Agro-Climatic Zones (ACZ) Using Climate Satellite Data in Iraq Republic

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Abstract. Agro-climatology is highly worthy in the identification of agro-climates with the climate change conditions to introduce new agricultural crops. Agro-Climatic Zones permits recognizing areas with different potential products according to their climate change environmental conditions. This study aims to produce Agro-Climatic Zones map using satellite-based climate data in Iraq. Climate data based on satellite data were downloaded and processed with a spatial resolution of 0.25º, then interpolated using the spline method. The annual precipitation was downloaded from TRMM_3B43 v7 satellite data from 1998 to 2018 and the average annual air temperature for the period 2000 to 2018 was downloaded from the GLDAS Model (NOAH025_M v2.1). The GIS-based approach was implemented to create the necessary datasets and to develop an Agro-Climatic Zones map in the Iraq Republic. The results have mapped Iraq republic Agro-Climatic Zones into five zones, which are arid, cool winter, very warm summer (ACZ 1 represent about 48.8 % of the total area); arid, mild winter, very warm summer (ACZ 2 about 36.8 % of the total area); semi-arid, cool winter, very warm summer (ACZ 3 about 8.8 % of the total area); semi-humid to Mediterranean, cool winter, very warm summer (ACZ 4 about 4.2 % of the total area); and very humid to humid, cold to cool winter, warm summer (ACZ 5 about 1.4 % of the total area).

1. Introduction
Food production and security in developing countries are frequently limited by many factors including the characteristics of natural resources like soil, water, vegetation, and climate and socio-economic conditions. Climatic variations have an additional impact by accentuating these limiting factors. Future challenges for food security require actions based on new, high impact technologies. It will be very important to raise agricultural yields sustainably as well as to increase the capacity and adaptation of farming systems to environmental changes.

Agro-climatology is highly valuable in the identification of agro-climates with the optimal conditions to introduce new agricultural crops. The requirements, limits and bio-meteorological tolerance and conditions of crops should be evaluated in reference to the native climatological characteristics for successful cultivation around the world [1]. Agro-Climatic Zones (ACZ) permits recognizing areas with different potential products according to their environmental conditions. All plants are sensitive to weather conditions in a way or another. They have a minimum as well as maximum requirements regarding weather conditions to satisfy their physiological needs; beyond certain limits, they are negatively affected [2]. Minimum/maximum range values, which is called the ideal temperature, represents the optimum level for plants physiological complex to work efficiently. In terms of criteria development, science-driven criteria for developing and implementing ACZs focus on the cause/effect as well as associations between inputs/influence factors and the outputs [3].
Iraq suffers from a scarcity of metrological data, and a lack of reliable data sets in terms of spatial and temporal resolution, so it is difficult to effectively develop management plans for agriculture. Satellite-based climate data considered as an option in supplementing ground-based meteorological observations data, with a good spatial and temporal cover.

Previous studies in different countries mapped the Agro-Climatic Zones to achieve the optimum agricultural production with good results [4][5][6][7]. Additionally, many researchers tried to evaluate the accuracy assessment of the Tropical Rainfall Measuring Mission (TRMM) satellite product, and its results showed that the TRMM products showed a good performance [8][9][10][11][12][13][14]. In addition, many researchers studied the accuracy of the Global Land Data Assimilation System data (GLDAS/NOAH) and found that it is generally showing good performance [15][16][17][18].

This study aims to produce ACZs map using satellite-based climate data in Iraq. It is expected to be highly important in the identification of agro-climates with favorable conditions for the introduction of new crops. It can assist in delineating climate change effects, as well as assisting in the planning process for strategic crop cultivation, also it is proposed to be helpful in setting the regions into one planning and management units aiming for economic integration.

2. Materials and methods

2.1. Study Area
Iraq topographically is shaped like a basin with a total area of 438 320 km² consisting of the Great Mesopotamian alluvial plain of the Tigris and the Euphrates rivers. This plain is surrounded by mountains in the north and the east, and by desert areas in the south and west (about 40% of land area). Nearly 26 % of Iraq area is cultivable, while the remaining part is practically not (Figure 1). The total cultivated area is estimated to be about 6 million ha, of which almost 50 % is rain-fed in northern Iraq.

Iraq climate is mainly of the continent, subtropical semi-arid type, with the north and northeastern mountainous regions having a Mediterranean climate. It is characterized by a very seasonal, wintertime rainfall (December to February), with an exception in the north and northeast where the rainy season is from November to April. Winters are cool to cold, while Summers are dry and hot to extremely hot [19].

