Remotely Sensed Vegetation Indices and Spatial Decision Support System for Better Water Consumption Regime in Nile Delta. A case Study for Rice Cultivation Suitability Map

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Abstract: Monitoring the locations and distributions of rice cultivation in Kafr El Sheikh Governorate in Nile Delta region is important for establishing linkages between policy decisions, regulatory actions and subsequent irrigational water requirements. Given the importance to the rice cultivation water requirements in water conservation plans, adequate scenarios and efficient multi-disciplinary remote sensing indices related to water availability and water consumption were obtained. In principle, Normalized Difference Vegetation Index (NDVI) was obtained from EgySat-1 satellite sensor acquired in June 2008 to drive four different water related indices calculated as NDVI derivatives. Seven factors and two constrains were implemented in Spatial Decision Support System (SDSS) to obtain final rice cultivation suitability map. Reciprocal matrix for the seven factors was established with accepted consistency ratio of 0.08. Final suitability map indicated that only half of Kafr El Sheikh Governorate is area highly suitable for rice cultivation, but in reality the whole agricultural land of the governorate is occupied by rice cultivation as symbol of mismanagement of water resources in Nile Delta region.

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1. Introduction

Vegetation indices (VIs) have been widely used to monitor terrestrial landscapes by satellite sensors and have been highly successful in assessing vegetation condition, foliage, cover, phenology [1; 2; 3]. VIs are robust satellite data products computed the same way across all pixels in time and space, regardless of surface conditions. As ratios, they can be easily cross-calibrated across sensor systems, ensuring continuity of data sets for long-term monitoring of the land surface and climate-related processes [4].

Studies have been carried out by Pettorelli *et al.* [2]; Kerr, and Ostrovsky [2]; Huete *et al.* [3] demonstrated that VIs have been employed exclusively in estimation of vegetation parameters such as Fractional Vegetation Cover (FC), leaf area index (LAI), Water Supply Vegetation Index (WSVI), Crop Water Shortage Index (CWSI), and Drought Severity Index (DSI).

Other studies have reported strong linear [5] or non-linear [6] relationships between VIs and FC in a variety of landscape types. However, Li *et al.* [6] pointed out a potential practical problem in using VIs to estimate FC over mixed scenes. At 100% cover, different plant species may have different VIs due to differences in chlorophyll content and canopy architecture.

Spatial data analysis techniques and expert knowledge are essential in the decision making process. A modern Spatial Decision Support System (SDSS) combines such data and knowledge within a process-based tool which is developed question-specific according to a given logical decision tree [7]. Comprehensive information about the desires, knowledge and individual requirements of the potential managers are essential during the development of such a computer based system. Therefore, the programming of an innovative SDSS needs to be based on the Geographical Information System (GIS), Remote Sensing (RS), and model-knowledge of the decision maker [8].

Criteria selection of suitability map is arbitrary where the decision will base on them, for this reason Malczewski [9] proposed Spatial Decision Support System (SDSS) as semi- structured problems solution. SDSS was constructed with Decision Support module available in IDRISI, which is a widespread, friendly and affordable GIS software tool. Multi Criteria Decision Analysis (MCDA) was among the many possible methods and techniques of SDSS [10]. The evaluation of land in term of rice cultivation was based on the methods described in FAO [11; 12; 13; 14; 15; 16] guideline for land evaluation and rice cultivation preferences concerning the study area.

The essence of land evaluation for rice cultivation is to compare or match the requirement of each potential land cover with the characteristics of each kind of land. A land unit is obtained by overlaying of the selected theme layers, which has unique information of land qualities for which the suitability is based on [10].

The aim of the study is to evaluate the present practice of rice cultivation in Kafr El Sheikh Governorate in Nile Delta region as it represents the largest governorate in term of its whole agricultural land occupied by rice cultivation, and produce a rice cultivation suitability map to help the decision makers to adopt more adequate water resources management in Nile Delta region.

