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Evaluation of Surface Energy Balance System (SEBS) Model for Estimation of Evapotranspiration in Eastern Ethiopia

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Abstract
Quantification of evapotranspiration (ET) is needed for a wide array of applications especially for water resources management. ET estimation by using either ground based direct measurement or modeling by using in-situ based meteorological variables is found cost inefficient or for some geographic areas it might be impractical. This issue is specially challenging in data scarce regions. This study evaluates remote sensing based surface energy balance system (SEBS) in arid and semi arid eastern Ethiopia. After undertaking a series of pre-processing and processing phases, surface parameters has been generated from MODIS level 1B products for dry season and dekadal composites from spot vegetation, down welling surface short web flux from LSA SAF and near surface meteorological variables from GLDAS has been utilized. By ingesting these parameters at prepackaged SEBS model, ET has been estimated. For comparative analysis, MSG ET with FAO-PM has been utilized. Our findings have shown that estimated ET ranges from 0 to 10 mm day $^{-1}$ with large spatial variability. In areas that are well vegetated, SEBS provides larger values both at dry and wet seasons but at arid and semi-arid vast expanses of the study site there is found very lower ET value at dry season and increases with vegetation regeneration in the summer season. It was observed that at both dry and wet seasons SEBS ET values were over estimated than MSG ET product and underestimated than FAO-PM values. These under and over estimations were very large at arid and semi-arid areas which is attested from point based analysis undertaken using meteorological stations located at different climatic characteristics. Our study confirmed that, though SEBS model provides reasonable results it is sensitive for vegetation cover of a site. Taking these into consideration there should be comparative analysis of the model with direct field measurements for more certainty.
Keywords: Evapotranspiration, Eastern Ethiopia, SEBS, Remote sensing

1. Introduction

Regional scale knowledge about evapotranspiration pattern helps better understanding of hydrological, climatic and carbon cycle interactions (Ambrose & Sterling, 2014). In addition to these, estimated evapotranspiration is used as premier variable for many practical applications like drought assessment (Wondimagegn, 2006) prediction and early warning (Tinebeb, 2012; Tewelde, 2012), environmental stress and vegetation monitoring (Cristobal *et al*., 2011; Henok *et al*., 2014; Senay, 2015), crop growth and yield simulation (Casa & Ovando, 2012), water resources management and crop water management for irrigation (Jia *et al*., 2007), root zone volumetric soil moisture content estimation (Hain *et al*., 2009), soil and water conservation planning (Morgan, 2005), environmental water availability resource assessment (Gibson *et al*., 2009). With these range of functionalities, for a long period of time and even today, evapotranspiration is being estimated by using models that consume datasets collected from conventional *in-situ* measurements. But this is extremely challenging in areas where there are scarce *in-situ* data measurement. Remotely sensed distributed hydrological models are recommended tools to estimate evapotranspiration in areas where there exists scarcity of *in-situ* hydro-meteorological variable observation or completely impractical to measure (Tenalem, 2003; Wosenu & Assefa, 2013).

More importantly, there is acute *in-situ* based meteorological data observing stations in the study area. There ere only 19 stations with full data set used to estimate reference evapotranspiration within 461,398 km^2. By taking this into account, model evaluation for frequent evapotranspiration estimation from satellite data to get pixel level information is found an essential task. Additionally, most parts of the study area were also reported as prone for recurrent drought and precipitation deficit (CSA *et al*. 2010) that demands critical studies to aide appropriate water resources management that evapotranspiration estimation is part and parcel of the activity. To these end if evapotranspiration is estimated from in-situ measurements sparsely located in vast study area, there is a possibility of inferring generalizations from single measurements for wide area. This can lead to biggest interpolation errors as point density has implications on accuracy of created evapotranspiration values (Zhang *et* *al*., 2015)

