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Indirect Estimation of Deep Percolation Using Soil Water Balance Equation and Nasa Land Simulation Model (LIS) for More Sustainable Water Management

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ACCURATE estimation for groundwater recharge is required for more sustainable management to water resources. On-farm level, deep percolation is one of the water loss sources that researchers and agronomists work hard to minimize. However, on a large scale or district level, it is considered as a valuable source for recharging the aquifer. Indirect estimation to deep percolation would be an economic effective mean, especially for large scale studies. The presented research study aims at checking the capability of Land Information System (LIS) model in estimating deep percolation by soil-water balance equation. The model was validated using precipitation data extracted from meteorological stations randomly selected and distributed along the Nile basin. Multi-thematic map layers including all soil water balance model parameters, *i.e.* deep percolation and change in soil moisture content were developed to the year 2013 at a scale of 10 km^2. The relationship between measured rainfall values and estimated ones by LIS has a coefficient of determination (R^2) of 0.88. The obtained results revealed a good capacity of LIS model in estimating deep percolation on large scale from its direct simulation to the soil-water balance parameters. It was found that deep percolation rates were generally higher in the Nile River's downstream than in upstream especially in Egypt, Sudan, and parts of Uganda. This is in contrary to the behavior of precipitation rates and both surface and sub-surface runoff. They were higher in upstream countries than in downstream ones. The highest deep percolation rate (19.63 mm day^{-1}) was observed in Ethiopia and parts of Sudan during May 2013. It was found that low elevated lands with loose texture tend to have higher rates of deep percolation than elevated rocky lands. The current research results could be of great benefit for sustainable water management in Egypt. However, further study should be conducted in different agro-ecological zones in Egypt for more precise model calibration and validation. This may require access to large amount of field data and long-term meteorological data to run the model.

Keywords GIS, Remote sensing, Water balance, Nile river, Agriculture and global models.

Introduction

Sustainable management to water resources involves precise estimation for groundwater recharge. The better understanding of the estimated amount of deep percolation and behavior would contribute to more sustainable water resources planning. Soil water balance (SWB) equation computes deep percolation (DP) precisely if adequately applied. Lysimeters are efficient instruments used to compute each component of SWB model with high accuracy. This method is very sophisticated and costs

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much effort and money. Indirect estimation of DP could be, economically, a more realistic mean especially, on large scale studies. Remote sensing (RS) is a trusted tool for precise estimation of evapotranspiration (ET), rainfall (P), infiltration rate, water level, surface runoff (R_s), change in stored water, river flow rates, and change in soil moisture content (ΔS) (Thakur et al. 2017; Lakshmi, 2013 and Dobriyal et al. 2012). The relatively few studies conducted on the Nile basin level were mainly aiming to estimate ET and P in irrigated and rainfed lands. Estimating DP on the Nile basin level needs further investigation and research for more reliable assessments. Grayson et al. (1992) indicated that the required parameters for estimating DP could be obtained using geospatial technologies. Remote sensing, as well, can provide information on the topo- and physio-graphic parameters besides morphometric indicators on the watershed level (Beven, 2001) together with other soil parameters including soil moisture content, vegetation cover and land use (Singh and Frevert, 2006), and runoff coefficients (Pechlivanidis et al., 2011).

Different approaches were developed to estimate the restoration of groundwater through the last few decades. Still there is a need for further investigation to find out more efficient satellite-derived products and RS applications to address groundwater recharge and its role in water scarcity problem management. Berehanu et al. (2017) applied the base flow separation method in the Upper Awash river basin (Ethiopia) to assess groundwater recharge. Their study found that the river basin aquifer recharge varies from 51.5 mm.yr^{-1} to 175 mm.yr^{-1}. In addition, Beyene et al. (2018) estimated actual ET and DP in irrigated lands in Ethiopia using Hydrus-1D model. Sarmadian and Taghizadeh-Mehrjardi (2013) applied a Multi-Linear Regression and used neural network model to create a pedotransfer function to estimate soil parameters, including infiltration rate and DP by using available soil characteristics. This method was evaluated through the processing of the test data set. Results revealed that neural network models have more capacity to figure out the non-linear relationship between parameters compared to linear regression. This proves the promising role RS can play in providing timely detailed information to improve water use and decision-making processes especially, in countries with a wide variety of agriculture cover and production systems (Brown et al., 2008 and Khalil et al., 2016).

Land Information System (LIS) is a software framework that combines the satellite and ground-based data with high-level of land surface models tools to precisely discriminate land surface fluxes (Kumar et al., 2006). LIS is a high-performance modeling and data-assimilation system that can perform local, regional or global land surface simulations (Peters-Lidard et al., 2007). The LIS software was the co-winner of NASA's 2005 software of the year award, and is directly relevant to NASA's mission "to understand and protect our home planet". LIS gives accurate results at the global scale for water and energy cycle forecast and gives valuable information for water balance, weather forecast, and air condition. The LIS software enables near-real-time simulations at the full global 1km resolution represented by EOS-era level 3 products (Peters-Lidard et al., 2007).

The main objective of this research study is to check the capacity of NASA Land Information System (LIS) model for indirect estimation to deep percolation rates in Nile river basin as a main player in aquifer recharge using soil-water balance equation.

Material and Methods

Study area

The Nile River is the longest river in the world. It extends between 4 S to 31.5 N. Its basin contains five broad climatic zones. Each zone has its climate characteristics, i.e., precipitation pattern and quantity, evapotranspiration and runoff water losses, and for sure, will differ in deep percolation rates and values. The five zones are i) the Mediterranean, ii) the arid region, iii) the semi-arid region, iv) the subtropical area, and v) the tropical area (Karyabwite, 2000; Dawod et al., 2007). The White Nile and the Blue Nile with their sources on different 10 African countries are the main water source to the Nile. Figure 1 represents the (a) location of the Nile basin through Africa and (b) a digital elevation model (DEM) of the entire basin.

Water balance model

Soil-water balance modeling contributes to improving crop-water productivity in both direct and indirect ways, especially in areas where water is a limiting factor for agriculture production. The method relays mainly on stating the change in soil water content ΔS in the root zone. This could be expressed as water mass added (Q_i) and withdrawn (Q_o) from root zone according to the model:

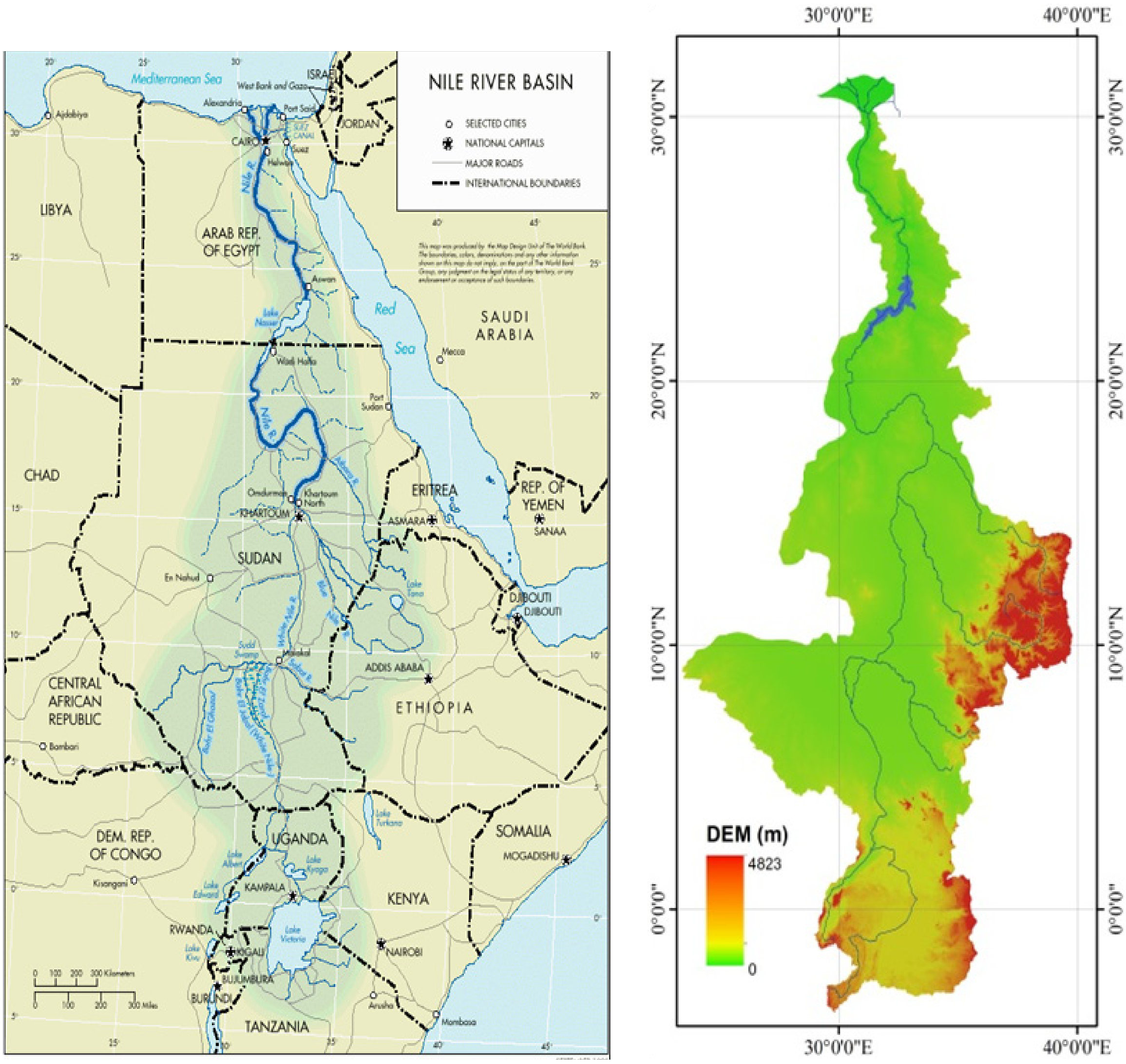

Fig. 1. Map of Nile River Basin location (a) and its Digital Elevation Model-DEM (b)

$$\Delta S = Qi - Qo$$

This model can be used to determine the deep percolation of a given crop as follows:

$$\mathrm{DP} = P + I + Cr - \mathrm{ET} - R \pm \Delta S$$

In which, DP downward drainage out of the root zone, ET is evapotranspiration, P is rainfall, I is irrigation, Cr is the capillary rise, R runoff from the field, and ΔS the change in soil water content of the root zone. A simple SWB equation may be calculated by accounting for P, I, R, ET, and ΔS.

Data exportation from LIS

The LIS software (LIS; http://lis.gsfc.nasa.gov/, 2006) is a model capable of integrating computing methods with land surface modeling techniques to establish its framework. It consists of several land surface models with capacity to run simultaneously on global or regional scales with horizontal resolution varies from 2.5° to 1 km (Peters-Lidard et al., 2007). It has a high interactive visualization mechanisms designed using object-oriented principles that are transparently accessible to the end users (Kumar et al., 2006).

On the Nile river basin level; and since irrigation water is mainly from Nile water surface and precipitation, amount of irrigation water will be estimated indirectly through LIS by estimating surface water budget. Consequentially, the SWB model is simplified to:

LIS model (National Aeronautics and Space Administration ®) version 7.3 was used to export the required parameters for the year 2013 to simulate DP rate using SWB model for the whole Nile basin.

Data validation

The ground meteorological data and terra climate product from Abatzoglou et al. (2018) were used to validate the exported rainfall and actual evapotranspiration data from LIS. A two-tailed t-Test statistical analysis was conducted between observed rainfall obtained from meteorological stations and estimated one by LIS. Compiled rainfall data from meteorological stations was selected randomly from different 18 stations distributed along the basin for one day in each season as demonstrated in Table 1. Data was compiled for days: i) 5th of January, ii) 5th of May, iii) 5th of August, and 5th of November from each selected station for the year 2013. The precision of exported LIS rainfall and ET products were validated conducting the regression analysis using SPSS 15 (SPSS Inc., 1989-2006). Results were checked at 95% significance level.

Data processing

Exported data from LIS has been geo-processed and analyzed to generate the multi-thematic maps following the flowchart represented in Fig. 2. The research team subjected to several difficulties during the study that consumed much time to be solved. The enormous amount of data is one of these obstacles. Difficulties have been faced while adding, rectifying, and saving a considerable amount of the obtained data to traditional programs such as ArcGIS, QGIS, and ENVI. Teamwork succeeded to overcome these obstacles using the SNAP Program to add, rectify, and save data entirely without any losses.

Geo-referencing NetCDF data

Once data was exported from LIS, The ENVI 5.3 software (Exelis Visual Information Solutions, Inc. ®) was used for NetCDF data geo-referencing. The geographic lookup table (GLT) was applied to geometry files. The required parameters were georeferenced based on the created GLT file.

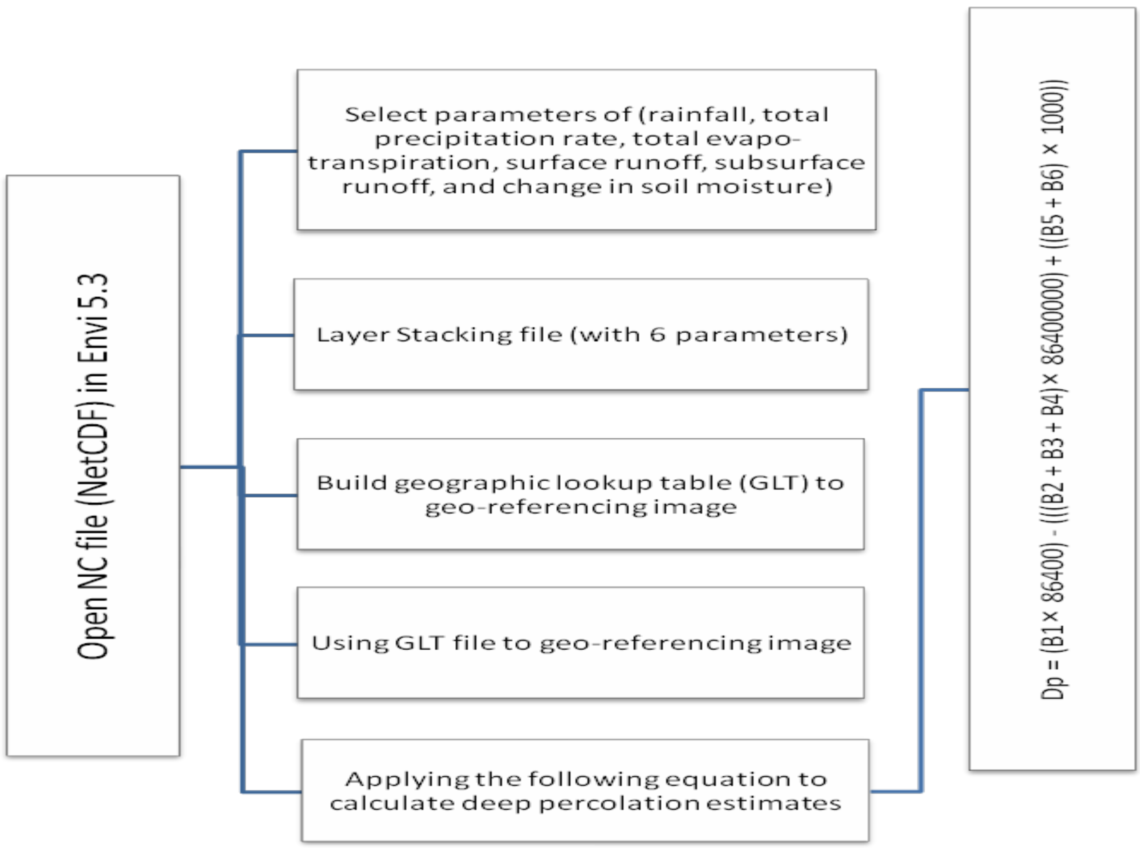

Fig. 2. Flowchart demonstrates the steps of obtaining and processing different parameters exported from LIS software to produce the multi-thematic maps. Where: B1 Rainfall, B2 Total evapotranspiration, B3 Surface runoff, B4 Subsurface runoff, B5 Change in soil moisture, B6 change in interception storage in m3/Km2

Preparation of soil-water balance model

The Band math tool in ENVI 5.3 software was used to build water balance equations.

$$DP = P\text{-}R\text{-}\ ET \pm \Delta S \pm Is$$

where I_s is the change in interception storage.

The interception storage here refers to the seized water quantity by land cover and did not penetrate the soil surface. This amount of water varies within time as it is exposed to reach the soil later or be evaporated again to the atmosphere. Runoff in the SWB model is the summation of both surface runoff (R_s) and sub-surface runoff (R_{sb}).

Multi-thematic maps' development

Final multi-thematic maps were developed at 10 km^2 scale for estimating deep percolation to the Nile river basin as well as rates of total P, ΔS, total ET, R_s and R_{sb}. The soil physical characteristics were imported from previous studies which collected in the book of The Hydrology of the Nile (Sutcliffe and Parks, 1999) were used to develop a map to predict where the higher and/or lower DP rates would be. The map was produced using the model-builder tool in ArcGIS software based on the imported soil bulk density, soil texture, parent material, as well as geology and topographic maps for the Nile basin.