2. Material and Methods

2.1 Study area

This study was carried out in one of the main agricultural governorates of the Nile Delta, Kafr El Sheikh Governorate, known as “Lower Egypt”. The total area of the governorate is about 3500 km^2 including Manzala lake (about 600 km^2) demonstrated in Figure 1 and represents the main agro-ecological zone known as “old lands in Egypt”. Rice cultivation is the main agricultural practice in the in the study area, rice cultivation comprises about 80% of the governorate terrestrial area which is closer to 600,000 feddan of rice [17] (1 feddan = 4200 m^2). Additionally, it is famous for the production of beets, wheat, and cotton. The study area is highly heterogeneous and is comprised by three main zones i.e., coastal plain, alluvial plain, and an interference zone lying in between. It is considered as an unstable ecosystem due to the active degradation processes resulting from the climate, relief, soil properties, and inadequate farming management practices. The most significant factors of land degradation are: a) wind, b) water erosion, c) water logging, d) salinization, and e) soil compaction. On the other hand, land reclamation processes, enclosing the wider Delta region, are very pronounced due to human activities. The land use and land cover categories are: a) agriculture, b) bare soil, c) sand area, d) salt flat, e) swamps, f) salt, g) fish farms, h) water bodies and i) urban areas [18].

2.2 Data set

The application of SDSS to produce rice cultivation suitability map for the governorate requires in principle the estimation of NDVI and its derivatives from a remote sensing data. NDVI was estimated from EgySat-1 acquired in June 2008. The NDVI derivatives were described and obtain as following:

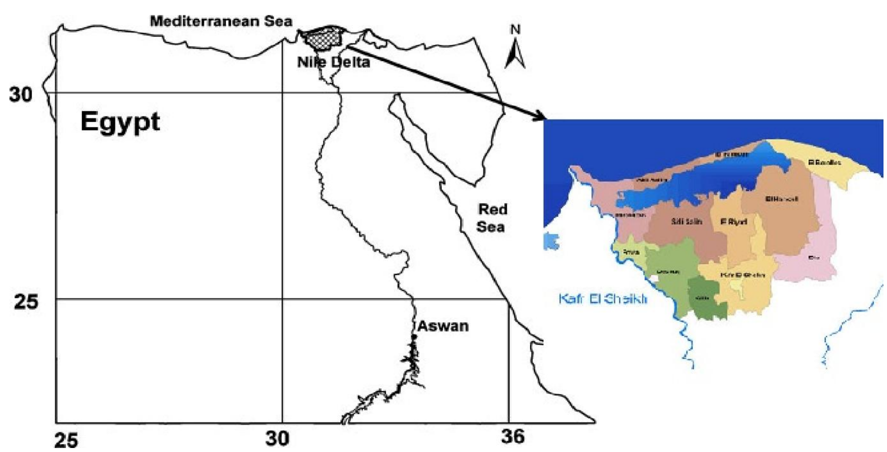

Figure 1, Location of Kafr El Sheikh Governorate and its administrative divisions [17].

Leaf Area Index (LAI):

It is important for assessing growth and vigor of vegetation on the planet. It is fundamentally important as a parameter in land-surface processes and parameterizations in climate models. This variable represents the amount of leaf material in ecosystems and controls the links between biosphere and atmosphere through various processes such as photosynthesis, respiration, transpiration and rain interception. The following equation is used to determine LAI from NDVI for agricultural land [19]:

$$LAI = NDVI \times 1.71 + 0.4 \quad (1)$$

Water Supply Vegetation Index (WSVI):

When crops are suffering from drought, their leaf apertures are partly closed in order to reduce the loss of water. It makes the increase of temperature of leaf surface. The more severe the drought is, the higher the temperature of leaf surface is. At the same time, the growth of crops is affected by drought, resulting in the decrease of leaf area index (LAI). Besides, leaf will also be under high air temperature.

All of these may result in reduction of NDVI. Water supply vegetation index (WSVI) is defined as following by Yang *et al.* [20]:

$$WSVI = NDVI/T_s \quad (2)$$

Where

T_s is the brightness temperature channel or related remote sensing imagery estimated [K]. The smaller this index is, the more severe the drought is.