Therefore, characterization of space based regional evapotranspiration is a principal component of environmental evaluation in arid environment (Ma *et al*., 2014).Taking the urgency of effective water management and optimal planning for sustainable world, it demands quantitative estimation of evapotranspiration (Yan *et al*., 2014). Though, current remote sensing technology is to its fore front to accurately estimate surface energy fluxes between earth's surface, sun and the atmosphere, accurate estimation of energy flux and evapotranspiration is still a concerted research environment as it needs the account of intricate systems in energy balance exchange (Liou & Car, 2014). In arid and semi arid areas where knowledge of evapotranspiration is demanded for better water resources management, remote sensing based evapotranspiration estimation is found a better alternative. Taking this into account the objective of this study was estimation of ET by remote sensing based Surface Energy Balance System (SEBS) and evaluation of the model performance at data scarce, arid and semi arid eastern Ethiopia

2. Methodology

2.1. The Study Area

Geographically, the study area is found within 3°32'56" and 9°52'8" North Latitude and 39°9'43" and 48°0'0" East Logitude (Figure 1)

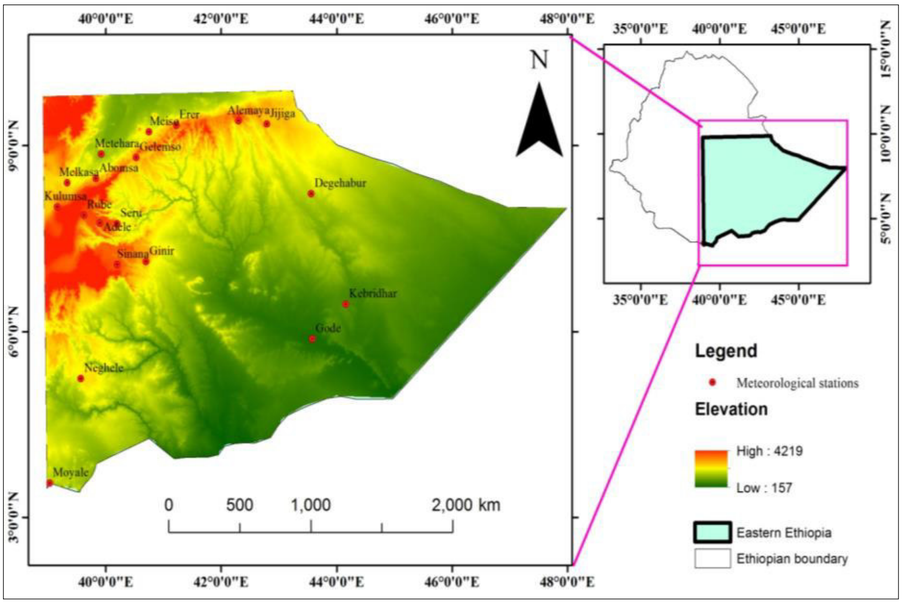

Figure 1: Location map of the study site in Ethiopia

The geographic extent of the study site encompasses the whole area stated as eastern Ethiopian census division (CSA *et al*. 2006). As it was presented there, in its relative position the study site covers eastern and south eastern Ethiopia. It has a total area of 461,398 km^2. It incompasses from a drought prone pastoral and agro-pastoral lowlands to afroalpine climatic situations (CSA *et al*., 2006). The study site is covered by various soil types that simultanously vary with physiography and climatic characters. The northern extremes and highland areas around the eastern marigins of Central Ethiopian Rift Valley are dominated by Leptosols, Cambisols, Vertisols and Luvisols. Its eastern extreme around the low lands of Somali and its east central part is dominated by Calsisols and Gypsisols (CSA *et al*., 2006; CSA & IFPRI, 2013). The study site is also characterized by seven broad vegetation classes ranging from desert to afroalpine vegetation (Zerihun, 1999). The northern, eastern and east central part of the study site is dominated by open xerophytic woodland vegetation. The area is dominated by desert and semi-desert ecosystem vegetation. Because of this, the flora has developed high xeromorphic adaptation; trees and shrubs have developed dwarf growth with small, sclerenchymatic or pubescent leaves (USAID, 2008).

