persian).

Assessment of Water balance using WetSpass-M model

WetSpass-M model uses monthly geographical information systems input grids of the mentioned inputs to simulate monthly groundwater recharge (R_m[mm/month]):

$$R_m = P_m - SR_m - ET_m \quad \ldots(1)$$

Where R_m is the monthly groundwater recharge, P_m is the monthly precipitation, SR_m is monthly surface runoff and ET_m is monthly evapotranspiration (Abdollahi *et al*, 2016).

The surface runoff depends on the soil, land-use, slope and precipitation intensity in relation to capacity of the soil infiltration. It is calculated in (mm/month) using a rational method applied on a monthly time-step using two coefficients:

$$SR_m = C_{sr} C_h (P_m - I_m) \quad \ldots(2)$$

Where Csr is the actual runoff coefficient (-) that parameterizes the part of the monthly precipitation that actually contributes to runoff, Ch is a coefficient (-) that represents soil moisture condition and I_m is the monthly interception.

Land use change causes to change in leaf area index that influences on evapotranspiration and interception. In WetSpass-M monthly interception is calculated by:

$$I_m = P_m I_R \quad \ldots(3)$$

Where I_m is the interception [mm/month], P_m is monthly precipitation [mm/month] and I_R is interception ratio.

Total actual monthly evapotranspiration per pixel (ET_m; mm/month) in WetSpass-M is calculated by:

$$ET_m = a_v ET_v + a_s ET_s + a_0 ET_o + a_i ET_i \quad \ldots(4)$$

Where a_v, ET_V; a_s, ET_s; a_0, ET_O; and a_i, ET_i are the area fraction and evapotranspiration for vegetated area, bare soil, open water and impervious surface respectively. Evapotranspiration for vegetated area (ETV) in WetSpass-M model is calculated as summation of interception and actual transpiration of vegetated area. (Batelaan and De Smedt 2003; Batelaan and De Smedt 2007; Abdollahi *et al*, 2012 & 2016).

B. Input Data

Recharge process is determined by the interaction of climate condition, soil types, land use/land cover, morphology and geology of the area (de Vriers and Simmers, 2002). Distributed groundwater depth, climatology data (monthly rainfall, wind speed, temperature, pan evaporation and number of rainy days per month), land-use, monthly LAI, soil texture, DEM and slope are the basic inputs of model (Batelaan and De Smedt2007; Ampe *et al*. 2012, Abdollahi *et al*. 2016). These data were collected for the period of 1986 to 2013 and prepared in the form of grid maps of selected meteorological, hydrological and geographical elements of the basin. Climate data for the study area have been provided by the Ministry of Water Resources and Meteorological Organization of Iran. Rainfall records are available for 40 stations, temperature, pan evaporation and wind speed were available for 15, 15 and 7 stations, respectively, for the period of 1986 to 2013.

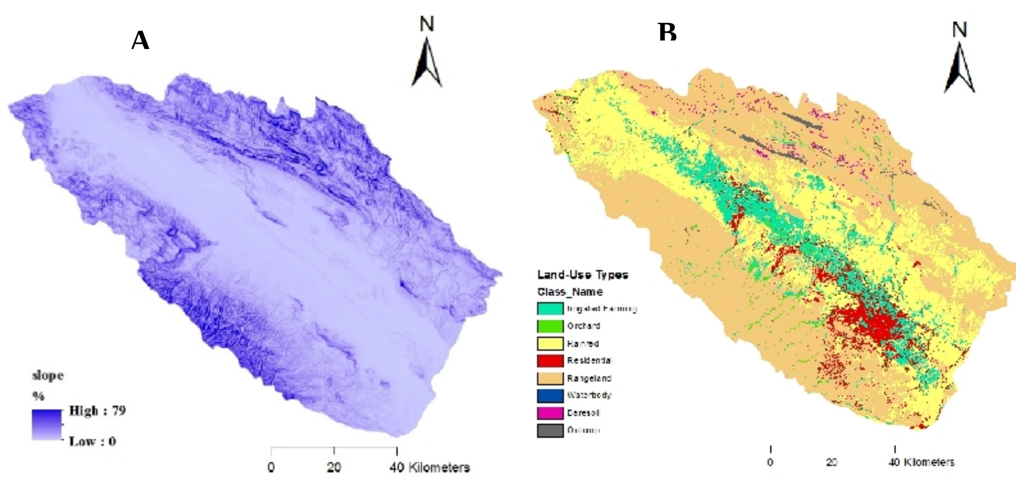

Fig. 2. (A) Slope map and (B) Land use map in the study area.