Crop Water Shortage Index (CWSI):

The estimation of crop water shortage index is performed following Gillies *et al.* [21] as follows:

$$CWSI = 1 - E_a/E_p \quad (3)$$

Where,

E_a is actual evapotranspiration [mm/day],

E_p is the evapotranspiration potential [mm/day].

The smaller the value of E_a is, the higher the value of CWSI is, indicating less water supply ability, namely land is arid. Because actual evapotranspiration has a close relation with soil moisture content, namely water supply ability, CWSI also has close relation with soil moisture content. Both CWSI and soil moisture content indicate the degree of soil drought.

Drought Severity Index (DSI):

Drought is usually defined as a significant, temporary reduction in water availability below the expected amount for a specified period and for a defined climatic zone. Drought episodes may be described by means of different characteristics, namely drought duration and intensity, considered as the two dimensions of this agro-climatic phenomenon. Among the several methods proposed for describing drought, the run method appears as suitable to provide an objective characterization of drought events. A simple drought index, obtained from either by Relative Plant Available Soil Water Content (R) or heat flux (H) following Moran *et al.* [22]:

$$DSI = 1 - R = (H - H_{wet})/(H_{dry} - H_{wet}) \quad (4)$$

Where H is the heat flux [W/cm^2]

H_{dry} is the heat flux at dry atmospheric condition [W/cm^2]

H_{wet} is the heat flux at wet atmospheric condition [W/cm^2]

R is the relative plant available soil water content [unit less]

The equation is able to describe different dimensions of drought phenomena (duration, intensity and severity), and to recognize normal conditions, both in statistical and ecological terms, is meaningful.

The process of evaluating the land for rice cultivation was adopted from the framework developed by FAO [11; 12; 13; 14; 15; 16]. The method to be proposed is intended to design for assessing land for different practices under the present condition in Kafr El Sheikh. In order to develop a set of themes for evaluation and ultimately to produce a suitability map, the condition requirement in terms of land qualities and land topography were reviewed [23].

Daily evapotranspiration (ET):

Daily evapotranspiration is always a major component in water resources management. The reliable estimation of daily evapotranspiration supports decision makers to review the current land use practices in terms of water management, while enabling them to propose proper land use changes. Estimation of ET values was conducted and forecasted following Elhag *et al.* [24], Psilovikos and Elhag [25].

2.3 Methodological Framework

Multiple criteria typically have varying importance. To illustrate this, each criterion can be assigned a specific weight that reflects its importance, relative to other criteria under consideration. The weight value is not only dependent on the importance of any criterion; it is also dependent on the possible range of the criterion values. A criterion with variability will contribute more to the outcome of the alternative and should consequently be regarded as more important than criteria with no or little changes in their range. Weights are usually normalized to sum up to 1, so that in a set of weights $\sum w_i = 1$.

Weight Linear Combination formula is described as following:

$$Suitability = \sum w_i x_i \times \prod c_j \quad (5)$$

Where

W_i weight of factor I,

X_i criterion score of factor and

C_j criterion score of constraint $_j$

To proceed with the analysis, criteria need to be identified. A criterion map is a layer in GIS database representing evaluation criteria. There are two different types of criteria, factor and constrain criterion. In the present study, seven factors and two constrain criteria were used:

I – A factor is a criterion that enhancement or detract from the suitability of a specific alternative. The current study includes five factors; the following table describes the different layers and their classification according to deterministic transformation in table 1.

II – A constraint serves to a limit alternative under consideration. There are two different constraints considered in the current study, DEM and land cover classes. Slope less than 30 % was considered to be suitable for rice cultivation and only agricultural land class was considered to be suitable for the same purpose.

Table 1 List of the used factors and its transformation.

