GLOBAL INDICATOR PROFILES

for the GEF Land Degradation Focal Area

Report by the GEF MSP
'Measuring Impacts from SLM – Development of a Global Indicator System" under the
KM:Land initiative

Profiles of Global Indicators selected for the GEF Land Degradation Focal Area

Prepared by the KM:Land initiative

Submitted to the UNU-International Network for Water and Environmental Health
by the Center for International Earth Science Information Network (CIESIN), The Earth Institute at Columbia University

This document includes indicator profiles that were developed based on consultations with the KM:Land project's expert advisory group (EAG) at a 21-23 January 2008 meeting in Bonn, Germany. The indicators will be used in conjunction with other criteria for prioritizing resource allocation in the GEF Land Degradation Focal Area.

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Acronyms

AET	Actual Evapotranspiration
AVHRR	Advance Very High Resolution Radiometer
CEH	Centre for Ecology and Hydrology, UK
CIESIN	Center for International Earth Science Information Network
CSD	Commission on Sustainable Development
DIA	Domestic, Industrial and Agricultural water use
EAG	Expert Advisory Group
ESA	European Space Agency
FAO	Food and Agricultural Organization of the United Nations
FAPAR	Fraction of Absorbed Photosynthetically Active Radiation
FGT	Foster, Greer, and Thorbecke Poverty Measure
GEF	Global Environment Facility
GEMS	Global Environment Monitoring System of UNEP
GEOSS	Global Earth Observation System of Systems
GIMMS	Global Inventory Modeling and Mapping Studies
GLC 2000	Global Land Cover 2000
GLCN	Global Land Cover Network
GRDC	Global Runoff Data Centre
GTN-H	Global Terrestrial Network-Hydrology
IGBP	International Geosphere-Biosphere Programme
ISRIC	International Soil Resources Information Centre
JRC	Joint Research Centre of European Space Agency
KM	Knowledge Management
LADA	Land Degradation Assessment in Drylands
LCCS	Land Cover Classification System
MA	Millennium Assessment
MDGs	Millennium Development Goals
MERIS	Medium Resolution Imaging Spectrometer
MISR	Multiangle Imaging SpectroRadiometer
MODIS	Moderate Resolution Imaging Spectroradiometer
NASA	National Aeronautics and Space Agency
NDVI	Normalized Difference Vegetation Index
NOAA	National Oceanic and Atmospheric Administration
NPP	net primary productivity
PET	potential evapotranspiration
RUE	rain use efficiency
SeaWiFS	Sea-viewing Wide Field-of-view Sensor
SEDAC	Socioeconomic Data and Application Center (of CIESIN)
UN CSD	United Nations Commission on Sustainable Development
UNEP	United Nations Environment Program
UNH	University of New Hampshire
UNU	United Nations University
USD	United States Dollar
VASClimO	Variability of Surface Climate Observations
WRI	World Resource Institute
WSAG	Water Systems Analysis Group of the University of New Hampshire

Introduction

During the Expert Advisory Group (EAG) meeting from 21-23 January 2008 in Bonn, Germany, a consensus emerged that the application of global-level indicators developed by the KM:Land initiative should be used for the purpose of prioritizing GEF resource allocation, while monitoring of the impact of GEF investments should be informed by measurements at the project-level, possibly through a different set of indicators. This was acknowledged to be a shift in the purpose of global-level indicators that were initially supposed to measure global impacts derived from GEF-funded initiatives to mitigate land degradation. The EAG placed emphasis on ensuring consistent measurements of global-level indicators in order to provide reliable and useful tools that support GEF decision-making regarding resource allocation.

The indicators presented in the following profiles fall within different areas of the SLM conceptual framework developed for this project (Figure 1). This framework explains the causal relationships that are essential to the characterization of land degradation, incorporating elements from both the Millennium Ecosystem Assessment and the DPSIR (Driving force-Pressure-State-Impact-Response) frameworks. In the context of land degradation, *driving forces*, such as population growth or climate change, exert *pressures* on the environment that translate into changes in the *state* of the environment, such as soil nutrient content, which have an *impact* on ecosystem services, ranging from crop production to carbon sequestration, which in turn affect *human well-being*. This may lead to a *response* from society (e.g., policies, projects, behavior) to change the *driving forces* or reduce the *pressure.*

Indicator profiles were compiled in four different categories: land cover (1 profile), land productivity (1 profile), water (1 profile), and rural poverty/income distribution (2 profiles). As a part of the profiles, illustrative maps are provided that present at least one possible version of an indicator map.[1] Each of the indicators was chosen based on an extensive review process by the KM:Land Project Expert Advisory Group (EAG), and has the potential to be monitored over time. The indicators will be used, along with other criteria, for prioritizing resource allocation in the GEF Land Degradation Focal Area.[2]