Results and Discussion

Data exportation and validation

The specific parameters for estimating SWB exported using LIS are presented in Table 2. Estimated rates of rainfall, surface and subsurface runoff, change in interception storage, total evapotranspiration, and change in soil moisture content was exported from LIS for the year 2013. These map layers are describing the modeled SWB parameters used for the estimation of DP rates.

The validation process was done only for P and actual ET. Results of the one-sample t-Test statistical analysis is presented in Table 3. No significant difference at $\alpha \leq 0.05$ was found between the observed rainfall by weather stations and estimated one by LIS. The tested coefficient of determination (R^2) for 15 locations is presented in Table 1 and Fig. 3 & 4.

TABLE 1. The location and R^2 of the used stations for validation

Station Name	Location		R^2	
	Lat	Long	ET	Rainfall
Arua	3.0303299	30.907304	0.69	0.65
Eldoret	0.404862	35.2238796	0.45	-
Damazn	11.785454	34.3421397	0.77	0.59
AboNaama	12.7161	34.114658	0.88	0.88
Gore	8.447702996	35.48280514	0.57	0.75
Lekemte	9.141072419	36.5532516	0.74	0.78
Kitale	1.019089	35.0023048	0.2	0.71
Kasese	0.1698986	30.078078	0.36	0.61
Kakamega	0.2827307	34.7518631	0.26	-
Masindi	1.6873134	31.7138458	0.35	0.43
Moroto	2.5282234	34.6579985	0.73	-
Gulu	2.769612617	32.28884018	0.63	0.56
Lira	2.2580829	32.8874067	0.65	-
Mwanza	-2.5164305	32.9174517	0.71	0.41
Bukoba	-1.3296409	31.8050125	0.38	0.51

TABLE 2. List of LIS parameters in $kg/m^2.S$ used for estimating deep percolation in Nile basin and the conversion factor per each one to m^3/km^2

Short name	Units	Long name	Conversion factor (m^3/Km^2)
Rainf	kg/m^2s	Rainfall rate	86.4 X10^6
Evap	kg/m^2s	Total Evapotranspiration	86.4 X10^6
Qs	kg/m^2s	Surface runoff	86.4 X10^6
Qsb	kg/m^2s	Subsurface runoff	86.4 X10^6
DelSoilMoist	kg/m^2	Change in soil moisture	1000
DelIntercept	kg/m^2	Change in interception storage	1000

TABLE 3. Statistical One-Sample t-Test results obtained by SPSS 15 for estimated and observed rainfall data in 2013

	Test Value = 0					
	t	df	Sig. (2-tailed)	Mean Difference	95% Confidence Interval of the Difference	
					Lower	Upper
Observed	1.224	31	0.230	0.785938	-0.52340	2.09527
Estimated	1.954	31	0.060	0.931500	-0.04086	1.90386

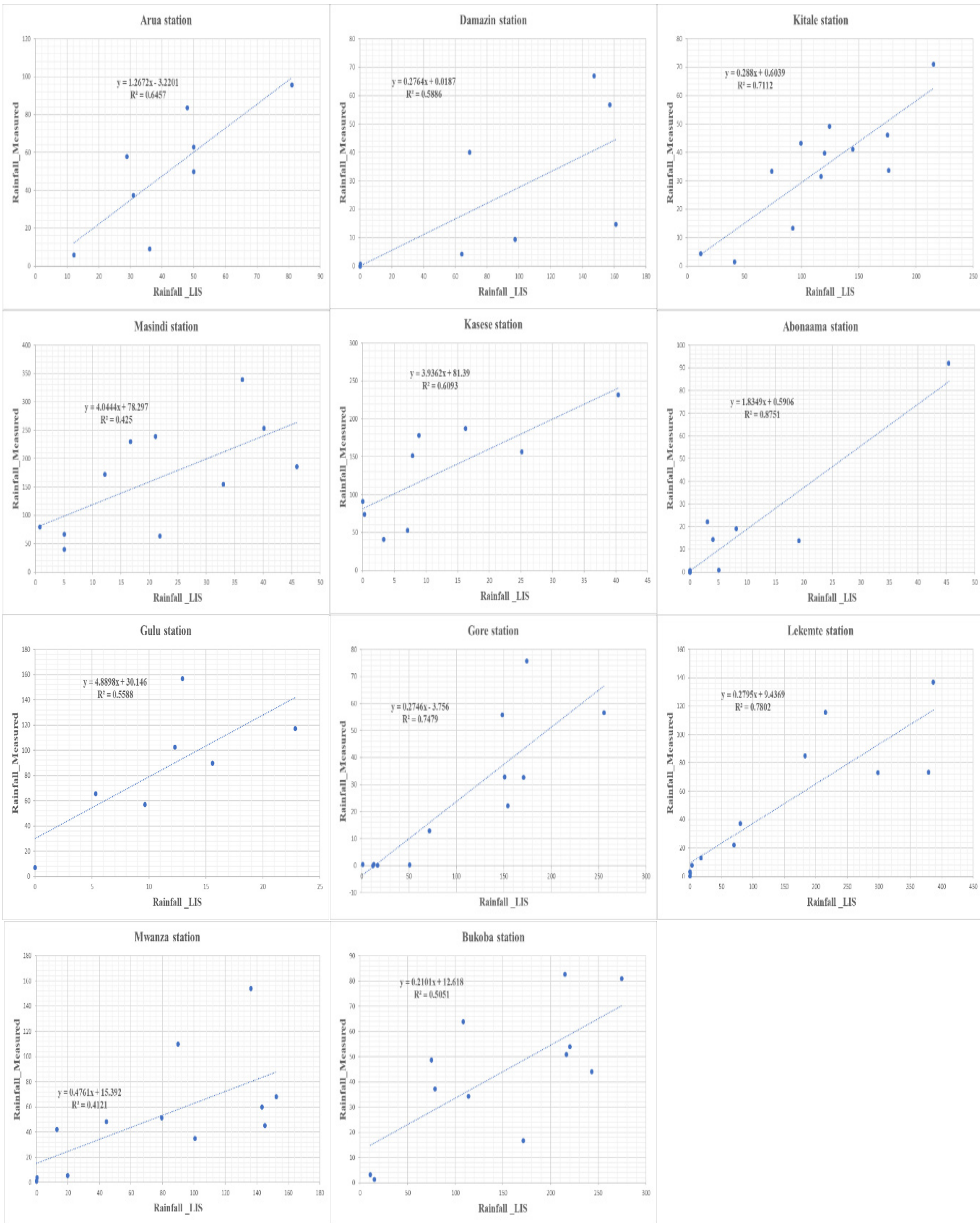

Fig. 3. The measured rainfall and LIS estimated rainfall relation during the year 2013 on monthly basis

Fig. 4. The Terra-Climate ET and LIS estimated ET relation during the year 2013 on monthly basis

Values of R^2 were found to be in acceptable range ($\geq$ 0.61) for rainfall in various stations along the basin. However, low R^2 values ($0.59 \geq R^2 \geq 0.41$) were found in Damazan, Masindi, Gulu, Mwanza, and Bukoba weather stations. For ET rates, R^2 values were higher than 60% in the majority of weather stations despite being in lower rates in Kitak, Kasese, Kakamega, Masindi, and Bukoba weather stations. The accuracy level of the obtained results from the model is acceptable. Yet, it is not considered to be at its utmost levels as it is better to conduct the study of at least 15 consecutive years which means to deal with enormous amount of data. This will require using supercomputers and more extensive data set for more accurate results.

Rainfall

Rainfall rates on monthly basis average for Nile basin during 2013 are presented in Fig. 5. Results revealed that total rainfall rate, in general, is higher in the Nile basin upstream countries than in Egypt at the far end of the Nile downstream. For the geographic location of each Nile basin country, please refer to Figure 1. Rainfall intensification in 2013 started to increase in April with maximum of 20.92 mm day^{-1} in Tanzania, Uganda and parts of Ethiopia. The highest rainfall rates were registered in July 2013 for the same areas with maximum rate of 26.97 mm day^{-1}. This coincides with what was observed by Arkin and Meisner (1987) who used RS to estimate rainfall based on the relationship between cloud top temperature statistics and convective rainfall on a large scale. This also agrees with the obtained results by Gairola et al. (2014), Bhandari and Varma (1995) and Arkin et al. (1989) who had cautioned against the applied techniques without extensive validations as well. In Egypt (downstream the Nile basin), P were extremely lower than upstream reaching its maximum in winter during January and February with no more than 4 mm day^{-1}. This follows the common pattern in downstream the river where its countries are located in arid and semi-arid areas characterized with low P rates. Areas downstream specially, in Egypt relay on Nile water annual share for all economic and domestic activities (Noaman, 2017).

