Using Remote Sensing Techniques for Estimating Water Stress Index for Central of Nile Delta

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Abstract. Water scarcity is one of the main challenges facing water management in Egypt. This in turn will have direct impacts on the agricultural sector which is a key sector for the socio-economic development in Egypt, and plays a significant role in the Egyptian national economy. In Egypt, water resources are limited to the Nile River, rainfall, deep groundwater, and potential desalination of sea. Climate change, rapid population growth, and economic development will significantly affect the future availability of water resources for agriculture sector, which consumes about 85% of total water resources in Egypt. Therefore, continuously monitoring of crop statutes and crop water consumption plays a vital role in water resources management in developing countries such as Egypt. Recently Remote sensing techniques provide decision makers with spatial information about crop statutes and water stress at region scale. Remote sensing techniques also have the ability to monitor large areas with saving time and cost. The main objective of this study is investigating the capabilities of satellite data in monitoring of water stress and crop statues in the central portion of Nile delta by using the water stress index (WSI). The water stress index was used to identify locations of poor irrigation in order to maximize the crop yield. The proposed model was calibrated and validated against the measured data by using 20 points of ground measurements for actual evapotranspiration (ETc) and wet evapotranspiration (ETwet). The performance of the model was measured using various evaluation criteria. Validation results showed that satellite data are capable of estimating WSI since the comparison between WSI_{obs} and WSI_{est} resulted in R^2=0.5003. Therefore WSI can be considered as a quick, costless and moderate tool to provide farmers and decision makers with spatial information about crop statues and water stress.

1. Introduction
Water resources management in Egypt is considered the major obstacle that faces its future development. Egypt has very limited water resources where the Nile participates every year with fixed share (55 billion cubic meters). The agriculture sector consumes 85% of total water supplies while the crop consumption in the center of Nile delta consumes about 45% of total agriculture water[1]. The water demands in all sectors are increasing rapidly due to the population growth and the increment in urban activities. Hence the stresses on the agriculture sector are growing every year. Detection the water stress in cultivated lands and evaluating its impacts on crop yield plays a vital role in monitoring the crop production and enables farmers and decision makers to optimize the irrigation
system [2]. Water stress indexes could be useful tool in detecting the crop water stress [3]-[5]. Water stress could be derived from optical remote sensing or thermal remote sensing. In water stress indexes based on optical remote sensing, the used bands are short wave infrared band (SWIR) and near infrared band (NIR). SWRI and NIR are used to detect the drought effects on the water content and the water stress on vegetation [6]-[9]. SWRI is more effective in detection water stress of crops as it is very sensitive to the water thickness in plant leaf. Moreover it is less affected by ozone, water vapour and aerosol content [10]. There are several indexes based on SWIR and NIR such as land surface wetness index (LSWI) which measures the interaction of the liquid molecules in the crop [11]. Normalized difference water index (NDWI) is similar to LSWI and derived by Chen et al., 2005[12]. There are several methods to derived information about crops statues based on the relation between vegetation indexes (VI) and the surface temperature [9]. These methods have the ability to cover very large areas with little information; in addition they can deal with the surface variations. Price 1990 [13] was the first to use the relation between NDVI-Ts scatter to derive spatial maps for latent heat fluxes. Latent heat flux is very important in monitoring crop productivity and crop water consumption to manage the limited water resources [14], [15]. Maron et al., (1994) assumed that the water deficit could be derived from the trapezoidal shape IV-(T_s-T_a) where T_a is the air temperature and VI was the vegetation index [16]. The selected IV was SAVI to cope with the spectral changes in soil background. Hence the water deficit index (WDI) was depending on the ratio between the actual evapotranspiration ET_a and the potential evapotranspiration ET_o. Jiang-Islam (2001) modified the WDI by replacing the evapotranspiration with Priestley and Taylor equation [17]. Then potential evapotranspiration was replaced with the wet evapotranspiration and the relation between Normalized Difference Vegetation Index (NDVI) and the land surface temperature (LST) was derived in order to assess the water stress index (WSI) [18].