2.2. Dataset (Climate data)
Remote sensing rainfall estimation based on satellite-derived data from the TRMM is a possible way of supplementing rain gauge data, with a good spatial cover [20]. Climate data based on satellite data
were downloaded and processed with a spatial resolution of 0.25 degree (Figure 2), Table 1 illustrates the dataset specification. The annual precipitation data, based on TRMM_3B43 v7 satellite, per mm over Jan 1998 until Jan 2018 were interpolated using the Spline method. The average annual air temperature based on satellite data during the period between Jan 2000 to Jan 2018 was downloaded from the GLDAS Model (NOAH025_M v2.1) and interpolated by the spline method. The temperature data were in Kelvin unit (K°), and was converted to Celsius (C°) using the equation:

$$T'(\text{C°}) = T'(\text{K}) - 273.15$$ (1)

![Table 1. Dataset specification.](image)

| Variable                  | Unit        | Source            | Spatial resolution | Period             |
|---------------------------|-------------|-------------------|--------------------|--------------------|
| Precipitation rate        | mm/ month   | TRMM              | 0.25 °              | 1998 Jan - 2018 Jan|
| Mean Temperature for Jan and July | K           | GLDAS Model       | 0.25 °              | 2000 Jan - 2018 Jan|
| Annual Temperature        | K           | GLDAS Model       | 0.25 °              | 2000 Jan - 2018 Jan|

Figure 2. Data grid coverage and the spatial resolution over the study area.

2.3. Data interpolation

Polynomial functions are methods that fit trend functions through the observations by x order polynomials. In general, they are global interpolators and fulfill the criteria of exact interpolators by fitting many polynomials in regions with the overlapping neighborhood. Polynomial functions are considered as a good method for interpolation of monthly and yearly climate data [21]. Thin-plate smoothing spline interpolation method was developed by Wahba and Wendelberger [22] and was applied to climate analysis by Hutchinson in 1991[23]. The method provides accurate estimates of climate and is able to provide a direct estimation of interpolation error [24]. Spline method performs a two-dimensional minimum curvature spline interpolation on a point dataset with a resulting smooth surface that passes exactly through the input points [25]. Spline method is preferable over polynomial interpolation method as errors can be minimized even when using low degree polynomials for the splines. It ensures a continuous, smooth and differentiable surface in addition to a continuous first-derivative surface. The algorithm used for the Spline method uses the following formula:

$$S(x,y) = T(x,y) + \sum_{j=1}^{N} \lambda_j R(r_j)$$ (2)

Where: $j = 1, 2... N$.

$N$ refers to the number of points.
\( \lambda_j \) are coefficients found by the solution of a system of linear equations. 
\( r_j \), refer to the distance from the point \((x, y)\) to the \( j \)th point. 
\( T(x,y) \) and \( R(r) \) are defined differently, depending on the selected option. 
In this study, Spline interpolation method was used to interpolate all the climate data.

### 2.4. GIS Operations and Implementation

The data processing was implemented in ESRI’s ArcGIS 10.5; the preprocessing steps include:

- Convert the Net CDF (precipitation and temperature) data to grid and point layers.
- Remove abnormal values.
- Interpolate the data using the spline method.
- Clip the data grids to the study area extent.

### 2.5. Agro-Climatic Classification

The agro-climatic zones can be defined as integrating and homogeneous portions of land in which the particular combinations of potentially available water resources and climate conditions create unique environments more or less suitable for crop cultivation. The agro-climatic classification is defining the major climate condition and its suitability for the cultivation of certain crops. The ACZs of an area helps to define the ecological potential of that area. In order to define the ACZs, a classification system [26] is adopted in this study based on the following three criteria:

- Winter type.
- Summer type.
- Moisture regime.

#### 2.5.1. Winter type.

The winter type is determined by the mean temperature of the coldest month, the winter type classes shown in Table 2.

| Winter type | Mean temp |
|-------------|-----------|
| Warm        | >20 ºC    |
| Mild        | 10-20 ºC  |
| Cool        | 0-10 ºC   |
| Cold        | ≤0 ºC     |

#### 2.5.2. Summer type.

The summer type is determined by the mean temperature of the warmest month as shown in Table 3.

| Summer type | Mean temp |
|-------------|-----------|
| Very warm   | >30 ºC    |
| Warm        | 20-30 ºC  |
| Mild        | 10-20 ºC  |
| Cool        | ≤10 ºC    |

#### 2.5.3. Aridity index.

The determination of the moisture regime follows the classification system of the arid zones in the world [27], which is based on the aridity index. Various indicators have defined aridity, and some include both temperature and precipitation, such as De Martonne’s aridity index, which is the ratio between the mean annual values of precipitation (P) and temperature (T) plus 10°C [28]. The following formula is used for calculation of De Mortonne’s index:

\[
\text{Aridity} = \frac{P}{T+10}
\]  

\( P \) = Annual average rainfall in mm.  
\( T \) = Annual average temperature in degrees centigrade.
De-Mortonne modified the Lang’s rain factor and suggested a new index of aridity in 1926; he has used this index for the climatic classification in France. According to De-Mortonne’s ‘Index of Aridity’, the value of aridity is less than 20, the climate becomes considered arid, where above is subhumid to per humid (Table 4).

| Climate Type      | Aridity Index |
|-------------------|---------------|
| Arid              | 0-10          |
| Semi-arid         | 10-20         |
| Mediterranean     | 20-24         |
| Semi-humid        | 24-28         |
| Humid             | 28-35         |
| Very Humid        | 35-55         |
| Extremely Humid   | >55           |

In this study, the ACZs of Iraq obtained using the GIS-based model illustrated in Figure 3.