Layer	Factor	Function	Score Range
Canals	distance	fuzzy sigmoidal	cost
Drains	Distance	fuzzy sigmoidal	cost
ET	Value	fuzzy trapezoidal	benefit/cost
CWSI	Value	fuzzy trapezoidal	benefit/cost
WVSI	Value	fuzzy trapezoidal	benefit/cost
DSI	Value	fuzzy trapezoidal	benefit/cost
LAI	Value	fuzzy trapezoidal	benefit/cost

The score range of each factor used in the establishment of weighted linear combination is described by the following equations:

Fuzzy sigmoidal function (Figure 3) according to Yager [26]:

$$f(x,a,b,c) = \frac{1}{1+e^{-a(x-c)}} \quad \text{Eq. (6)}$$

Fuzzy trapezoidal function (Figure 4) according to Yager [26]:

$$f(x,a,b,c,d) = \max\left(\min\left(\frac{x-a}{b-a}, 1, \frac{d-x}{d-c}\right), 0\right) \quad \text{Eq. (7)}$$

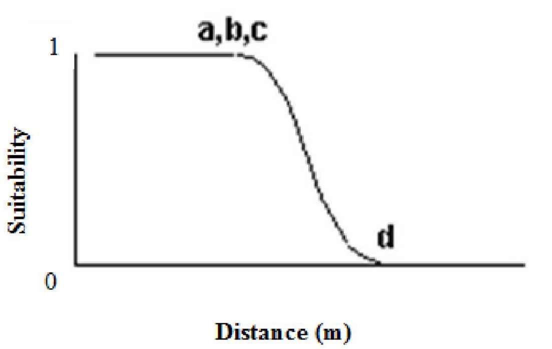

Figure 2 Sigmoidal function [26]

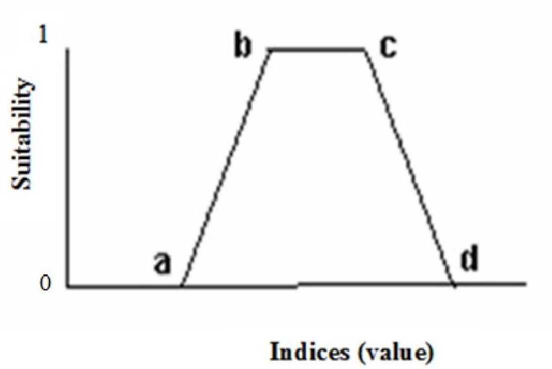

Figure 3 Trapezoidal function [26]

Where x, is the desired parameter, and a, b, c and d are the recommended factors specific threshold defined following FAO [11; 12; 13; 14; 15; 16] guidelines for rice cultivation and based on natural groupings inherent in the input data factors [27].

Pairwise comparison method was developed by Saaty [28], quoted by Malczewski [9] in the context of his decision rule called Analytic Hierarchy Process. The method involves pairwise comparisons to create a ratio matrix. Through the normalization of the pairwise comparison matrix the weights are determined. The method uses an underling scale with values, from 1 to 9 to describe the relative preferences for two criteria. The result of the pairwise comparisons is a reciprocal matrix.

The significant point is that the estimated rank of ***A*** (if ***A*** is consistent) is 1 and the estimated *eigenvalue* is equal to number of compared criteria (n). In inconsistent cases the estimated maximum eigenvalue is greater than n while the others are close to zero. The *eigenvector* of matrix ***A*** is an estimate of the relative weights of the criteria being compared.

In ideal cases the comparison matrix (***A***) is fully consistent, the rank (***A***) = 1 and λ = ***n*** (***n*** = number of criteria). In this case, the following equation is valid:

A x ***x*** = ***n*** x ***x*** (where ***x*** is the *eigenvector* of ***A***)

3. Results and Discussion

The study provides an approach to find out valuable parametric values in identifying rice cultivation suitability map based on SDSS approach where the total area of the highly suitable locations would be calculated.

Table 1, describes the correlations of the used factors performed in a matrix known as "reciprocal matrix". The eigenvector weight of the seven used factors and its importance were estimated through the reciprocal matrix. The results of the matrix pointed out that the distance to canals is very important and had the biggest eigenvector weight followed by the distance to the drainage network [29]. Moreover, the correlation between the Leaf Area Index and

Evapotranspiration is the strongest among the rest of the used factors according to the reciprocal matrix key demonstrated below. Such a correlation need to be considered in water conservation plans regarding to rice cultivation [1]. Only ratios less than 0.1 are accepted for a proper Spatial Decision Support System, the importance and the weights of the used factor need to be reconsider in case of consistency ratios higher than 0.1 [10; 27].