Digital Elevation Model (DEM) of the study area was prepared with a 250 m cell size based on the 1:50,000 scale topography maps (Fig.1) the lowest point of the study area is 862m in the eastern part and the highest is 3248m in the southwest of the area, while the mean elevation of the basin is 1975 m. the slope map was derived by the slope analysis tool in ArcGIS directly from DEM (Fig. 2A). All inputs for the WetSpass-M model was obtained based on the DEM with total number of 631, 467 raster cells and a cell size of 250 m × 250 m. Long-term monthly LAI (Leaf Area Index) was obtained from AVHRR and MODIS products (downloaded from: ftp://ftp.glcf.umd.edu/glcf/GLASS/LAI/AVHRR/1981), and resample for study area based on digital elevation model using ArcGIS tools.

Landsat TM satellite images for the year 1987 of the study area under investigation was downloaded from http://earthexplorer.usgs.gov. Land use/cover classification was performed using supervised classification method with the maximum likelihood algorithm in ERDAS 9.3 imagine software and Eight land-use classes was identified (Fig. 2B). We applied the maps of soil and land capacity developed by the Agricultural and Natural Resource Center of Khorasan-Razavi Province. Soil type classes were translate into USGS soil texture classes using the percentage of coarse medium, fine particle size fractions in the topsoil. Land use of the study area was dominated by rangeland and the main soil type in Mashhad basin was silty clay loam. Tables 1 is shown the area of each land use and soil classes in the study area.

Table 1: Summary of land use and soil classification of the Mashhad basin.

Land Use Classes	Area (Km2)	Percent of total area (%)	Soil Classes	Area (Km2)	Percent of total area (%)
Rangeland	5331.52	53.802	Clay	2342.6	23.64
Bare soil	69.67	0.703	Loam	2918	29.45
Residential	509.85	5.145	Sandy Clay	148	1.49
Outcrop	69.73	0.704	Sandy Clay Loam	90.5	0.92
Irrigation Farming	867.46	8.754	Silt	703.9	7.1
Rain-Fed Farming	2983.06	30.104	Silty Clay	93.14	0.94
Orchard	77.65	0.784	Silty Clay Loam	3214.9	32.44
Water body	0.39	0.004	Silty Loam	398.3	4.02
Total	9909.34	100	Total	9909.34	100

RESULTS AND DISCUSSION

The WetSpass-M model results consist several monthly hydrologic outputs. The major outputs are the digital maps of monthly groundwater recharge, surface runoff, actual evapotranspiration and interception in the 28-years period from 1986 to 2013 (336 time steps). These maps are raster-shaped, in which every pixel represents the magnitude of the respective component of water balance, expressed as layer thickness (in mm).

The actual evapotranspiration per pixel is calculated by WetSpass-M as a sum of evaporation from bare soil, open water and impervious surface area, summation of transpiration and interception of vegetated area (Batelaan and De Smedt, 2003; Abdollahi *et al*, 2016). WetSpass-M model simulates the monthly evapotranspiration of the basin to be 0 and 63.9 mm as minimum and maximum values during the study period, respectively. The average and standard deviation of this distribution are 12.74 mm and 13.37 mm, respectively (Table 2). Annual actual evapotranspiration were calculated using accumulation of the monthly simulated data in the Mashhad basin. Maximum, minimum and average values of annual evapotranspiration for the study period were 225 mm, 50 mm and 152 mm, respectively. The average evapotranspiration accounts for 57% of the total annual rainfall. This is attributed to high rates of radiation and persistence dray winds. The result shows that evapotranspiration is the major process by which water is lost in the study area (Table 3). WetSpass-M model simulates evapotranspiration from vegetated area as summation of interception and transpiration of vegetation, also this model simulates monthly interception as a fraction of precipitation depending on land-use. Mean annual evapotranspiration in different types of land-use is showed in table 4. This results indicate that agricultural land (including irrigation farming and rain-fed farming) have the highest values of evapotranspiration, while rangeland area show the lowest evapotranspiration. The WetSpass-M model uses a retinol method on a monthly time step to simulate surface runoff using an actual runoff coefficient and soil moisture condition coefficient (Abdollahi *et al*, 2016). The surface runoff coefficient is a function of soil texture, land-use, slope, precipitation intensity and its relation to capacity of the soil infiltration. The simulated average monthly surface runoff of the Mashhad basin ranged from 0 mm/month to 42 mm/month as the minimum and maximum values respectively, with the standard deviation 5 mm/month and long-term monthly mean value of 3.2 mm/month. Total annual surface runoff was calculated by accumulation of the monthly simulated runoff during the study period (Table 2). Total annual runoff of the Mashhad basin ranged from 74/7 mm/y and 10.6 mm/y as the maximum and minimum values, respectively.