3. Results and discussion

3.1. Generating Agro-Climatic Zones

The ACZs of Iraq was obtained based on the above-described method. In accordance with this methodology, the following maps were prepared as follows:

The annual precipitation based on TRMM_3B43 v7 over Jan 1998 to Jan 2018 ranged from 857 mm to 63 mm as shown in Figure 4. The average annual air temperature during the period 2000-2018 based on the GLDAS Model (NOAH025_M v2.1) is shown in Figure 5, the values varied between 5-28 °C.
Figure 4. The annual precipitation based on TRMM data for the period 1998-2018.

Figure 5. The average annual air temperature during the period 2000-2018 based on the GLDAS Model.

Aridity index was calculated based on De Martonne’s method as shown in Figure 6. The aridity index values were ranging between 1.9 to 36.6, which lies in six categories as shown in Figure 7 and Table 5, it is observed that about 3.3% only of the Iraq area lie under very humid, humid and semi-humid classes, about 11.1% under the Mediterranean and semi-arid classes, and about 85.6% of the Iraq area is arid.

| Climate Type     | Percentage |
|------------------|------------|
| Arid             | 85.6 %     |
| Semi-arid        | 8.8 %      |
| Mediterranean    | 2.3 %      |
| Semi-humid       | 1.9 %      |
| Humid            | 1.3 %      |
| Very Humid       | 0.1 %      |
The mean temperature during the warmest month, which is July, illustrated in Figure 8. The temperature values varied from 20.8 °C to 40.3 °C. According to the classification system, the summer classes lie under two category that is warm and very warm as shown in Figure 9.
Figure 8. The mean temperature for the warmest month (July).

Figure 9. Summer type classes.

The mean temperature during the coldest month, which is January, was shown in Figure 10. The temperature values ranged between -6.4 °C to 13.5 °C. According to the classification system, the winter type classes lie under three categories that is cold, cool, and mild as shown in Figure 11.
After preparing the data, all the data converted to the vector format (Figure 12) then intersect to generate the ACZs map. In order to improve the readability of the resulting ACZs, a synthesis was operated by making no distinction between warm and very warm summer for the arid moisture regimes, and by aggregate ACZs that occupy the very small area to a bigger one. Finally, the ACZs geometries are also simplified in order to remove the classical effects due to vectorization process. This reduces the ACZs classes into five categories; Figure 13 shows the final ACZs.

The results mapped Iraq Agro-Climatic Zones into five zones, which are arid, cool winter, very warm summer (ACZ 1); arid, mild winter, very warm summer (ACZ 2); semi-arid, cool winter, very warm summer (ACZ 3); semi-humid to Mediterranean, cool winter, very warm summer (ACZ 4); and very humid to humid, cold to cool winter, warm summer (ACZ 5). The percentage of each zone was calculated as shown in Table 6, about 48.8 % of the Iraq area lies under ACZ1, 36.8 % lie under ACZ2, 8.8 % under ACZ3, 4.2 % under ACZ4, and only 1.4% under ACZ5. The ACZs are also characterized by a high degree of fragmentation especially in Northern Iraq, due to the strong variability of topography, temperature and precipitation regimes.
4. Conclusions
The main objective of this study is to produce ACZs map using satellite-based climate data in Iraq. The precipitation data were obtained from TRMM, and the temperature data were obtained from the GLDAS model for the period (2000 – 2017). The main conclusions are:

- The aridity index values lie under six categories, very humid to humid and sub-humid classes, which constitute only about 3.3 %, Mediterranean and the semi-arid class was 11.1 %, and the arid area constitutes about 85 % of the Iraq area.
- The results mapped Iraq Agro-Climatic Zones into five zones, which are arid, cool winter, very warm summer (ACZ 1 represent about 48.8 % of the total area); arid, mild winter, very warm summer (ACZ 2 about 36.8 % of the total area); semi-arid, cool winter, very warm summer (ACZ 3 about 8.8 % of the total area); semi-humid to Mediterranean, cool winter, very warm summer (ACZ 4 about 4.2 % of the total area); and very humid to humid, cold to cool winter, warm summer (ACZ 5 about 1.4 % of the total area).
- This study expected to be highly important in the identification of agro-climates with favorable conditions for the introduction of new crops. It is expected that it will assist in delineating climate change effects, as well as assisting in the planning process for strategic crop cultivation. Moreover, it is proposed to be helpful in setting the regions into one planning and management units aiming for economic integration.

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