Evapotranspiration showed moderately importance with the rest of the Vegetation Indices (Crop Water Shortage Index, Water Vegetation Supply Index and Drought Severity Index) and need to be integrated together for satisfactory results [4]. Each one of the eigenvector weights was multiply to its corresponded layer and then the layers were overlaid all together to be introduced to a final suitability map [10].

Rice cultivation suitability values were ranging from zero to one and demonstrated in Figs. 4-10 according to the corresponding factor. The spatial distribution of rice cultivation suitable areas varies in whole Kafr El Sheikh Governorate [29].

Table 2 Reciprocal matrix of seven factors and their importance

	Canals	Drains	ET	CWSI	WVSI	DSI	LAI
Canals	1						
Drains	1/3	1					
ET	1/9	1/9	1				
CWSI	1/3	1/3	3	1			
WVSI	1/3	1/3	3	1/3	1		
DSI	1/3	1/7	3	1	1	1	
LAI	1/9	1/9	5	1/3	1/3	1/3	1

Where, the reciprocal matrix keys are given below:

$\frac{1}{9}$ *extremely* $\frac{1}{7}$ *very strongly* $\frac{1}{5}$ *strongly* $\frac{1}{3}$ *moderately*	Less Important
1	Equal
3 *moderately* 5 *strongly* 7 *very strongly* 9 *extremely*	Very Important

The eigenvector of weights is:

1-Canals = 0.3545 2-Drains = 0.2920
3-ET =0.0263 4-CWSI = 0.1144
5-WVSI = 0.0828 6-DSI = 0.0855
7-LAI = 0.0446
Consistency ratio = 0.08

Suitable area for rice cultivation, based on Leaf Area Index factor, is distributed on both east and west side of the governorate (Fig. 4) in contradiction with the spatial distribution of Water Supply Vegetation Index (Fig 5). Crop Water Shortage Index suitable area distribution (Fig. 6) showed no definite pattern and is distributed all over the governorate. Drought Severity Index (Fig. 7) expressed the same pattern of CWSI. Daily evapotranspiration suitable area (Fig. 8) demonstrated marginal spatial distribution pattern surrounding the lake and keep most of the governorate area with less rice cultivation suitable values.

Vegetation indices were developed to monitor and estimate agronomic variables. Crop monitoring can be guided irrigators and farmers; therefore, vegetation cover can be necessary data for agriculture science in general and rice cultivation in specific [4; 29].

Water supply and quality are important issues which are impacting water reuse. The reuse of the irrigational water without proper treatment, declines water availability in both terms of quality and quantity and intimidate food security in [24; 29]. Irrigational water treatment is one of the major water reuse limitations in Egypt, as the irrigational water is mostly reused with no treatment [29].

The current agricultural practice in Kafr El Sheikh Governorate is based on rice cultivation covering most of the governorate agricultural land as it mentioned above. According to MPWWR [30], such practice consumes about 11.4 Billion Cubic Meter (BCM) every year with water reuse efficiency closer to 80% [30] assuming that the whole agricultural land of the governorate is suitable for rice cultivation.

Highly suitable areas, based on canals and drainages factors, are confined closely to both networks and leave the rest of governorate less suitable areas (Figs 9 and 10). Suitable areas based on the implemented constrains (DEM slope derivative and land cover classes) were mostly highly suitable for most of the governorate area.

Overall suitability map (Fig. 11) defined fewer areas for rice cultivation in Kafr El Sheikh Governorate. These areas were mostly located around the lake and according to Figure 12, the total area available to each suitability class is formulated as follows:

a) Highly suitable (S1) 1157 km^2, b) Moderately suitable (S2) 488 km^2, c) Marginally suitable (S3) 490 km^2 and d) Not suitable (N) 126 km^2 which represent the 51%, 22%, 22% and 5% of the total area respectively.