Surface and subsurface runoff

Surface runoff (R_s) rates on monthly basis for the Nile basin during the year 2013 is presented in Fig. 6. Rates of R_s were almost coincided with the P rates for same location and time. It reached its maximum in April (6.53 mm day^{-1}) in in Tanzania, Uganda and parts of Ethiopia when rainfall rates were at its highest levels. During July and August, the highest R_s rates were observed in Ethiopia (15.92 and 14.17 mm day^{-1}, respectively) where higher rates of P were registered as explained before. On contrary, R_s rates downstream in Egypt were almost zero. This is due to the low P rates and the positive impact of water management projects that aims to increase water use efficiency and reduce water loss. The elevated R_s rates were also subjected to the high elevation levels in the upstream countries, *i.e.* Tanzania, Uganda and Ethiopia (Fig. 1) compared to in downstream.

Subsurface runoff rates (R_{sb}) for each month in 2013 in Nile basin are presented in Figure 7. The R_{sb} rates were found to be higher in upstream countries than in downstream following the observed R_s pattern except for the North of Sudan. In April, the highest R_{sb} rates (15. 07 mm day^{-1}) were observed in Tanzania, Uganda and parts of Ethiopia. In July, the maximum subsurface flow rates (15.20 mm day^{-1}) were registered in Ethiopia. In Downstream, Egypt experienced small amounts of R_{sb} rates (~zero mm day^{-1}). However, relatively higher levels of R_{sb} rates especially, in January (4.87 mm day^{-1}) were detected in Sudan despite the observed low P and R_s in this area. This may be due to the presence of the Nubian Sandstone in Sudan that acts as a subsurface reservoir to recharge the aquifer in this area. In addition, the adopted techniques in Sudan for increasing groundwater recharge that includes building small retention dams and infiltration ditches as well as creating sub-surface dams of cut-off walls to intercept the sub-surface flow could play a relevant role in increasing the R_{sb} in this area.

Change in interception storage and soil moisture

Change in interception storage (I_s) in the entire Nile basin in 2013 is presented in Figure 8. An obvious fluctuation in I_s from month to another is observed along the Nile basin. Generally, It is lower in the Nile downstream than upstream. The observed higher rates of I_s in downstream were registered in winter during November (9.00 mm day^{-1}), December (9.00 mm day^{-1}) and January (67.58 mm day^{-1}) 2013. For the rest of the year, the I_s rates downstream were near to zero. This is probably because of the vast desert area downstream where precipitation is, and the majority of the leading causes of interception storage are null.

Change in soil moisture content (ΔS) is presented in Fig. 9. Values of ΔS were observed to have the same pattern of rainfall. Whenever and wherever P rates are high, ΔS rates are high as well. The maximum rates were registered in Ethiopia during summer in July 2013 (15.84 mm day^{-1}). In Tanzania and Uganda, the highest rates were monitored through March to May (15.79 to 19.94 mm day^{-1}) which coincides with the observed higher P rates in these are at same time of the year.

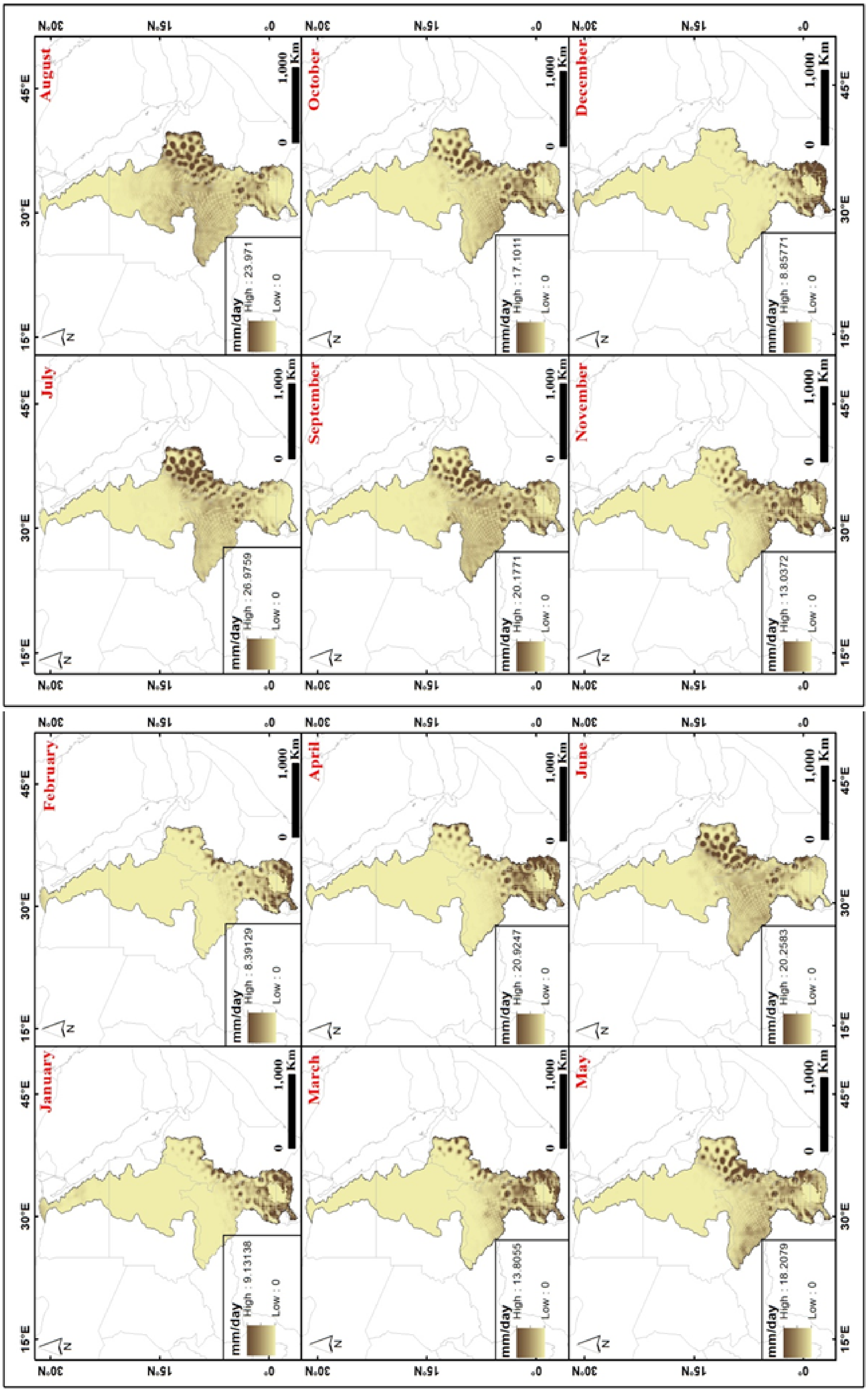

Fig. 5. Map for the rainfall rate in Nile basin during the year 2013 on monthly basis