This study aims to assess the ability of WSI in detecting the water stress locations in the center of the Nile delta and validate WSI with old approach WDI.

2. Methodology

2.1. Study Area

The study area located over the center of the Nile delta with longitudes of 30°54’42.15” - 31°1’37.35” E and latitude of 30°43’43.75” - 30°57’40” N[19]. The center of the Nile delta is a flat region with homogenous clay- silt soil. The study area has a very rich irrigation system with two main canals Al-Qasid and Tanta Al-Melahia canal as shown in Figure 1. The main crops are wheat and clover in winter season while in summer, are maize and rice.

2.2. Data

The study area is located in zone N36 with UTM coordinate system and WG84 datum. Two free clouds images of Landsat 8 with 30 meter ground resolution were corrected radiometrically in order to calculate WSI and WDI through estimating the land surface temperature (LST), actual evapotranspiration \( ET_a \) and NDVI. Table (1) summaries Landsat 8 images dates and their Path/Row.

2.3. Water Stress Indexes

Figure (2) shows the methodology for estimating the water stress index for the study area. Two free clouds were radiometric corrected in order to study the water stress locations in the study area. Then Normalized Difference Vegetation Index (NDVI) was derived by using the following equation,

\[
NDVI = \frac{\rho_{\text{NIR}} - \rho_{\text{Red}}}{\rho_{\text{NIR}} + \rho_{\text{Red}}} \tag{1}
\]

Where; the red band with width width (0.67 – 0.90 \( \mu \text{m} \)) in Landsat 8 is called \( \rho\text{Red} \) while near infra-red band with width (0.63 – 0.67 \( \mu \text{m} \)) is called \( \rho\text{NIR} \) [20].

In order to estimate the water stress statues, the surface temperature should be estimated in accurately and efficiently way as it is considered the most driving factor in crop stress. Hence temperature could be estimated from Landsat 8 data using the algorithm of split window [15] with the equation,

\[
LST = TB_{11} + C_1(TB_{10} - TB_{11}) + C_2(TB_{10} - TB_{11})^2 + C_3 + (C_4 + C_6 W)(1-m) + (C_5 + C_8 W) \Delta m \tag{2}
\]
Where, $c_1 - c_6$ split- window coefficient values [15], $m$ is the mean of land surface emissivity (LSE), the difference of LSE is $\Delta m$, $TB_{10}$-$TB_{11}$ are the brightness temperature of 10 and 11 Bands and $W$ is the atmospheric water-vapour content.

The relationship between LST and NDVI was derived in order to estimate the maximum and minimum temperature through the study area using PYTHON language.

The actual evapotranspiration was derived by Surface energy balance algorithm for land (SEBAL) model over the Nile delta for winter season 2015-2016 in previous studies by the authors.

One of the famous method to estimate the Reference evapotranspiration ($ET_o$) is FAO- Penman Monteith formula which depends on several meteorological data such as temperature, humidity and wind speed proceed [21]. Water deficit index (WDI) was first introduced by [16] and related with the ratio between actual evapotranspiration and potential evapotranspiration and could be estimated by the following equation,

$$ WDI = 1 - \frac{ET_c}{ET_o} $$

On the other hand, WSI is a modification of WDI where $ET_o$ was replaced with $E_w$ which replaced with Priestley-Taylor equation [22] and $ET_c$ was replaced with Jiang and Islam method, hence the new index of WSI could be obtained by the following equation [18],

$$ WSI = \frac{T_{1i} - T_{min}}{T_{max} - T_{min}} $$

Where, $T_{1i}$ is the temperature of each pixel, $T_{max}$ is the maximum temperature of vegetation class with NDVI equal 0.0 which could be obtained from Ts-NDVI scatter plot and $T_{min}$ is the minimum temperature of vegetation and presented by the average surface temperature of free water pixels.