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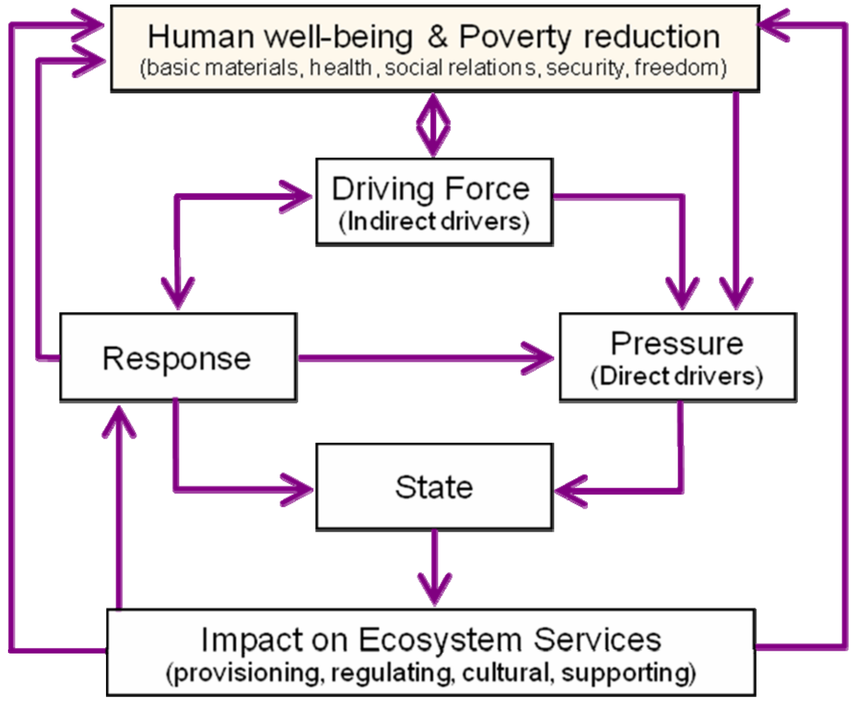
[1] In some cases, such as for land productivity, multiple possible indicator maps are available depending on permutations in the methodology, and we have selected a subset. In other cases, such as for water stress, we provide a map showing results for only one model, whereas other models are discussed in the profile.

[2] In the context of this document, the definition of land degradation is taken from Article 1 of the Convention to Combat Desertification, where it is defined as a "reduction or loss of biological or economic productivity of ecosystems resulting from climatic variations, land uses and a combination of processes such as: soil erosion, deterioration of soil properties and long-term vegetation loss" (see article 1 for details).

Figure 1. Conceptual Framework for Sustainable Land Management



The indicator profiles included in this package follow a template developed by the Commission on Sustainable Development (CSD), but which has been modified in order to accommodate the needs of the KM:Land project. Cost estimates for updating the indicators are provided in section 4(d) of each profile. It must be emphasized up front that these estimates only cover the end-of-pipe processing of data from various streams. Actually maintaining the underlying data streams, whether from satellite observations or in situ observation networks, requires substantial financial outlays (see section 3(a) of the Water Stress profile for an example of these challenges). Ultimately, the indicators are only as robust as the underlying data flows and the models built upon them, but it is important to point out that a number of these data streams are in serious need of investment by the global community.

Land Cover	
Category: *Land cover*	***Country Coverage:*** *Global*
Time Series: *2000*	***Spatial Refinement*** *1 km*
Placement Within SLM Framework: *State*	***Status:*** *Indicator ready*

1. INDICATOR

(a) **Name:** Global Land Cover, circa 2000

(b) **Brief Definition:** This indicator shows the distribution 23 of the world's major land cover categories, as classified by the Global Land Cover 2000 (GLC 2000) product.

(c) **Unit of Measurement:** Land cover class

(d) **Related Measures:** This indicator relates to land cover change. Unfortunately, at the present time and at the global scale, there are no comparable land cover products for two points in time with which it would be possible to derive change matrices. The Food and Agriculture Organization of the UN (FAO) Global Land Cover Network (GLCN) has undertaken several country studies in which land cover change was monitored by reclassifying older imagery with the Land Cover Classification System (LCCS) legend and then comparing the results with GLC 2000 to produce a land cover change matrix. Under the FAO Land Degradation Assessment in Drylands (LADA) project such "backward compatibility" studies have been conducted for Senegal and Kenya. GLCN is also developing a software tool which would make comparisons much faster, as the present method is quite time consuming.

2. POLICY RELEVANCE

(a) **Purpose:** To measure current land cover, and especially the distribution of land cover types of greatest concern for land degradation (cropland, rangeland, etc.).