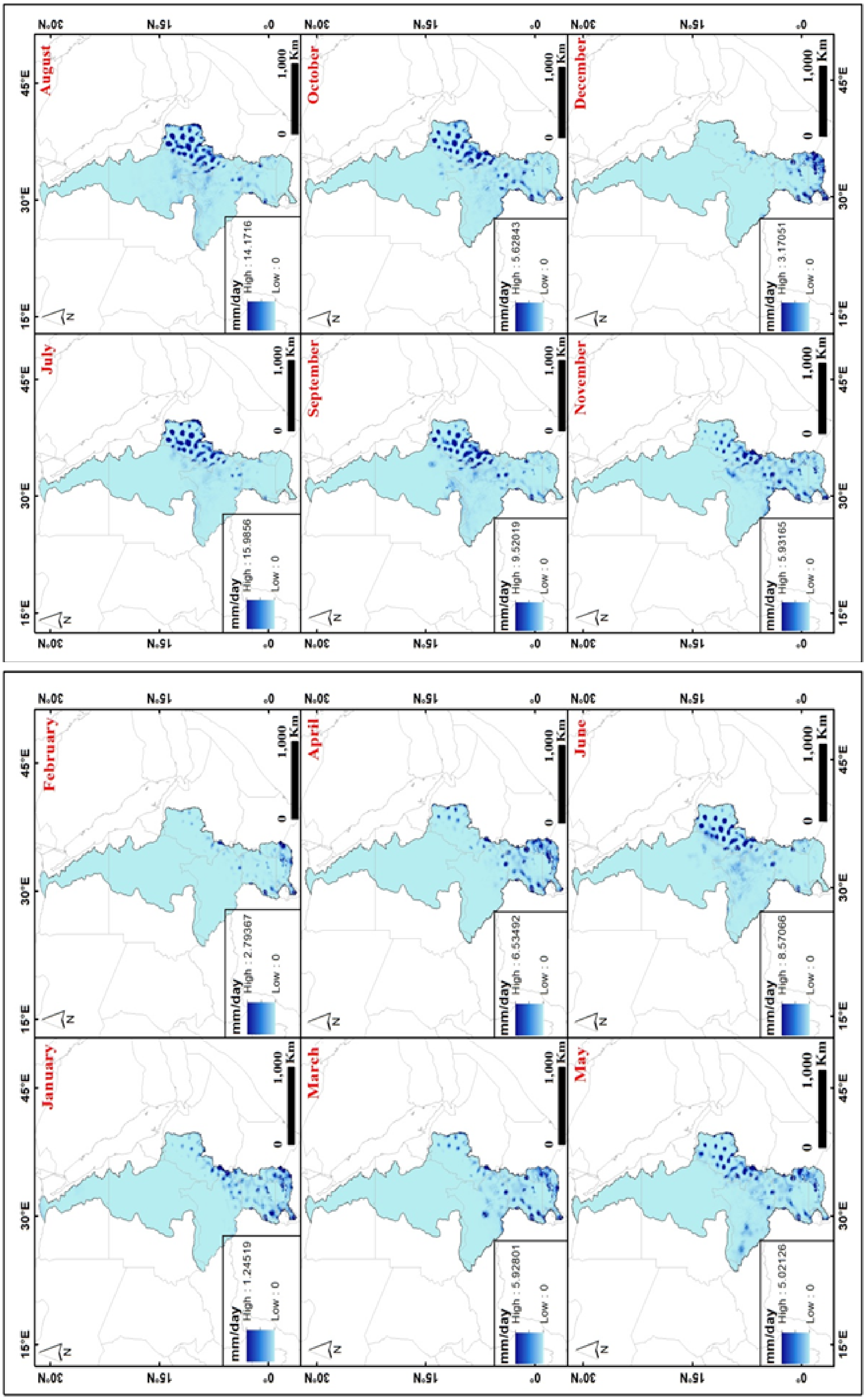

Fig. 6. Map for the surface runoff rate in Nile basin during the year 2013 on monthly basis

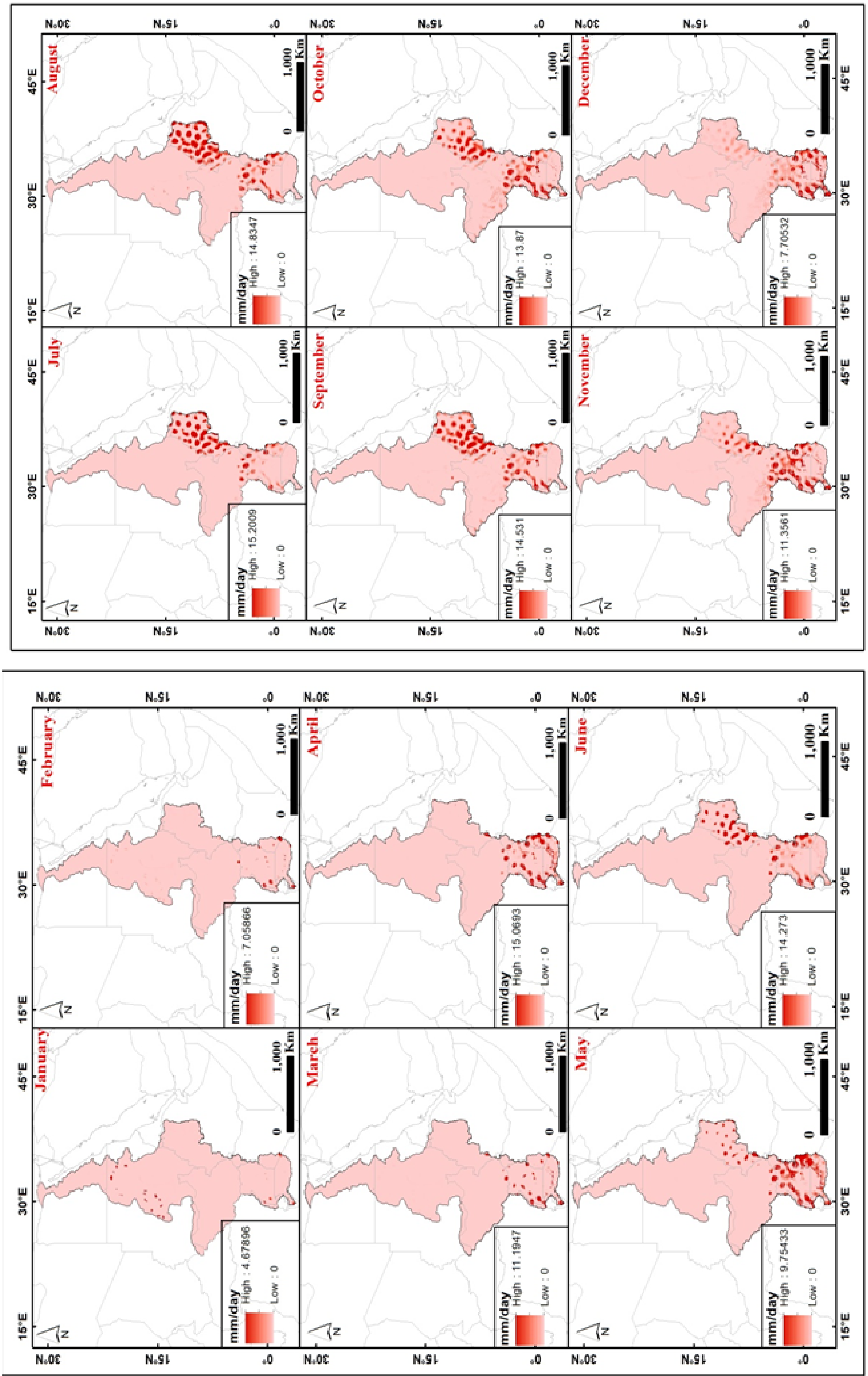

Fig. 7. Map for the subsurface runoff rate in Nile basin during the year 2013 on monthly basis