Table 2: Monthly water balance components of the Mashhad basin during 1986-2013.

Water Balance Components	Monthly Values (mm/month)			
	Max	Min	Mean	Std. dev.
Precipitation	107.4	0	22	21.9
Evapotranspiration	63.9	0	12.7	13.4
Recharge	38	0	6.5	5.9
Surface Runoff	41.9	0	3.2	4.9
Differences	P-AET-S-R= -0.4			

Table 3: Annual water balance components of the Mashhad basin during 1986-2013.

Water Balance Components	Annual Values (mm/y)			
	Max	Min	Mean	Std. dev.
Precipitation	393	143	265	67
Evapotranspiration	225	50	152	42
Recharge	120	46	78	19
Surface Runoff	74.7	10.6	38	15
Differences	P-AET-S-R= -3			

Table 4: Mean annual actual evapotranspiration simulated using WetSpass-M model in different land use types.

Different land-use	Annual evapotranspiration (mm/y)			
	Max	Min	Mean	Std. dev.
Irrigation Farming	254	159	207	28
Residential	209	82	145	37
Rangeland	206	58	128	41
Rainfed Farming	254	156	205	29
Bare Soil	240	134	171	27
Orchard	250	141	193	33

Table 5: Mean annual surface runoff simulated using WetSpass-M model in different land use types.

Different land-use	Annual surface runoff (mm/y)			
	Max	Min	Mean	Std. dev.
Irrigation Farming	141	30	82	31
Residential	69	4	33	17
Rangeland	89	4	47	25
Rain-fed Farming	130	29	74	27
Bare Soil	68	16	42	15
Orchard	106	23	62	23

The average and standard deviation of this distribution are 38 mm/y and 15.3 mm/y, respectively (Table 3). Table 5 shows the mean annual surface runoff simulated by WetSpass-M model in different land use classes. The larger surface runoff occurs on irrigation farms, while the lowest value is for residential class.

Recharge is an important factor in assessing groundwater resources however evaluating of recharge is difficult (Alley *et al*, 2002). There are many studies on the estimation of groundwater recharge in arid and semi-arid regions. Principle there are differences between various techniques to estimate groundwater recharge. However, numerical method is widely used to estimate groundwater recharge (Manghi *et al*, 2009; Xu *et al*, 2011; Barthel *et al*, 2012). TheWetSpass-M model estimates monthly long-term spatial distribution amounts of groundwater recharge of Mashhad basin by subtracting the monthly surface runoff and evapotranspiration from the monthly precipitation. The simulated average monthly recharge of the study area is ranging from 0 mm/month to 38 mm/month as the minimum and maximum values, respectively. The standard deviation and mean values of this distribution are 5.9 mm/month and 6.6 mm/month respectively (Table 2). Average annual groundwater recharge for the Mashhad basin ranged from 120 mm/y and 46 mm/y as a maximum and minimum values, respectively, were calculated based on the monthly simulated data. The mean and standard deviation of this distribution are 78 mm/y and 19 mm/y respectively (Table 3). Table 6 indicates the mean annual simulated recharge using WetSpass-M model for different land-use types.

Table 6: Mean annual recharge simulated using WetSpass-M model in different land use types.