2.2. Data Sources

The study has utilized differrent surface parametres and near surface meteorological variables from different sources. The data sources used for this study are MODIS level 1B calibrated products for derivation of surface reflectance and surface parametres used for SEBS model at the dry season, downwelling surface short web flux from LSA SAF, image based surfce metreological variables from Global Land Data Assimilation (GLDAS), dekadal vegetation composites from spot vegetation used for summer season and point based metreological data is utilized from Ethiopian National Meteorological Servive Agency (ENMSA)

2.3. Derivation and Comparative Analysis of SEBS Output

By using prepackaged SEBS model, to estimate evapotranspiration three steps operation has been made. These are preprocessing of image which incorporates digital signal from level 1B MODIS product has been concerted to radiance and reflectance, brightness temperature computation from radiance bands, derivation of water vapour for atmospheric correction and undertaking atmospheric correction at reflectance bands. Following these surface parametres which are ingested to SEBS model has been estimated. These parametres include, NDVI, LAI, FVC, LST, Surface roughness characteristics from surface vegetation characteristcisb are derived. By using these parametres and image based near surface metreological variables from GLDAS, ET has been estimated by SBS model. Overall parametrization and derivation is made by following steps stated in Su (2002) by using prepackaged SEBS model at ILWIS 5.8. For comparative analysis purpose, SAF LSA based MSG daily ET product which is delivered at regional and global scale has ben processed and point based FAO-PM referrence ET has been estimated from 19 metreological stations by using ET calculator software. The comparative analysis is done by three phases. First ET values are extracted from SEBS and MSG pixels where point based station underly and correlation (r) and coeeficient of determination (R^2) is done. Second, after interpolation of point based FAO-PM using ordinary krigging, 500 random sample points has been extracted from SEBS, MSG and FAO-PM at simmilar pixel locations. These values extracted from sample pixel locations are presented by using scatter plots. Third, SEBS and SAF MSG is qualitatively compared by using spatially distributed maps.

3. Results and Discussion

As shown on Figure 2 and 3, SEBS model has shown ET that ranges from 0 to 10 mm/day at both dry and wet season with big spatial variability. In the dry season SEBS shows the presence of ET in well vegetated small highland areas while areas that are devoid of better vegetation cover has experienced very low or null ET rate. At the summer season the model has shown presence of evapotranspiration even at vast expanses of arid and semi arid areas which is associated with vegetation regeneration at the summer season. Compared to others, SEBS model has brought overestimated values than MSG ET product. MSG ET has showed presence of evapotranspiration only at areas that have better vegetation cover both at dry and wet season. In vast expanses of arid and semi-arid areas both MSG and SEBS yield null or extremely lower ET rates but relatively SEBS brought larger values than MSG ET product.