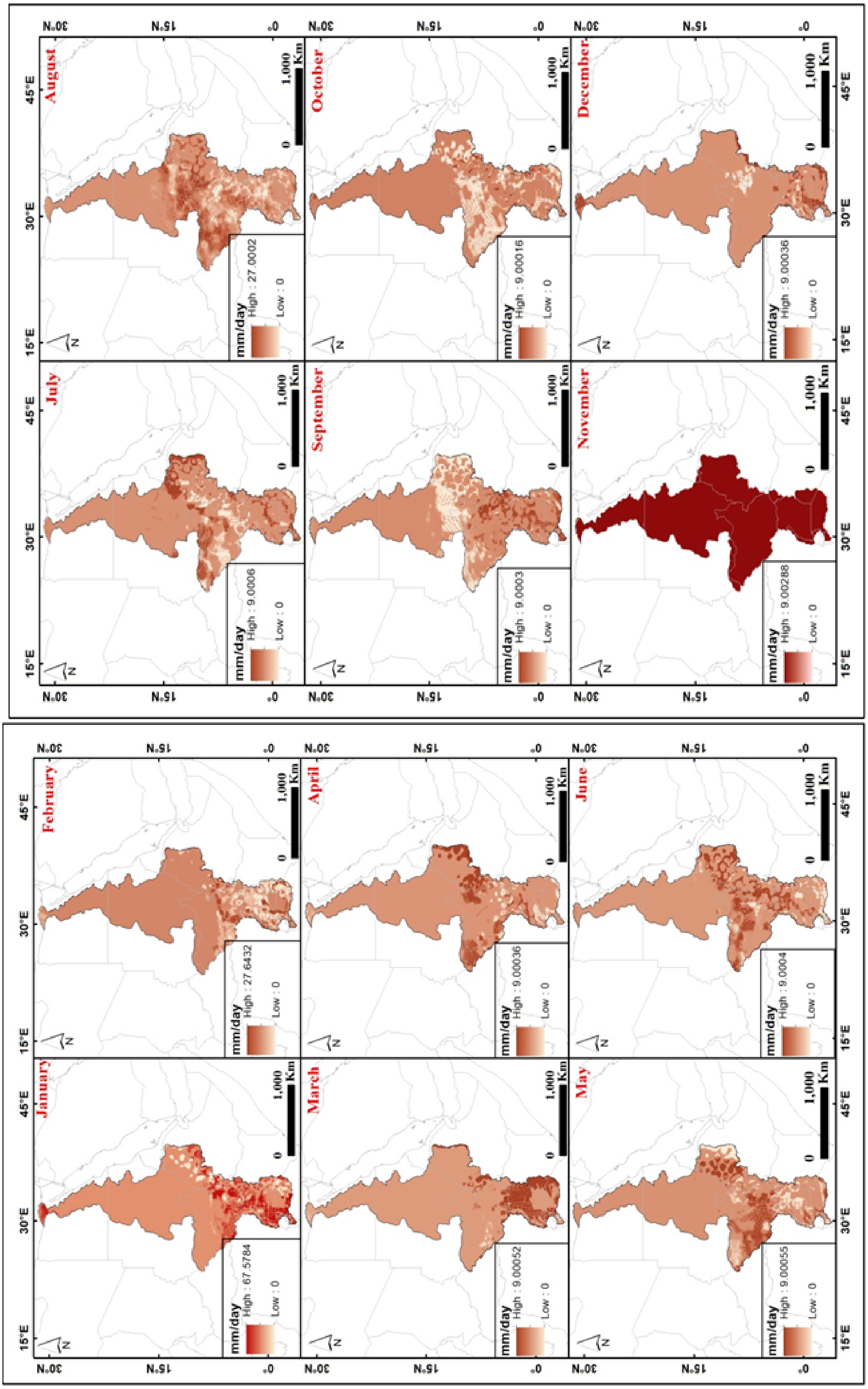

Fig. 8. Map for the change in interception storage in Nile basin during the year 2013 on monthly basis

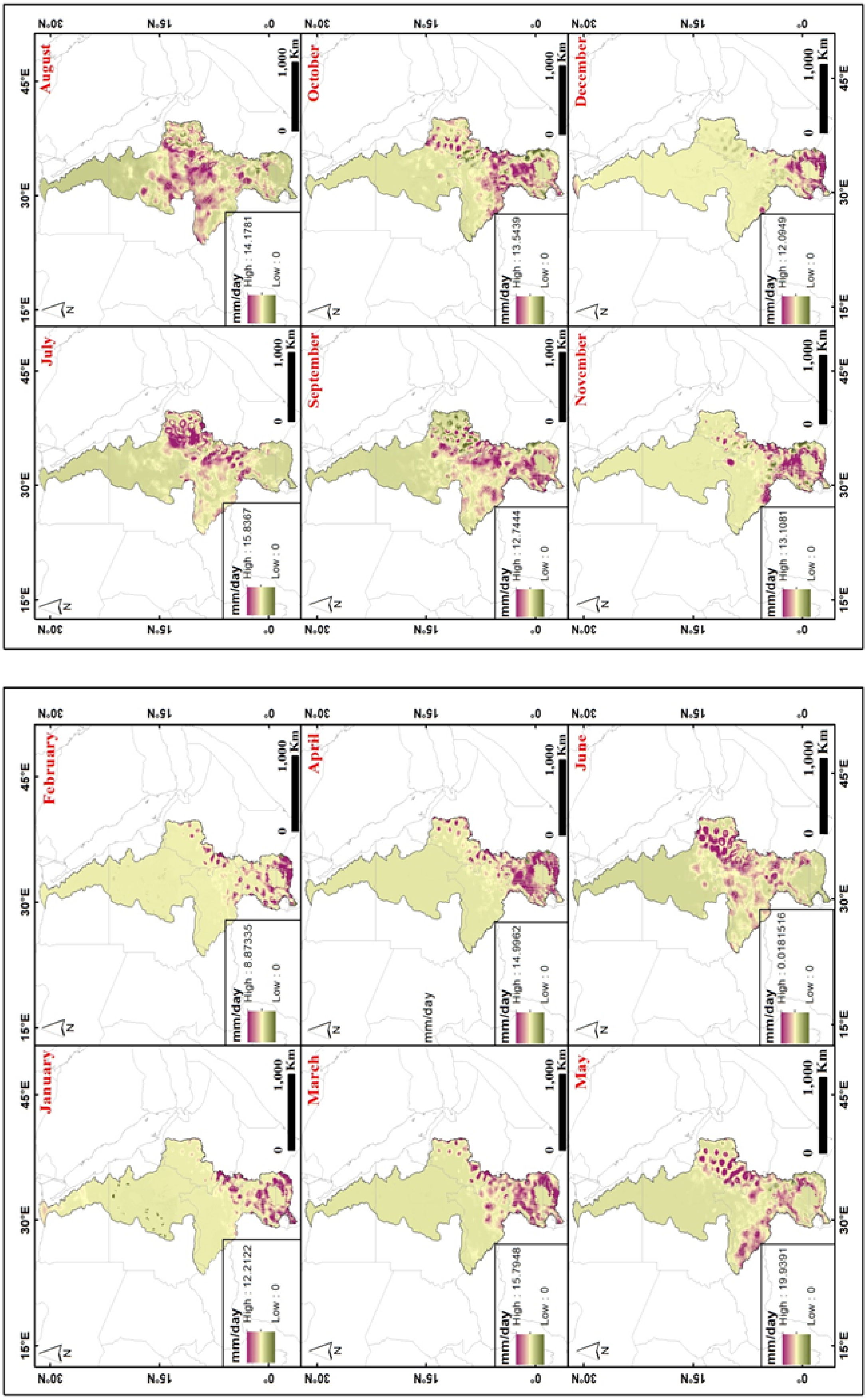

Fig. 9. Map for the change in soil moisture rate in Nile basin during the year 2013 on monthly basis

Total evapotranspiration

Evapotranspiration rates for the year 2013 are presented in Fig. 10. Higher ET rates were observed during summer than during winter in both down- and upstream countries. The elevated rates of ET in Egypt (downstream) are mainly due to the high temperature in summer and agricultural activities especially irrigation practices (Noaman, 2017). In upstream countries, ET rates coincide with the high rainfall rates in these areas, especially in the summer season.

Estimated deep percolation

The map for the estimated deep percolation rates in Nile basin based on the SWB equation in 2013 is presented in Fig. 11 on a monthly basis. DP reached its lowest rates along the Nile basin during November and December 2013 where the highest rate at this time (1.79 mm day^{-1}) was observed in Egypt. During summer, In Egypt, the DP rates ranged from 6.64 to 9.80 mm day^{-1}. These rates were relatively higher in Sudan at the same time of the year where they varied from 8.00 to 19.63 mm day^{-1}. The observed higher DP rates in Sudan may be attributed to the Nubian sand stone and development projects to increase aquifer recharge rates in Sudan as explained above. The highest rates of DP where observed in Ethiopia during the period from April to July and ranged from 12.68 to 19.63 mm day^{-1}. The observed DP spatial distribution pattern along the Nile basin during 2013 may be due to the low elevation level of the downstream countries, as shown in Fig. 1. The elevated areas in upstream countries encouraged runoff rates (both surface and sub-surface) to be increased, especially when rainfall is high. The downstream area at this scale acts as a large catchment for the runoff water from the upstream countries, and it is used to recharge the aquifer.

Projected DP rates in Nile basin based on available topographic and geological maps, soil texture, porosity, bulk density, and vegetation cover are presented in Fig. 12, in which “low” refers to the highly compacted heavy textured soil and/or hard parent materials while “high” is for loose plain soils. The integration overlaying of different abovementioned layers has a good indicator for predicting where the higher and lower rates of DP could be located. According to the obtained results, the potential to have moderate deep percolation rates could be found in downstream (Egyptian Nile valley) and in Uganda (upstream). This would be thanks to the observed soil texture that varies from clay to clay loam in these regions accompanied with the relatively lower elevated lands (Fig. 1). It could be found as well that the lower DP rates are expected to be found in high elevated lands associated with rocky areas with high slope percentage.

Conclusions

NASA Land Information System (LIS) model is capable of reasonably estimating deep percolation indirectly based on soil water balance equation. Results of deep percolation rates are conjunction with rains meanwhile associated with the topography. Where higher rates could be found in the loose soil with low slope and low in rocky areas in elevated zones. The interaction between surface and groundwater flow is accounted in the LIS model. The preliminary results reveal that LIS could also be useful to estimate many items that could assist both scientists and decision-makers for better water management on a large scale such as precipitation, actual evapotranspiration, change in soil moisture and surface and subsurface runoff.

