Land cover land use change effects on surface water quality: Integrated MODIS and SeaWiFS assessment of the Dnieper and Don River basins and their reservoirs

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The collapse of the Soviet Union at the end of 1991 produced major socio-economic and institutional dislocations across the agricultural sector. Without planting schedules or crop energy subsidies in the form of fertilizers, pesticides, and fuel, or access to markets, the agricultural sector contracted sharply during the 1990s throughout the Former Soviet Union and its client states.

Myriad institutional changes brought about by the collapse of the Soviet Union induced changes in the distribution and extent of land cover types, land use intensity, enforcement of water pollution regulations, availability and choice of consumer products in urban areas, and the economic productivity in the industrial and agricultural sectors.

The Don and Dnieper Rivers form two of the major basins in western Eurasia. Five very large surface water reservoirs occur within these basins. They cover at total of 862,000 ha or 17% of the impounded surface area in the Former Soviet Union.

Within the context of a NASA project to study the consequences of land cover land use change for water quality, we examined key aspects of land surface phenology (LSP) and water quality (in terms of phytoplankton chlorophyll-a and total suspended solids concentrations) within the two basins.

Questions we aim to answer:

• To what extent can the significant changes in surface water quality following the collapse of the Soviet Union be linked to the significant changes in land cover and land use?

• Can inland water quality be effectively monitored using SeaWiFS and MODIS standard data products and new value-added products?

Why observe reservoirs?

• Flow of water over and through land influences the chemical composition of the receiving waters.

• Streams and rivers can be considered as “integrators” of the environmental and ecological conditions of watersheds and basins.

• Significant changes in land cover and/or land use can affect surface water quality.
Data Sources

*LSP:* 1982-2000 using AVHRR NDVI data and from 2003 using MODIS NBAR NDVI.

- Pathfinder AVHRR Land (PAL) NDVI 10-Day composites at 8 km. (ftp://disc1.gsfc.nasa.gov/data/avhrr/global_8km/)

Best Index Slope Extraction (BISE) was applied to the NDVI derived from MODIS NBAR data and to the PAL NDVI to attenuate for imperfections and noise in data. Backward (n-1) threshold was set to 0.03 and the forward (n+1) threshold was 0.05.

- MODIS/Terra Land Cover Type Level 3 Global 1km ISIN Grid. 2001 second composite period MOD12Q1 V004 Land Cover Product IGBP (http://edcdaac.usgs.gov/modis/mod12q1.asp)
- Daily minimum and maximum temperature from the NCEP/NCAR Reanalysis Project, daily measurements on a 2°×2° grid (http://wesley.wwb.noaa.gov/ncep_data)

*Water Quality:* 1982-2001 using MSS and TM Landsat data and from 2001 using MODIS data (http://modis.gsfc.nasa.gov/data/dataprod/index.php); we derived chlorophyll-a pigment concentrations and water attenuation coefficient using the *ms/12* processing via the program SeaDAS.
Originating south of Moscow, the Don River flows for nearly 2000 km south through the Central Russian Upland and discharges into the Gulf of Taganrog at the northern end of the Sea of Azov. The Don River Basin covers more than 45,000,000 ha, of which roughly 83% is used for agricultural purposes. Average population density within the Don River basin is 47 persons/km with 7 cities having more than 100,000 inhabitants.

The Dnieper stretches from Russia through Belarus and Ukraine before flowing into the northern Black Sea at Kherson. The Dnieper River Basin covers more than 53,000,000 ha, of which roughly 87% is used for agricultural purposes. Average population density within the Dnieper River basin is 64 persons/km with 16 cities having more than 100,000 inhabitants.
Analysis of Land Surface Phenologies

We used the contemporary land cover data, based on the MODIS IGBP classification, to peer into the past land surface phenologies (LSP) using AVHRR and MODIS data. NDVI time series from the PAL and GIMMS AVHRR datasets and the MOD43 product were extracted by MODIS land cover type within the Don and Dnieper River basins, separately. We focused on three key land cover types in which we expected some change following the collapse of the Soviet Union: agricultural lands, forests, and shrublands. These three superclasses were composed by simple aggregation of the MODIS IGBP land cover classes. NDVI time series were integrated by accumulated growing degree-day (base 0 °C) to summarize LSP dynamics. The points show the medians of the land cover classes within each basin for different datasets segregated into before or after the collapse of the Soviet Union.
The LSP dynamics are greater in the Don River basin than in the Dnieper River basin. In PAL (but not in GIMMS), there is a difference between prior and post collapse LSP trajectories. MODIS trajectories agree with PAL post trajectories, but not with GIMMS post trajectories.
Interannual dynamics in the shrublands are greater and the areal coverage is much less than in aglands. There is a suggestion of differential changes between the river basins. However, MODIS data fall between GIMMS and PAL AVHRR LSP trajectories.
There is little strong evidence of change in land surface phenology in the forests class. The LSP trajectories fall along the 1:1 line. MODIS data are comparable to GIMMS data but not to PAL.
Algorithm for chlorophyll-a concentration retrieval

In inland productive turbid waters MODIS blue band is affected by many sources of absorption in addition to chlorophyll, such as colored dissolved organic matter, and by scattering from all suspended particulate matters. Thus, the blue-green ratio used for chlorophyll-a retrieval in case 1 waters fails in productive turbid inland waters.