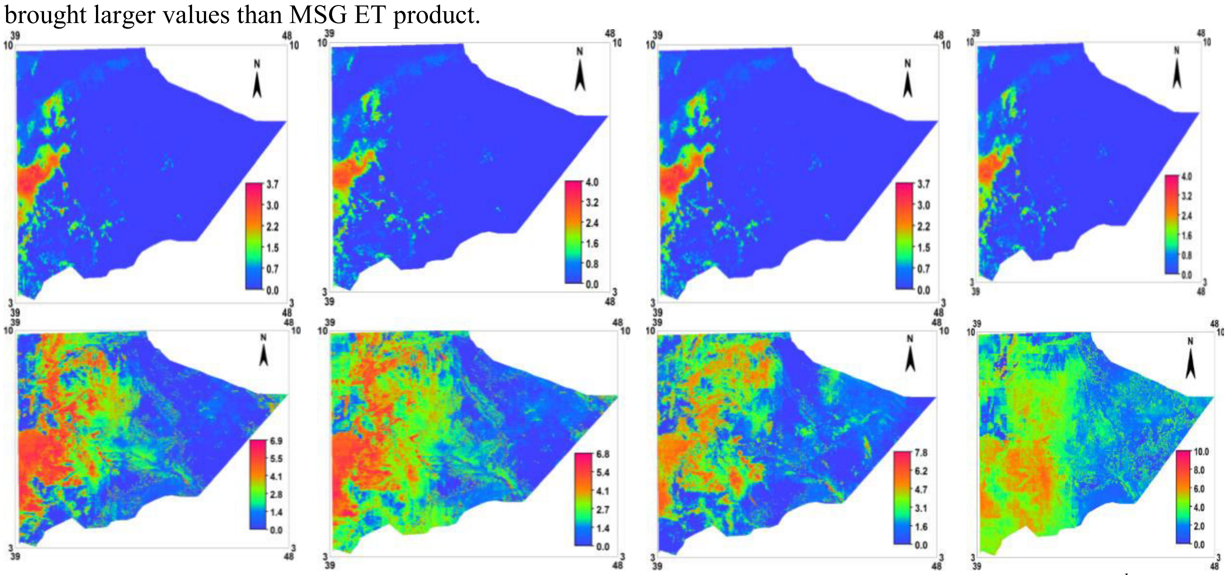

Figure 2: Comparative analysis of MSG and SEBS ET values at dry season. 1st row for SAF LSA and 2nd row for SEBS, Similar columns for similar days

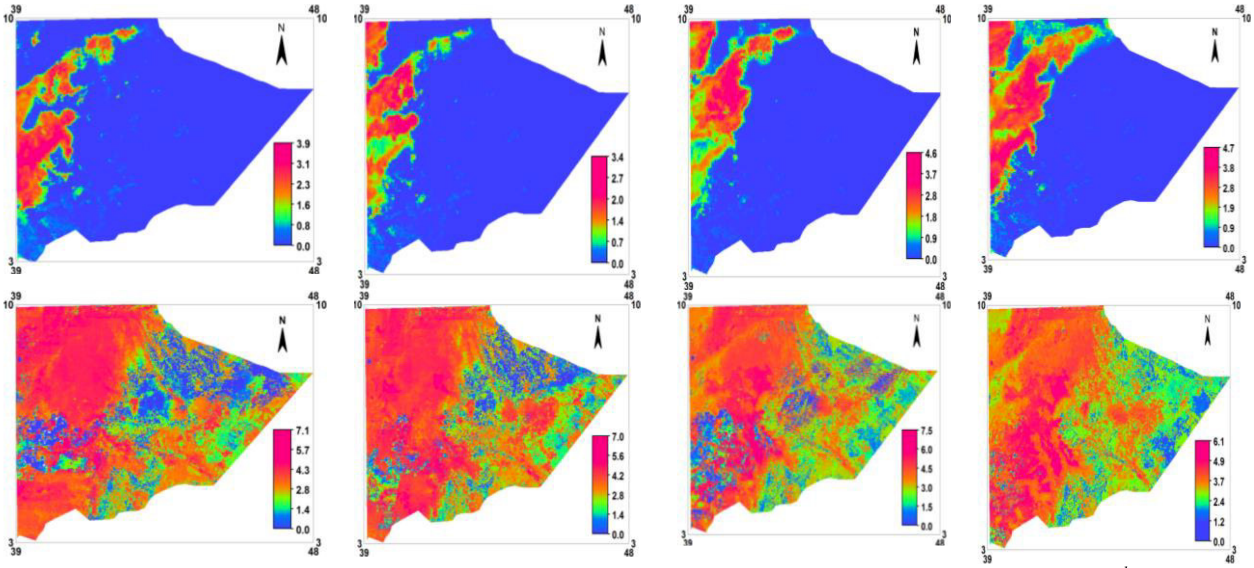

Figure 3: Comparative analysis of MSG and SEBS ET values at dry season. 1st row for SAF LSA and 2nd row for SEBS, Similar columns for similar days