According to Figure 12, both of marginally suitable and not suitable areas (27%) of the total current water consumption must be saved (3.1 BCM). A wise decision need to be taken towards the moderately suitable areas to be used for rice cultivation or not, such decision my save additional 2.5 BCM every year. The decision should be based on the fact that some areas of the governorate must be used for rice cultivation to maintain the pressure on the ground water table to avoid water logging [29], generally the pressure need to be kept around the west side of the lake.

The Spatial Decision Support System mission is to develop and disseminate information about site-specific management methods that are profitable and practical for agricultural producers and those who supply inputs or process products [32].

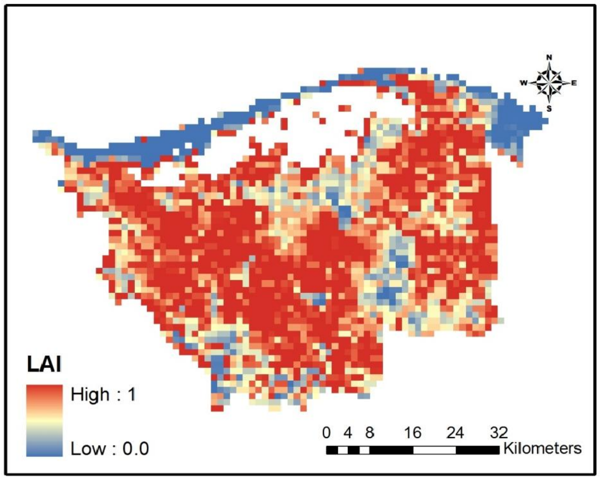

Figure 4 Leaf Area Index suitability map for Kafr El Sheikh Governorate

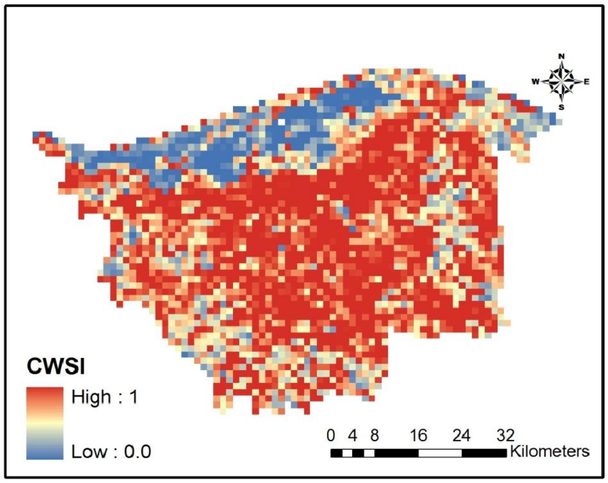

Figure 6 Crop Water Shortage Index suitability map for Kafr El Sheikh Governorate

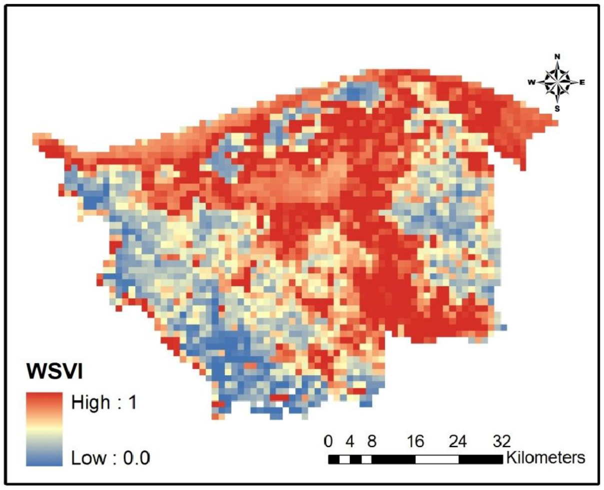

Figure 5 Water Supply Vegetation Index suitability map for Kafr El Sheikh Governorate