We developed and tested an inversion technique to retrieve chlorophyll-a concentrations from reflectance spectra of turbid productive waters using conceptual three-band model

\[ \text{Chl} \propto (R^{-1}_{\lambda_1} - R^{-1}_{\lambda_2})R_{\lambda_3} \]

To retrieve chlorophyll-a concentrations from MODIS data we used the special 2-band case of this model in the form

\[ \text{Chl} \propto R^{-1}_{\lambda_1} \times R_{\lambda_3} \]

where \(\lambda_1\) and \(\lambda_3\) are MODIS the red (667nm) and the NIR (748 nm) bands, respectively.
Model Calibration using *in situ* radiometric measurements

- Table 1. Optical Water Quality Parameters Measured in Calibration Data Set Containing 145 stations

<table>
<thead>
<tr>
<th></th>
<th>min</th>
<th>max</th>
<th>median</th>
<th>average</th>
<th>STD</th>
<th>COV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chlorophyll-a, mg/m³</td>
<td>4.4</td>
<td>217.3</td>
<td>36.1</td>
<td>46.34</td>
<td>41.2</td>
<td>0.89</td>
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<tr>
<td>Secchi disk depth, cm</td>
<td>18.0</td>
<td>299.0</td>
<td>63.0</td>
<td>81.09</td>
<td>56.8</td>
<td>0.70</td>
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<tr>
<td>Turbidity, NTU</td>
<td>1.7</td>
<td>78.0</td>
<td>16.9</td>
<td>20.09</td>
<td>15.7</td>
<td>0.78</td>
</tr>
<tr>
<td>TSS, mg/L</td>
<td>0.2</td>
<td>213.5</td>
<td>14.0</td>
<td>20.39</td>
<td>25.9</td>
<td>1.27</td>
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<tr>
<td>OSS, mg/L</td>
<td>0.5</td>
<td>213.5</td>
<td>10.0</td>
<td>13.75</td>
<td>25.8</td>
<td>1.88</td>
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<tr>
<td>ISS, mg/L</td>
<td>0.0</td>
<td>139.8</td>
<td>2.5</td>
<td>7.61</td>
<td>15.3</td>
<td>2.01</td>
</tr>
<tr>
<td>$a_{\text{cdom}(440)}$</td>
<td>0.5</td>
<td>4.4</td>
<td>1.0</td>
<td>1.20</td>
<td>0.66</td>
<td>0.55</td>
</tr>
<tr>
<td>$a_{\text{trip}(440)}$</td>
<td>0.4</td>
<td>6.7</td>
<td>2.0</td>
<td>2.24</td>
<td>1.34</td>
<td>0.60</td>
</tr>
</tbody>
</table>

TSS, total suspended solids; ISS, inorganic suspended solids; OSS, organic suspended solids; $a_{\text{CDOM}(440)}$, absorption coefficient of CDOM at 440 nm; $a_{\text{trip}(440)}$, absorption coefficient of tripton at 440 nm; STD and COV are standard deviation and coefficient of variation (STD/mean), respectively
Model Calibration using *in situ* radiometric measurements

Chl-a = 136.21x - 16.175

$R^2 = 0.9283$, RMSE = 11.8 mg/m$^3$
Model Calibration
AISA-Eagle sensor

\[ \frac{R_748}{R_{665}} = 0.0142 \times \text{Chl-a} + 0.8497 \]

\( R^2 = 0.948 \)
Chlorophyll-a distribution in Dnieper delta retrieved from MODIS image (May 20, 2003)
## Model Validation
Simulated MODIS red (667 nm) and NIR (748 nm) bands

### Table 2. Results of model validation

<table>
<thead>
<tr>
<th></th>
<th>N</th>
<th>a</th>
<th>b</th>
<th>r²</th>
<th>RMSE</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Set 1</td>
<td>156</td>
<td>9.42</td>
<td>0.899</td>
<td>0.90</td>
<td>12.33</td>
<td>&lt;0.0001</td>
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<tr>
<td>Set 2</td>
<td>85</td>
<td>14.55</td>
<td>0.913</td>
<td>0.94</td>
<td>15.78</td>
<td>&lt;0.0001</td>
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<tr>
<td>Set 3</td>
<td>17</td>
<td>8.76</td>
<td>0.916</td>
<td>0.98</td>
<td>7.48</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Set 4</td>
<td>18</td>
<td>12.12</td>
<td>0.977</td>
<td>0.98</td>
<td>11.92</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>All together</td>
<td>275</td>
<td>10.81</td>
<td>0.920</td>
<td>0.92</td>
<td>13.25</td>
<td>&lt;0.0001</td>
</tr>
</tbody>
</table>

*a* and *b* are the intercepts and slopes, respectively, of the best linear fits between observed and predicted chlorophyll-a values. *N* is the number of samples.
Next Steps

• The use of Landsat image time series since 1982 to investigate (a) changes in land cover at finer spatial resolution in areas of significant change identified in the coarser grained analysis, and (b) change in chlorophyll-a and total suspended matter concentrations in key Dnieper and Don reservoirs and Gulf of Taganrog.

• Atmospheric correction of MODIS ocean red and NIR radiances.

• Algorithms calibration for chlorophyll and total suspended matter retrieval from MODIS imagery.
Acknowledgments

Research supported by the NASA LCLUC program.

THANK YOU!

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