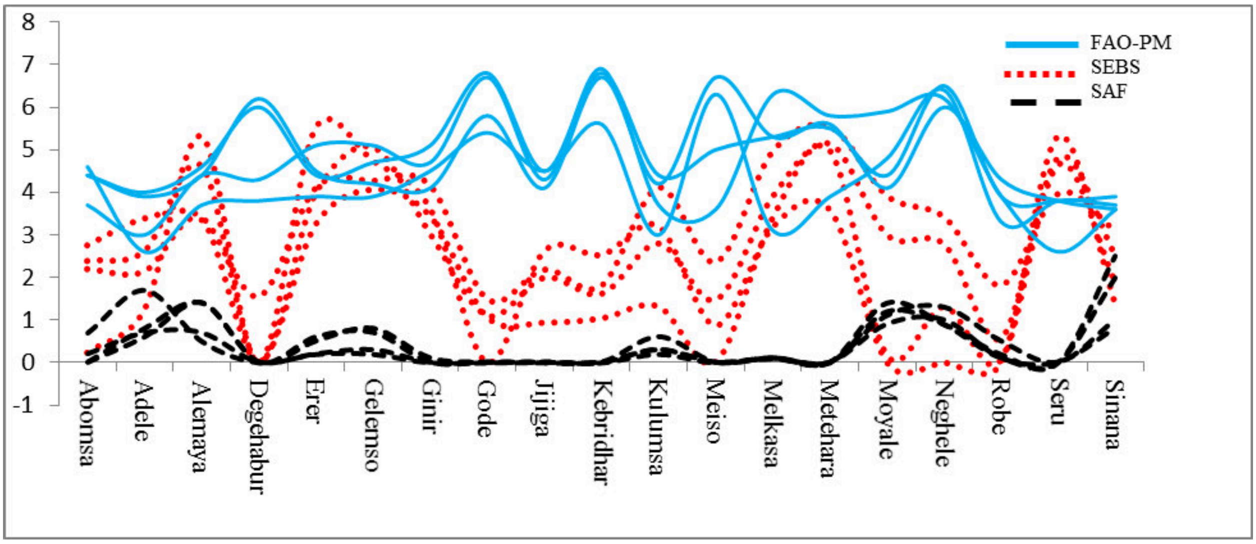

Figure 4: Point based comparison of SEBS ET with SAF MSG & FAO-PM for dry season

As shown on Figure 4, most stations SEBS model under estimates evapotranspiration values than FAO-PM model in general and specifically in stations located at arid and semi-arid sites of the study area. Seasonal vegetation dryness winter coupled with vegetation status of arid and semi-arid environment, remote sensing based SEBS model has yielded relatively lower values. In highland areas with relatively better humidity and vegetation cover like Adele, Alemaya, Ginir, Gelemso, Metehara, Melkasa and Seru, SEBS model has yielded approximate values with results of FAO-PM and MSG actual ET products. Though both SEBS based and MSG evapotranspiration products have experienced nearly similar trends, SEBS model has inflated the amount of evapotranspiration than MSG ET results. Patterns of underestimation over arid and semi arid areas have followed similar to SEBS model. As stated in Ghilain (2011) and SAF PUM (2015), this is because of evapotranspiration products that have good association but with a lot discrepancy is mainly the result of differences in model input datasets and biophysical variable derivation. Similarly, many empirical studies like Kwast *et al*. (2009), Gokmen *et al*. (2012) and Lu *et al*. (2012) have reported as SEBS model underestimates sensible heat flux in mixed landscapes where different land cover classes are aggregated to a single pixel. This underestimation of sensible heat flux intends the model to overestimate evapotranspiration. In water balance terms, the deviation can result large water balance deviations if utilized for annual water balance studies.

As lucidly stated in Lu *et al*. (2012) under complex surface cover characteristics, SEBS model is reported to overestimate evaporative fraction. In addition to under estimation of sensible heat flux, deviations of SEBS based evapotranspiration and ET generated from *in-situ* measurements is resulted from inaccuracies in model inputs and lack of energy closure in *in-situ* measurements as *in-situ* measurements does not account canopy conditions. As investigated by Huang (2015), overestimation of evapotranspiration is large in arid and semi-arid environment because of prevailing water stress condition. Similar to this, Chen *et al*. (2013) have attributed cases related with roughness length parameterization for under estimation of sensible heat flux and over estimation of evapotranspiration. Simultaneously, their result has reported the case is land cover selective, of which bare land is the most vulnerable landscape. To provide a clue to what extent SEBS model can associate with station based FAO-PM and image based MSG ET values, a correlation analysis has been run and the result is presented in the following Table 1.