Different land-use	Annual recharge (mm/y)			
	Max	Min	Mean	Std. dev.
Irrigation Farming	46	0	22	13
Residential	139	39	91	28
Rangeland	168	40	106	34
Rain-fed Farming	42	0	20	12
Bare Soil	81	11	44	19
Orchard	72	7	38	18

From this table it appears that rangeland land-use has the highest values of groundwater recharge, while the lowest values of groundwater recharge are belonged to the rain-fed and irrigation lands respectively.

CONCLUSION

Water balance is a representation of the net result of the inflow and outflow of system. Precipitation is the main inflow component of water balance. Evapotranspiration, groundwater recharge and surface runoff are the most significant outflow components of water balance. All water balance components are dependent on the land use/land cover classes and soil texture types. In this study, steady state distributed water balance model (WetSpas-M) has been applied to calculate monthly water balance components in Mashhad basin, Iran. We employed remote sensing method and cloud free Landsat TM to provide land use map in Mashhad basin. In order to identify land use classes, supervised classification method with the maximum likelihood algorithm in ERDAS 9.3 imagine software. Land use and soil types in Mashhad basin were dominated by rangeland area and silty clay loam, respectively.

Results of the model indicate that evapotranspiration is the major process by which water is lost in the study area. Monthly actual evapotranspiration simulated by model ranges from 0 to 63.9 mm/month with a mean of 12.7 mm/month which constitutes 57 % of the average monthly precipitation (22 mm/month). This is attributed to high rates of radiation and persistence dray winds. The simulated result shows that 14% (3.2 mm/month) of the average monthly precipitation ranged from 0 to 41.9 mm/month as a minimum and maximum value, becomes runoff in study area. WetSpass-M model simulates monthly recharge in Mashhad basin ranges from 0 mm/month to 38 mm/month as the minimum and maximum values, respectively. Only 29 % of the average monthly precipitation of the study area recharges to groundwater system. According to the results the highest values of evapotranspiration observed in irrigation and rain-fed farming due to these land-uses have more vegetation cover and more temperature. Rangeland area produce the highest groundwater recharge in Mashhad basin, while agricultural land yields the lowest values of recharge. This is could be due to the high temperature, evapotranspiration and surface runoff in agricultural lands of Mashhad basin. Analysis of the simulated results indicates that WetSpass-M model is good enough to simulate the hydrological water balance components of the Mashhad basin under the same land use and variable climate data during the study period.

REFERENCES

Abdollahi K, Bashir I, Verbeiren B, Harouna MR, Griensven AV, Husmans M, Batelaan O. (2016). A distributed monthly water balance model: formulation and application on Black Volta Basin. Environmental Earth Science.

Abdollahi, K., Bashir, I., O. Batelaan. (2012). WetSpass Graphical User Interface. Version 31-05-2012. Vrije University Brussel, Department of hydrology and hydraulic engineering.

Abu-Saleem, A., Al-Zubi, Y., Rimawi, O., Al-Zubi J., and Alouran, N. (2010). Estimation of water balance components in the Hasa basin with GIS based WetSpass model. *J. Agro.* **9**(3): 119-125.

Aish, A.M. (2014). Estimation of water balance components in the Gaza Strip with GIS based WetSpass model. 2014. *Civil. Environ. Res*. ISSN 2224-5790 (Paper) ISSSN 2225-0514 (Online).

Akbari M, Jarge MR, Madani Sadat H (2009). Assessment of decreasing of groundwater-table using Geographic Information System (GIS) (Case study: Mashhad Plain Aquifer). *Iranian J. Water & Soil Conservation,* **16**(4): 63-78. www.gau.ac.ir/journals

Al-Kuisi, M., and El-Naqa, A. (2013). GIS based spatial groundwater recharge estimation in the Jafr basin, Jordan- application of WetSpass models for arid regions: *Revista Mexican de Ciencias Geologicas*. **30**: 96-109.

Alley, W., Healy, R., LaBaugh, J., Reilly, T. (2002). Flow and storage in groundwater systems. Science. **296**: 1985-1990.

