SUSTAINABLE PRODUCTION ZONING FOR AGROCLIMATIC CLASSIFICATION USING GIS AND REMOTE SENSING

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Objectives

Identification of sustainable production zones using:

- Remote Sensing (satellite derived indices) and
- GIS.
Study Area

Study area: Thessaly and specifically Thessaly water district.
Data Base

Satellite Data (NOAA/AVHRR) for 20 hydrological years 1981 – 2001, with 8x8 km spatial resolution:

- 730 Normalized Difference Vegetation Index (NDVI) ten-day composite images.
- 730 CH4 Brightness Temperature (BT) ten-day composite images.
- 730 CH5 Brightness Temperature (BT) ten-day composite images.
Data Base

Conventional Data:
- 240 monthly rainfall maps with grid cell size 50x50 km for the same period.
- Mean monthly air temperature measurements from Larissa meteorological station.
- Soil map of the study area.

GIS Data:
- Thematic layer of Thessaly Water District.
- 100m contours for Thessaly region.
Methodology

Step 1: Calculation of Vegetation Health Index (VHI).

Step 2: Calculation of Aridity Index (AI).

Step 3: Definition of Water Limited Growth Environment (WLGE).

Step 4: Digitization of the soil map.


Step 6: Thematic Classification.
Methodology

Schematic representation of the methodology

- AI
- VHI
- WLGE
- DTM + Soil Maps
- Sustainable Production Zones
Normalized Difference Vegetation Index

From NOAA/AVHRR data NDVI is given by the following equation:

\[
\text{NDVI} = \frac{CH_1 - CH_2}{CH_1 + CH_2}
\]

<table>
<thead>
<tr>
<th>LAND COVER</th>
<th>NDVI</th>
<th>PIXEL VALUE (0-255 gray scale)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dense Vegetation</td>
<td>0.500</td>
<td>210</td>
</tr>
<tr>
<td>Intermediate Green Vegetation</td>
<td>0.140</td>
<td>118</td>
</tr>
<tr>
<td>Sparse Vegetation</td>
<td>0.090</td>
<td>105</td>
</tr>
<tr>
<td>Bare Soil</td>
<td>0.025</td>
<td>88</td>
</tr>
<tr>
<td>Clouds</td>
<td>0.002</td>
<td>83</td>
</tr>
<tr>
<td>Snow and Ice</td>
<td>-0.046</td>
<td>70</td>
</tr>
<tr>
<td>Water Surface</td>
<td>-0.257</td>
<td>16</td>
</tr>
</tbody>
</table>
Vegetation Condition Index (VCI)

The VCI is an extension of the NDVI and is given by the following equation:

\[
VCI = 100 \times \frac{\text{NDVI} - \text{NDVI}_{\text{min}}}{\text{NDVI}_{\text{max}} - \text{NDVI}_{\text{min}}}
\]

where NDVI, NDVI\(_{\text{max}}\) and NDVI\(_{\text{min}}\) are the smoothed ten-day normalized difference vegetation index, its multi-year maximum and its multi-year minimum, respectively.

Smoothing/Filtering: “4253 compound twice” median filter applied to remove the noise from the NDVI series (Van Dijk, 1987).

VCI provides a quantitative estimation of weather impact on vegetation.

VCI characterises the moisture conditions of vegetation.
Temperature Condition Index (TCI)

TCI characterises the thermal conditions of vegetation and is given by the following equation:

$$\text{TCI} = 100 \times \frac{BT - BT_{\min}}{BT_{\max} - BT_{\min}}$$

where BT, BT\text{max} and BT\text{min} are the smoothed ten-day radiant temperature, its multi-year maximum and its multi-year minimum, respectively.

Smoothing/Filtering: conditional statistical mean spatial filter (window size ranging from 3x3 to 7x7, according to image needs) (Tsiros et al. 2008).

Thermal stresses can be monitored with the use of TCI. VCI and the TCI varies from zero, for extremely unfavorable conditions, to 100, for optimal conditions.
Vegetation Health Index

Kogan (2000) proposed the Vegetation Health Index (VHI) which represents overall vegetation health and used it for drought mapping.

VHI is expressed by the following equation:

\[
VHI = 0.5 \times (VCI) + TCI
\]

An equal weight has been assumed for both VCI and TCI since moisture and temperature contribution during the vegetation cycle is currently not known (Kogan 2001, Bhuiyan et al. 2006)
VHI drought classification schemes (Kogan 2001).