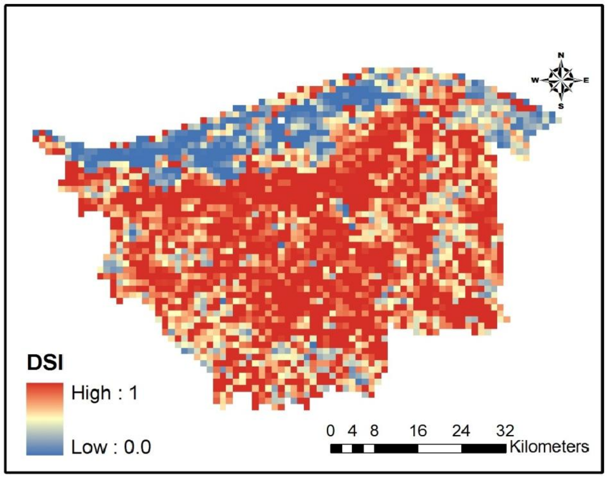

Figure 7 Drought Severity Index suitability map for Kafr El Sheikh Governorate

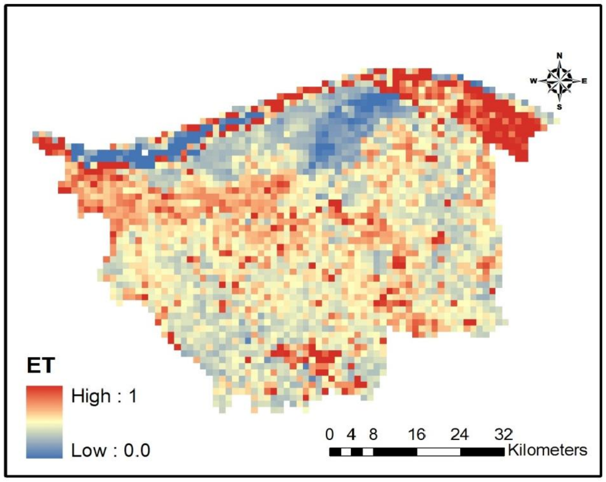

Figure 8 Evapotranspiration suitability map for Kafr El Sheikh Governorate

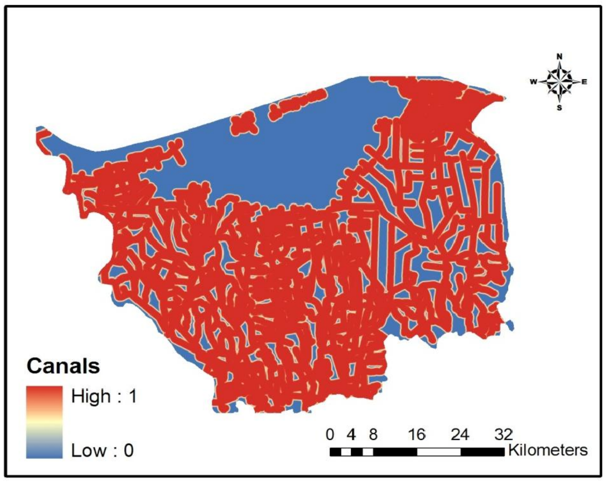

Figure 9 Distance from Canals network suitability map for Kafr El Sheikh Governorate

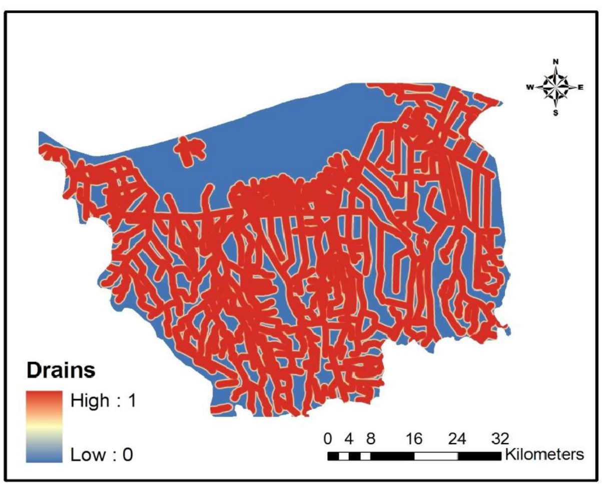

Figure 10 Distance from Drainage network suitability map for Kafr El Sheikh Governorate