Table 1: Correlation analysis of SEBS model results with FAO-PM and SAF ET values

	Wet season				Dry Season			
	FAO-SEBS		SAF-SEBS		FAO-SEBS		SAF-SEBS	
Stations	R	R^2	R	R^2	r	R^2	r	R^2
Abomsa	0.62	0.39	-0.09	0.01	-0.70	0.49	0.27	0.07
Adele	0.43	0.18	-0.48	0.23	0.28	0.08	-0.32	0.10
Alemaya	0.21	0.04	-0.68	0.46	-0.62	0.39	0.32	0.10
Degehabur	0.07	0.00	*	*	-0.43	0.18	*	*
Erer	-0.92	0.85	0.00	0.00	-0.59	0.34	0.59	0.35
Gelemso	0.98	0.96	-0.05	0.00	-0.04	0.00	0.11	0.01
Ginir	-0.90	0.81	0.86	0.74	-0.25	0.06	0.09	0.01
Gode	0.89	0.78	*	*	0.82	0.68	*	*
Jijiga	-0.47	0.22	0.61	0.37	0.85	0.72	*	*
Kebridhar	0.43	0.18	*	*	-0.77	0.59	*	*
Kulumsa	0.77	0.59	-0.53	0.28	-0.48	0.23	0.43	0.18
Meiso	0.31	0.09	-0.45	0.20	-0.97	0.94	*	*
Melkasa	0.54	0.29	-0.67	0.45	0.80	0.65	*	*
Metehara	0.90	0.80	*	*	0.98	0.96	*	*
Moyale	-0.73	0.53	-0.86	0.73	0.64	0.41	0.27	0.07
Neghele	0.27	0.07	-0.55	0.30	0.01	0.00	-0.68	0.47
Robe	0.25	0.06	-0.16	0.03	0.14	0.02	-0.63	0.40
Seru	-0.17	0.03	0.80	0.63	0.33	0.11	*	*
Sinana	-0.84	0.71	0.65	0.43	0.18	0.03	-0.63	0.40

* *Values not computed as SAF value remain zero for all observations and*

Note: Significance value is not computed as station based observations are too small that it might provide inflated results

As presented on Table 1, for the wet season SEBS model has yielded evapotranspiration values with FAO-PM potential evapotranspiration values in stations where there is better vegetation cover and precipitation that are situated in highland and adjacent highlands like Abomsa, Adele, Kulumsa, Melkasa and Metehara while Gode has better association from arid and semi arid environment. This can be attributed with seasonal vegetation greenness and summer shower rains that can yield moisture to surface for evaporative demand (Henok *et al*., 2014). In remaining stations located in arid and semi arid environment, there is inverse association (negative correlation coefficient) which is resulted from SEBS model under and over estimation of evapotranspiration value in association with reference FAO-PM model. The correlation analysis done with MSG evapotranspiration for stated stations has only shows better association for three stations – Seru, Sinana and Ginir. In stations where there is negative correlation coefficient, it does not connote the models does not provide any value rather the presence of discrepancy in ET pairs for analysis, which is resulted from under and over estimations.

Rather than simply relying on quantitative aspects; graph scatter plot is opted to have a clear clue as how the models provide ET estimates. After interpolation of *in-situ* based FAO-PM evapotranspiration values, randomly generated sample values has been extracted from SEBS, FAO and SAF MSG products at similar locations and the values is presented on Figure 5. As clearly shown on Figure 5, SEBS has yielded relatively moderate results that are higher than MSG product value which is distributed across the study area and lower than FAO-PM values in dry season. Similar to dry season, SEBS model underestimates ET than FAO-PM and overestimates than MSG values but there is a better tendency of association in some pixels taken randomly selected values. The level of over and under estimation is not uniform across study area.