<table>
<thead>
<tr>
<th>VHI Values</th>
<th>Vegetative drought classes</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;10</td>
<td>Extreme drought</td>
</tr>
<tr>
<td>&lt;20</td>
<td>Severe drought</td>
</tr>
<tr>
<td>&lt;30</td>
<td>Moderate drought</td>
</tr>
<tr>
<td>&lt;40</td>
<td>Mild drought</td>
</tr>
<tr>
<td>&gt;40</td>
<td>No drought</td>
</tr>
</tbody>
</table>
Aridity can be presented by the use of Aridity Index (AI).

AI is used to determine the adequacy of rainfall in satisfying the water needs of crops.

\[ AI = \frac{P}{ET_p} \]

where, \( P \) is the cumulative monthly precipitation and \( ET_p \) is the monthly potential evapotranspiration.

Potential evapotranspiration was calculated by the use of Blaney-Criddle method.

<table>
<thead>
<tr>
<th>Category</th>
<th>AI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Extremely Dry</td>
<td>&lt;0,03</td>
</tr>
<tr>
<td>Dry</td>
<td>0,03 - 0,20</td>
</tr>
<tr>
<td>Semi-dry</td>
<td>0,20 - 0,50</td>
</tr>
<tr>
<td>Semi-wet</td>
<td>0,50 - 0,75</td>
</tr>
<tr>
<td>Wet</td>
<td>&gt;0,75</td>
</tr>
</tbody>
</table>

Characterization of an area according to Aridity Index (UNESCO, 1979).
Potential Evapotranspiration

Blaney-Criddle Method (1950).

\[ \text{ET}_p = C \left[ P \left(0.46 \times T_\alpha + 8.13\right) \right] \quad \text{(Papazafiriou, 1999)} \]

- \( C \) is the weighted crop coefficient.
  (C values were defined according to land use, as defined by Corine 2001 database)
- \( P \) ratio of mean daily daytime hours for a given month to the total daytime hours in the year as a percent.
- \( T_\alpha \) is the mean monthly temperature °C.

Land Surface Temperature (LST) is used instead of air temperature.
Land Surface Temperature

The generation of LST maps is based on the “split-window” algorithm from Becker and Li (1990):

\[
\text{LST} = 1.274 + \left( \frac{\text{T}_4 - \text{T}_5}{2} \right) \left( 1 + 0.15616 \left( \frac{\text{de}}{\text{e}} \right) \right) + \frac{\left( \text{T}_4 - \text{T}_5 \right)}{2} \left( 6.26 \text{e} - 3.989 \frac{1-\text{e}}{\text{e}} \right) + \frac{1}{\text{e}} \left( 1 - \text{e} \right)
\]

where LST, T4 and T5 represent the black body temperature of the land surface, the temperature in channel 4 and 5, respectively.

\[\text{e} = \frac{\text{e}_4 + \text{e}_5}{2}\] and \[\text{de} = \text{e}_4 - \text{e}_5\], with \text{e}_4 and \text{e}_5 representing the emissivity in channel 4 and 5, respectively.
Surface Emissivity

The emissivity used in split-window algorithms is a critical parameter for the accuracy of LST.

For estimating surface emissivity the relationship given by Van de Griend and Owe (1993) is applied.

\[ e_4 = 1.0094 + 0.047 \ln(NDVI) \]
\[ e_5 = e_4 + 0.01 \]

NDVI stands here for the MVC image of the month under consideration.
In order to avoid over-estimations, LST was converted to air temperature.

Regression Model between LST and Tair for Larisa

\[ y = 0.6878x + 3.1551 \]

\[ R^2 = 0.8374 \]
VHI and AI are used to define areas where plant growth is limited by water availability.

VHI drought map was derived using the frequency of occurrence of agricultural drought events.

**WLGE classification scheme (Tsiros et al. 2008).**

<table>
<thead>
<tr>
<th>Agricultural drought classes</th>
<th>Aridity classes</th>
<th>WLGE classes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Extreme drought</td>
<td>Extremely dry</td>
<td>Limited Environment</td>
</tr>
<tr>
<td>Severe drought</td>
<td>Dry</td>
<td></td>
</tr>
<tr>
<td>Moderate drought</td>
<td>Semi-dry</td>
<td>Partially Limited Environment</td>
</tr>
<tr>
<td>Mild drought</td>
<td>Semi-wet</td>
<td></td>
</tr>
<tr>
<td>No drought</td>
<td>Wet</td>
<td>No Limitations</td>
</tr>
</tbody>
</table>
“Limited environment”: moisture and rainfall cannot satisfy the water needs of crops or even a part of them.