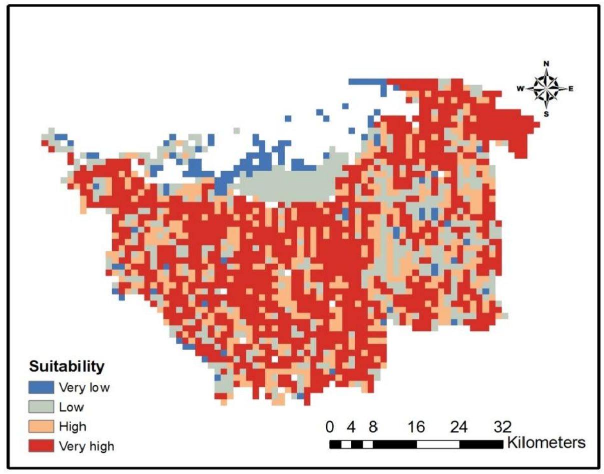

Figure 11Overlaid suitability map for rice cultivation in Kafr El Sheikh Governorate

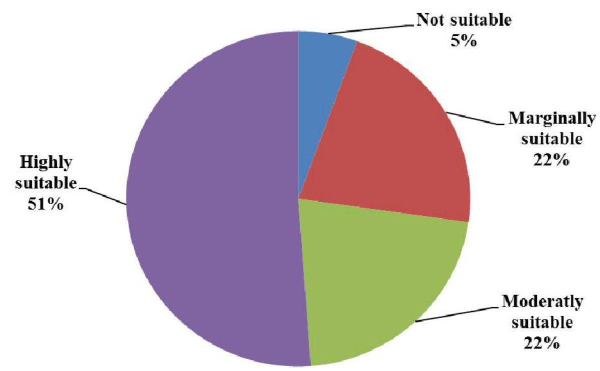

Figure 12Rice cultivation suitability percentages in Kafr El Sheikh

4. Conclusions

The Pairwise Comparison Matrix (PWCM) was constructed with the 7 important factors mentioned previously and the relative importance of each one was measured through the calculation of weights. The computed weight of different parameters/factors with composite layers is shown in Table 3. Once the factor maps and the weight of composite layers were obtained and then the physical suitability map at four suitability classes (highly suitable, moderately suitable, marginally suitable and not suitable) was evaluated for the rice cultivation by weighted overlay.

In this study, application of Remote Sensing (RS) and GIS techniques to identify suitable areas for rice crop was successful. The results obtained from this study indicate that the integration of RS-GIS and application of Multi-Criteria Evaluation using Pairwise Comparison Matrix could provide a superior database and guide map for decision makers considering crop substitution in order to achieve better agricultural production. This approach has been used in some studies in other countries. However, in Egypt this approach is a new and original application in agriculture, because it has not been used to identify suitable areas for rice crop intensively. The study clearly brought out the spatial distribution of rice crop derived from Remote Sensing data in conjunction with evaluation of biophysical variables of soil and topographic information in GIS context is helpful in crop management options for intensification or diversification.

This investigation is a biophysical evaluation that provides information at a local level that could be used by farmers to select their cropping pattern. Additionally, the results of this study could be useful for other investigators who could use these results for diverse studies. This study has been done considering current land use/cover, topography and soil properties that affected the suitability classification of land use types. Therefore, it gives primary results. For further study, we propose to select more number of factors like soil, climate, irrigation facilities and socio-economic factors which influence the sustainable use of the land.

The common thread in rice cultivation water requirements is an attempt to achieve greater accuracy from remotely sensed data. In order to accomplish this, researchers have looked into various alternatives. Most of these alternatives have to do with the type of sensor (i.e., optical or microwave), number of images (i.e., single-date or multi-date), timing of the imagery, or processing technique. Although these characteristics certainly make a difference in the results attained, the trait that seemed to be most relevant was an appropriate use of the spatial data in combination with process understanding. Appropriate ground validation data and accuracy assessment is also critical for testing and reporting results.

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