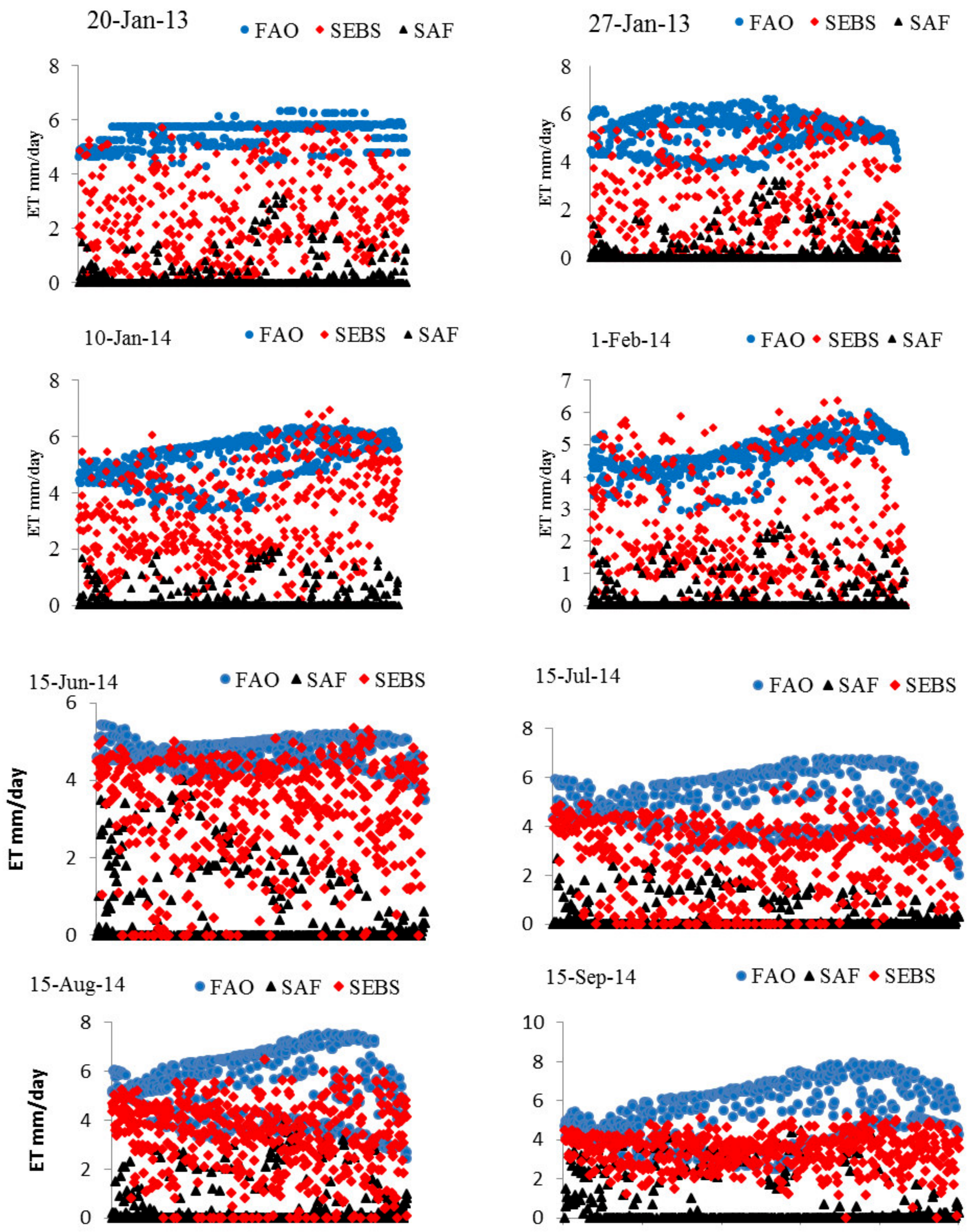

Figure 5: Comparison of randomly selected SEBS, FAO-PM and SAF ET

4. Conclusion

This study has evaluated remote sensing based SEBS model to estimate evapotranspiration at data scarce arid and semi arid eastern Ethiopia. SEBS model has brought higher evapotranspiration values in areas where there is better vegetation cover and moisture. This is ascertained from higher values in highland areas that have better vegetation and moisture both in dry and wet season and lower values at vast rid and semi arid low land part of the study area. In the summer season, following vegetation regeneration at arid and semi arid areas, SEBS shows presence of better ET values, which is an indication as SEBS model outputs are sensitive for vegetation cover of a site. Compared to other models, SEBS model has yielded evapotranspiration which is lower than FAO-PM model results and higher than MSG evapotranspiration product. Over and under estimation is large in arid and semi arid lowland areas. In some instance, disparity between remote sensing based SEBS and *in-situ* based FAO-PM is attributed to FAO-PM is potential ET and SEBS outputs are actual one. For the future there needs a further model evaluation by using direct field based ET from sentilometres measurement and FAO-PM outputs adjusted with vegetation coefficient.

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