In order to satisfy crop requirements in those areas, large quantities of water supply from irrigation are required, leading to unsustainable use of water resources and increase of the cost of the final products.

“Partially limited environment” due to water availability: smaller amount of irrigations.

“No limitations” even smaller.
Agricultural drought map of Thessaly water district derived using incident frequencies.

Climatic Aridity map of Thessaly water district.
WLGE zones in Thessaly water district
Processes were made using ArcGIS 9.1.

Soil types were digitized according to fertility (appropriate or not for sustainable agricultural use) and desertification limitations.

Soil types were grouped into three classes during the digitization.

The digitized vector maps was converted to raster (grid) with cell size 100x100m.
# Classification scheme of soil types according to sustainable use and desertification vulnerability

<table>
<thead>
<tr>
<th>Class name</th>
<th>Sustainable agronomic uses</th>
<th>Desertification vulnerability</th>
<th>Soil types category</th>
</tr>
</thead>
<tbody>
<tr>
<td>No agricultural use</td>
<td>Wild nature, Forest, Controlled pasture</td>
<td>Very high, High</td>
<td>Rock outcrops, Leptosols, Regosols (low quality), Cambisols (medium-low quality)</td>
</tr>
<tr>
<td>Controlled agricultural use</td>
<td>Controlled agriculture and pasture, Forest</td>
<td>Medium</td>
<td>Regosols (medium quality), Cambisols (medium-high, high quality), Luvisols (medium quality)</td>
</tr>
<tr>
<td>Agricultural use</td>
<td>Agriculture</td>
<td>Low</td>
<td>Fluvisols, Vertisols, Luvisols (high quality)</td>
</tr>
</tbody>
</table>
Zones of sustainable use according to soil characteristics in Thessaly
Digital Terrain Model

Processes were made using ArcGIS 9.1.

DTM was constructed using 100m interval contours.

Three major crop growth zones were selected according to altitude limitations.

0 – 600m: Appropriate for almost all crops.

600 – 900m: Appropriate for non-tropic crops and fruit trees (maize, winter wheat, apple trees, chestnuts etc.)

> 900m: Not appropriate for crops.

The zones were converted to raster (grid) with cell size 100x100m.
Digital Terrain Model

DTM of Thessaly water district
Digital Terrain Model

Crop growth zones according to altitude limitation

- Unclassified
- Non-tropic crops
- Fruit trees
- No crops
- Almost all crops

Altitude based crop growth zones of Thessaly water district
Supervised Classification

In order to define the sustainable production zones, a thematic classification was performed using WLGE zones and zones derived from the soil map and the DTM.

Thematic classification pattern:

- Unsustainable: Areas characterized by any of the “limiting” classes.
- Sustainable under restrictions: Partial limitations regarding to WLGE or soil map or DTM (intermediate classes).
- Sustainable for non-tropic crops: No “limitations” and 600 – 900m altitude.
- Sustainable: No “limitations” and <600m altitude.
Sustainable Production Zones

THESSALY SUSTAINABLE PRODUCTION ZONES (1981-2001)

Scale 1:1250000

Characterization of agricultural use:
- Undclassified
- Unsustainable
- Sustainable (non-tropical crops)
- Sustainable
- Sustainable under restrictions
Results

Agriculture is not a sustainable agronomic use in almost 1/3 of Thessaly water district (water, altitude or soil limitations). The term “under restrictions” refers to the cultivation of crops that don’t need large quantities as “input” regarding to irrigation and fertilizers. Also the type of cultivation must be extensive and not intensive.

Sustainable productions areas for non-tropic crops have small spatial coverage because they are delimited by relatively high altitudes.

Sustainable productions zones cover about 25% of Thessaly water district.
Conclusions

- The main advantage of the methodology is that it provides continuous spatial and temporal information.

- This way there are no fuzzy borders regarding to the derived zones.

- AI and VHI can be used in order to define zones adequate for sustainable farming according to water limitations.

- There is no area in Thessaly water district were plant growth is prohibited by water availability.
Conclusions

- WLGE can be combined with soil maps and DTM in order to identify sustainable production zones.

- The use of soil maps and DTM excludes areas unsuitable for agricultural activities.

- The combination of the frequency of occurrence of agricultural drought events along with climatic aridity, soil types and elevation information is essential in developing any sustainable farming plan.

- In “under restrictions” areas further work has to be done in order to define the type of crops and cultivation techniques.