However, further investigation is required, on the long term, for more precise model calibration and validation in different agro-climatic zones in Egypt. This will require access to field data or data collection for long run estimation. It will also need access to long-term meteorological data for proper data validation. SNAP program is recommended for processing and saving data exported from LIS and proved its efficiency in work and analysis time management.

Acknowledgment

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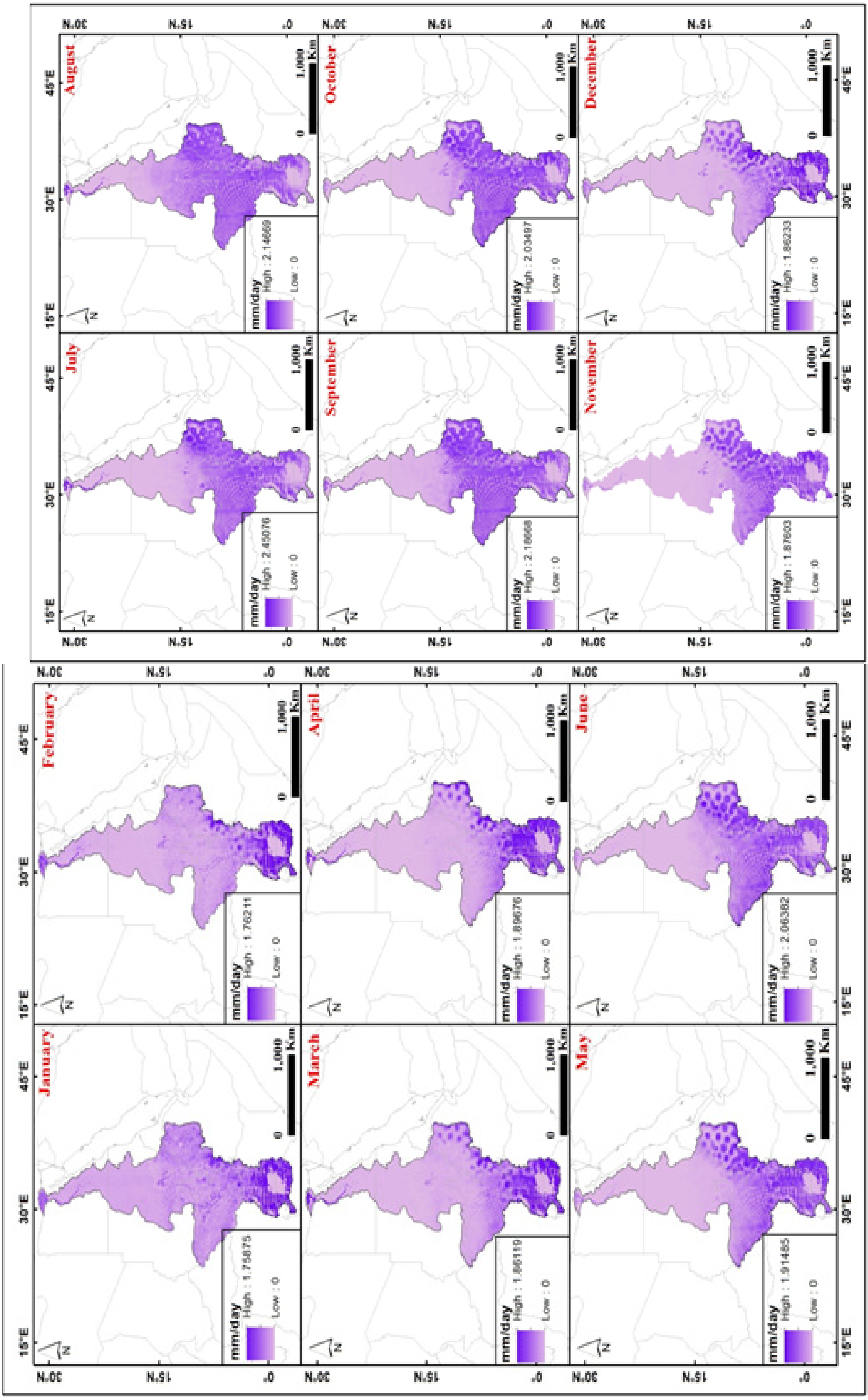

Fig. 10. Map of total evapotranspiration rate in Nile basin during the year 2013 on monthly basis

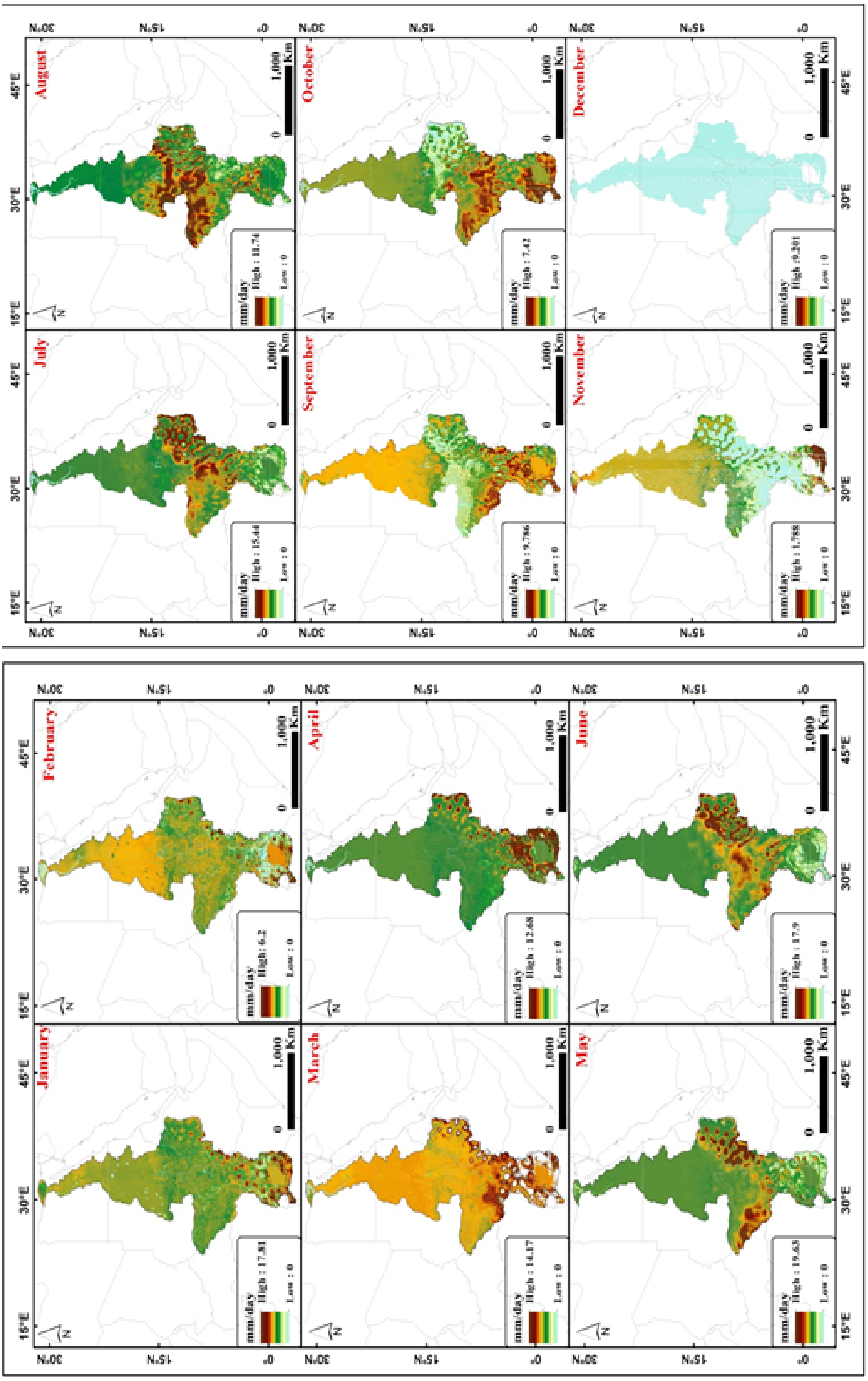

Fig. 11. map of the estimated deep percolation rates in Nile basin based on the SWB equation in 2013