Ampe, E., Vanhamel, I., Salvadore, E., Dams, J., Bashir, I., Demarchi L., Chan, J., Sahli, H., Canters, F., and Batelaan, O. (2012). Impact of urban land-cover classification on groundwater recharge uncertainty, *IEEE Journal.* **5**: 1859-1867.

Anuraga, T.S., Ruiz, L., Mohan Kumar, M.S., Sekhar, M., Leijnse, A. (2006). Estimating groundwater recharge using land use and soil data: a case study in south India. *Agricultural Water Management.* **84**: 65-76.

Arefaine, T., Nedaw, D., T, Gebreyohannes. (2012). Groundwater Recharge, Evapotranspiration and Surface Runoff Estimation Using WetSpass Modeling Method in Illala Catchment, Northern Ethiopia. *Momona Ethiopian Journal of Science (MEJS).* Volume **4**. PP: 96-110.

Barthel R, Reichenau TG, KrimlyTD, Schneider K, MauserW (2012). Integrated modeling of global change impacts on agriculture and groundwater resources. *Water ResourManag* **26**: 1929-1951. Doi:10.1007/s11269-012-0001-9.

Batelaan, O., De Smedt, F. (2007). GIS-based recharge estimation by coupling surface-subsurface water balances. *Journal of Hydrology*. Vol. **337**. PP: 337-355.

Batelaan, O., De Smedt, F., and Triest, L. (2003). Regional groundwater discharge: phreatophyte mapping, groundwater modelling and impact analysis of land-use change, *J. Hydrol.,* **275**(1-2), 86-108.

Crosbie, R., Jolly, L., Leaney, F., Petheram, C., D. Wohling. (2010). Review of Australian groundwater recharge studies CSIRO: water for a healthy country National Research Flagship Report series ISSN: 1835-095X.

De Vries, J.J., Simmers, I. (2002). Groundwater recharge: an overview of processes and challenges. *Hydrogeology. J.* **10**: 5-17.

Faramarzi, M., Yang, H., Schulin, R., Abbaspour, K.C. (2010). Modeling wheat yield and crop water productivity in Iran: implications of agricultural water management for wheat production. *Agric. Water. Manag*. **97**: 1861-1875.

Gebreyohannes, T., F. De Smedt., K. Walraevens., S. Gebresilassie., A. Hussien., M. Hagos., K. Amare., J. Deckers., K. Gebrehiwot. (2013). Application of a spatially distributed water balance model for assessing surface water and groundwater resources in the Geba basin, Tigray, Ethiopia. *Journal of Hydrology*.

Holger, T., Jose Luis, M.B., Jason J.G. (2012). Climate Change Effects on Groundwater Resources. International Association of Hydrogeologists.

Manghi F, Mortazavi B, Crother C, Hamdi MR (2009). Estimating regional groundwater recharge using a hydrological budget method. *Water Resour Manag,* **23**: 2475-2489. Doi: 10.1007/ s11269-008-9391-0#

Rafiei Emam, A. (2015). Impact of climate and land use change on water resources, crop production and land degradation in a semi-arid area (using remote sensing, GIS and hydrological modeling). Doctoral program of Geoscience/Geography. The Georg-August University School of Science (GAUSS).

Shabani, B., Mousavi Baygi, M., Jabari Noghabi, M., and Ghahreman, B. (2013). Modeling and prediction of monthly maximum and minimum temperature of Mashhad plain using time series models. *Iranian Journal of Water and Soil*. **27**(5): 896-906.

UN/WWAP (United Nations/World Water Assessment Programme), UN World Water Development Report 2: Water a shared responsibility. United Nations Educational, Scientific and Cultural Organization, Paris, France and Berghahn Books, New York, USA, 600 pp., 2006.

Xu X, Huang G, Qu Z, Pereira LS (2011). Using MODFLOW and GIS to assess changes in groundwater dynamics in response to water saving measures in irrigation districts of the Upper Yellow River Basin. *Water ResourManag* **25**: 2035-2059. Doi:10.1007/s11269-011-9793-2

Yongxin, X., Beekman, H. E. (2003). Groundwater's recharge estimation in Southern Africa. Paris: United Nations Educational Scientific and Cultural Organization. UNESCO IHP Series No. 64. ISBN 92-9220-000-3. 206 P.