![Figure 1. Location of the study area [19]](image1.png)

| Acquired Date | Path/Row | Pixel Size (m) |
|---------------|----------|----------------|
| 11th March 2016 | 39/177   | 30             |

**Table 1.** Landsat 8 data for the study area
3. Results and Discussion

Well knowledge about the Water stress statues is the backbone in maximizing the crops productivity and minimizing the irrigation water consumption for the decision makers in order to manage the limited water resources efficiently. NDVI for the study area in March 2016 ranged from 0.223 to 0.511 with mean 0.3438 and standard deviation (SD) 0.0986 as it is considered the mid-season where the vegetation cover is full however it ranged from 0.0 to 0.271 with mean 0.1238 and standard deviation 0.0617 in May 2016 where the absence of the vegetation cover took place (harvesting season) as shown in Figure 3. The land surface temperature was derived for March using split window algorithm and ranged from 296.0 to 302.0 K with mean 299.67 K and SD 1.6 as shown in Figure 4 while it was 304.0 to 318.0 K with mean 313 and SD 2.723 in May. The relationship between NDVI and LST was drawn to get the maximum and minimum temperatures to determine the water stress locations as shown in Figure 5. It can be extracted from figure 5 that the Maximum temperature with NDVI 0.0 was 295 K in March while it was 309K in May.

This relation between NDVI and LST was the base to estimate the thermal index of water stress through estimating Tmax and Tmin. Figure 6 shows the spatial distribution of WSI over the center of the Nile delta in March and May 2016. During the growing season represented by March, lower values have been occurred and ranged from 0.0 to 0.75. On the other hand, higher values of WSI were obtained in May 2016 due to the harvesting season where they were 0.2 to 0.8as shown in Figure 6. The water stress was lower in March than May due to dense vegetation cover in growing months (March) compared to the harvesting season (May). Similar trends were obtained by Dangwal (2014) [23] where WSI was 0.1 to 0.2 in February 2009-2010 (growing season) and was 0.35 to 0.2 in April 2009-2010 (harvesting season). While WDI in March was 0.4 to 0.7 and it was 0.7 to 0.9 in May as shown in Figure 7.

Comparison between WSI and WDI was proceeded in order to validate the applicability of WSI in determination water stress locations. The comparison between WSI and WDI illustrated that the correlation R² =62% as shown in Figure 8. This error between WSI and WDI could be related to the difference between ETo and Ew.

![Figure 3. Distribution of NDVI over the center of the Nile delta, A) in March 2016, B) in May 2016](image-url)
Figure 4. land surface temperature (LST) over the center of the Nile delta, A) in March 2016, B) in May 2016

Figure 5. NDVI-TS scatter plot over the center of the Nile delta, A) in March 2016, B) in May 2016

Figure 6. Water stress index (WSI) over the center of the Nile delta, A) in March 2016, B) in May 2016
4. Conclusions
In this study the water stress for the center of the Nile delta was detected by using WSI and WDI. WSI was ranged from 0.0 to 0.75 for March lower than WDI which was 0.4 to 0.70 due to the difference between ET₀ in WDI and Eₚ in WSI. Otherwise, the WSI was 0.2 to 0.8 in May higher than WSI in March due to the absence of vegetation cover in harvesting season. However, WSI was lower than WDI in May which ranged from 0.7 to 0.9. The correlation between the old approach (WDI) and the new approach (WSI) was 0.5003 (50.03%) which strongly indicate that the WSI could be used for moderate estimation for the water stress location for vegetation at regional scale.

5. References
[1] Khadr, M., B.A. Zeidan, and A. Elnmer, *On-Farm Water Management in the Nile Delta*. 2016.
Acknowledgements
The author would like to thank Egyptian Ministry of Higher Education (MoHE) for the full-funded of this research and Egypt-Japan University of Science and Technology (E-JUST) for providing the tools that needed for this research.