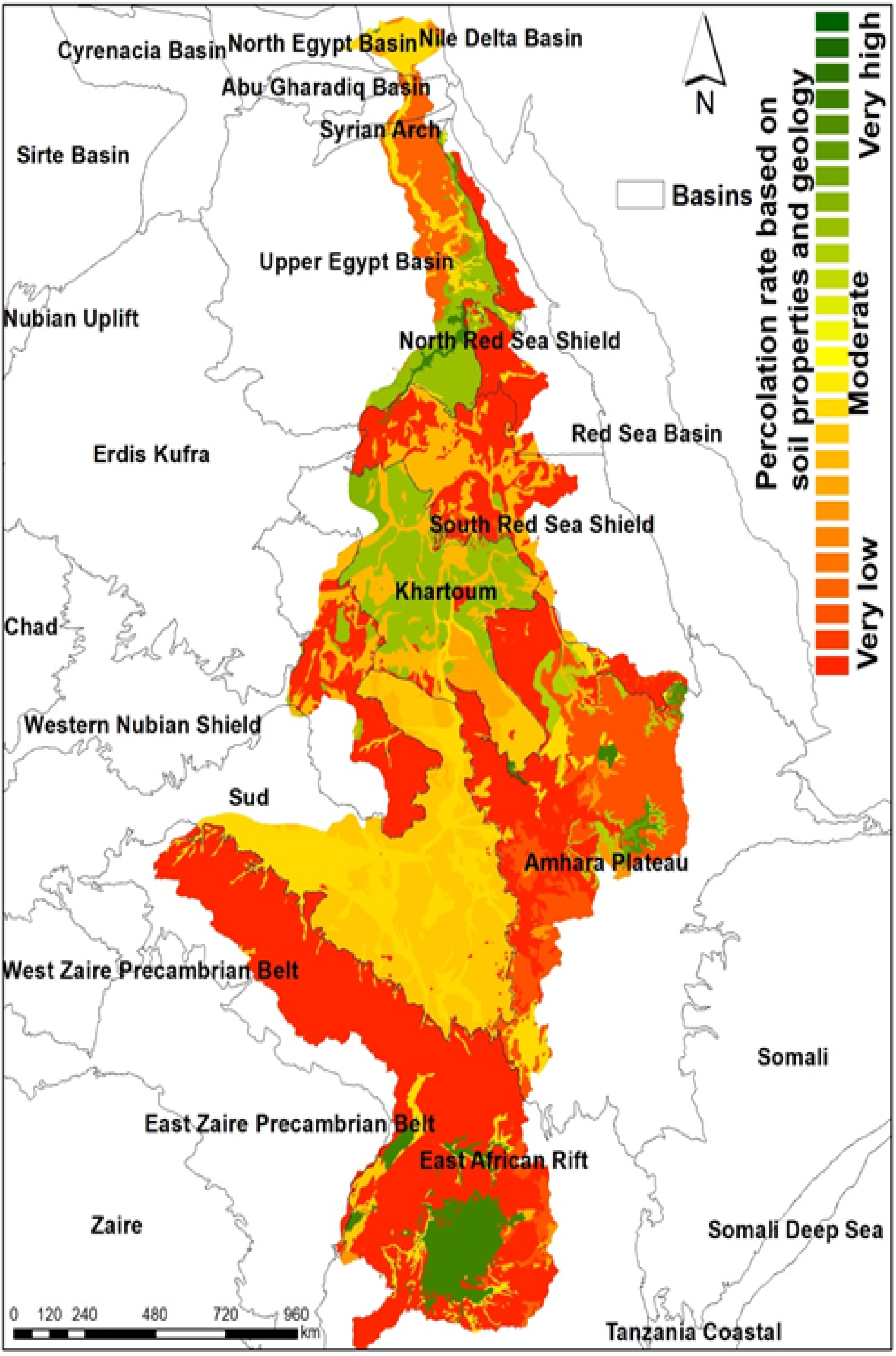

Fig. 12. Projected deep percolation rates based on soil properties and geology in Nile basin

Symbols and abbreviation list

ΔS: Change in soil moisture content in root zone
Cr: Capillary rise
DP: Deep percolation
ET: Evapotranspiration
GLT: Geographical lookup table
I: Irrigation
I_s: Change in interception storage
LIS: Digital Elevation model
P: Rainfall
Q_i: Water mass added to the root zone
Q_o: Water mass withdrawn from the root zone
R: Runoff
RS: Remote sensing
R_s: Surface Runoff
R_{sb}: Subsurface runoff
SWB: Soil water balance

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التقدير غير المباشر للتسرب العميق باستخدام معادلة توازن ماء التربة ونموذج ناسا لمحاكاة الأرض (LIS) من أجل إدارة أكثر استدامة للمياه

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يعتبر التقدير الدقيق لمعدل شحن المياه الجوفية من العوامل الأساسية في التخطيط المستدام لاستخدام الموارد المائية. يلعب فقد الماء بالرشح العميق دورا هاما في إعادة شحن المياه الجوفية. فعلى الرغم من أن فقد الماء من قطاع التربة يعتبر من العوامل التي قد تؤثر سلبا على كفاءة عملية الري على مستوى المزرعة، إلا أنه يعتبر أحد العوامل الرئيسية في إعادة شحن المياه الجوفية عند دراسته على نطاق واسع مثل نطاق حوض النيل.

تعتبر عملية التقدير الدقيق لمعدل شحن المياه الجوفية بالرشح العميق للمياه مكلفة جدا خاصة عند دراستها على مستوى حوض النيل أو غيره من الأنهار، ولذلك يلجأ الباحثون حاليا لمحاولة تقدير فقد الماء بالرشح العميق باستخدام نظم المعلومات الجغرافية والاستشعار عن بعد بشكل غير مباشر. وتهدف الدراسة البحثية المقدمة إلى التحقق من قدرة نموذج نظام معلومات الأرض المطور من قِبَل وكالة الفضاء الأمريكية (ناسا) على تقدير كمية فقد الماء بالرشح العميق في منطقة حوض النيل باستخدام معادلة الميزان المائي للتربة. حيث تم أولا معايرة بيانات هطول الأمطار المستخرجة من النموذج بقيمها المتحصل عليها من محطات الأرصاد الجوية المقابلة لها في مناطق مختلفة على طول حوض النيل حيث تم اختيار هذه المناطق بشكل عشوائي تام. بعد التحقق من البيانات، تم عمل خرائط متعددة الطبقات لمنطقة حوض النيل توضح كمية الماء المفقودة بالرشح العميق. معدلات سقوط الأمطار، معدل التغير في رطوبة التربة ومعدلات البخرنتح الحقيقي وكذلك معدل الجريان السطحي في منطقة الدراسة كمدخلات ضرورية لمعادلة الميزان المائي للتربة. تم انشاء الخرائط بناء على البيانات المستخرجة من نموذج نظام معلومات الأرض لعام ٢٠١٣ وبدقة مكانية ١٠ كم^{٢}.

وتكشف نتائج الدراسة البحثية كفاءة نموذج نظام معلومات الأرض والمطور بواسطة وكالة الفضاء الأمريكية في تقدير كمية الماء المفقودة بالرشح العميق في منطقة حوض النيل بطريقة غير مباشرة معتمدة على الميزان المائي للتربة؛ حيث وجد أن معدل فقد الماء بالرشح العميق كان أعلى في دول المصب عنه في دول المنبع لحوض النيل، وهذا مخالف لسلوك حركة المياه السطحية والجوفية السطحية. ويفسر هذا السلوك ارتفاع معدل الأمطار في دول المنبع عن دول المصب والمقترن بارتفاع سطح الأرض في دول المنبع عن مستوى سطح البحر مقارنة بدول المصب. كما أنه من المتوقع أن الأراضي المنخفضة ذات البناء المتفكك والقوام الخفيف تكون له قدرة أعلى على حفظ الماء لشحن المياه الجوفية من الأراضي المرفعة والصخرية والتي تشجع عملية الجريان السطحي في أعالي حوض النيل ودول المنبع — كما أثبتت نتائج البحث - وهي العملية التي لا تسمح للماء باختراق سطح التربة؛ وبما أن معدل الجريان السطحي في دول المصب منخفض نسبيا عن دول المنبع، فقد سمح ذلك بدخول الماء لطبقات التربة والرشح العميق لها وما يترتب عليه من إعادة شحن للمياه الجوفية في دول المصب. وتعتبر نتائج هذه الدراسة ذات قيمة كبيرة عند التخطيط المستدام لاستخدام الموارد المائية بمصر. ويلزم لذلك دراسة طويلة الأجل لمعايرة النموذج والتحقق من صحته في مختلف المناطق المناخية الزراعية المختلفة لجمهورية مصر العربية. ومع ذلك، فإن هذا يتطلب إجراء دراسات وقياسات ميدانية مكلفة لكافة عناصر الميزان المائي للتربة وجمع بيانات الأرصاد الجوية للتحقق من صحة البيانات المستخرجة من النموذج على مستوى جزء صغير من حوض النيل وهو جمهورية مصر العربية.