(b) **Relevance to KM: Land Indicator Category:** The indicator shows the distribution of land cover categories within each country.

(c) **International Conventions and Agreements:** N/A

(d) **International Targets/Recommended Standards:** N/A

(e) **Comparison to Other Indicators and Strengths and Weaknesses:** Several global land cover products are available from different satellite remote sensing instruments, including AVHRR, MODIS, and SPOT VEGETATION. This dataset compares well with other global land cover data sets (see section 3(a) below).

3. METHODOLOGICAL DESCRIPTION

(a) **Underlying Definitions and Concepts:**

According to de Sherbinin and Zimmerman (forthcoming), "The Global Land Cover 2000 (GLC 2000) data set was prepared in a collaborative effort led by the European Commission Joint Research Centre (JRC) using the VEGA 2000 data set, which comprises 14 months of pre-processed daily images from the VEGETATION sensor of the SPOT4 satellite. The land cover map is benchmarked to the year 2000. The project team sought to develop a data set that would be suitable for use in connection with United Nations environmental initiatives, as the reference year is a significant date for several such UN efforts. The GLC 2000 data were included as a core data set in the Millennium Ecosystem Assessment (MA).

"Local and regional experts from 30 countries participated in a "bottom-up" process where data from each country or region was assigned to a local team that led the classification effort. According to Giri *et al.* (2005), "The major advantage of GLC 2000 is that the project was implemented with the active participation of more than 30 national, regional, and international organizations… The major weakness is that the methodology used … is not repeatable."

"The primary classification system used in GLC 2000 is the FAO and UNEP's Land Cover Classification System (LCCS), a flexible system that allows the identification of regional differences in landcover class (Mayaux *et al.* 2004). GLC 2000 allowed the use of different classification systems depending on the needs of the regional partners involved. Partners were thus free to choose as many land cover classes as they wished once the threshold of 22-24 basic classes (e.g. tree cover, needle-leaved, evergreen, regularly flooded, saline water, mosaic: cropland / shrub or grass cover, artificial surfaces and associated areas, etc.) had been established (Giri et al. 2005). GLC 2000 products are available in global and regional coverages.

"GLC 2000 has undergone a two-layered validation process (Mayaux, 2003). First, a systematic "confidence-building" review was carried out by regional experts inspecting a 2 degree x 2 degree grid and scoring the cells as very good, good, acceptable, and unacceptable (coded as green, yellow, and red, respectively). Second, a "design review" of the global product was carried out in which high-resolution imagery was used to validate a stratified random sample of sites.

"Validation of GLC 2000 has now been completed (Mayaux et al. 2006), and the analysis suggests that the product has difficulties in distinguishing "mosaic" landscapes of mixed forest and agriculture or mixed savannah and agriculture as found in Africa. According to Bartholomé (2004), "forest-agriculture mosaic landscapes tend to be classified as forest, whereas savannah-agriculture landscapes tend to be classified as mixed agriculture classes, which can be misleading for uninformed users. Such bias can only be resolved by improved and explicit identification of pure rather than mosaic classes by using higher resolution imagery."

"A study comparing MODIS Land Cover and the SPOT-based GLC 2000 data sets found that, on a global scale, they agree reasonably well in terms of how much land they assign to each classification, but that per-pixel agreement by classification is only 59%. According to Giri et al. (2005), "This finding is not surprising given that these data sets were prepared using different data sources, classification schemes, and methodologies." Comparison of land cover types between local, regional or global scales may prove to be difficult (Giri et al. 2005).

"Iwao et al.'s (2006) validation of several land cover maps using "ground-truth" data from the Degree Confluence Project (see section 5.0.4 on validation) found that for Eurasia, GLC 2000 land cover designations at confluence points were in agreement with ground-based assessments and photographs at those same points for 55% of the points. Although this accuracy level may seem low, it is actually statistically indistinguishable from the best performing land cover data set, which was MODIS Land Cover, which had a 58% agreement rate. Latifovic et al. (2004) found high levels (79%) of spatial correlation for North and Central America between the GLC 2000 maps and the MODIS, IGBP and University of Maryland land cover datasets and found that the GLC 2000 dataset allow for more controlled use of temporal information provided in remote sensing data.

"The objectives and structure of the GLC 2000 dataset have made it ideal for use in projects related to the UN Millennium Ecosystem Assessment (MA). The Ecosystem Services in Southern Africa regional assessment component of the MA utilized the GLC 2000 dataset in its analysis of biodiversity and landcover in the Southern Africa region and found its outputs to be comparable to those of the IGBP DISCover and FAO LCCS remote sensing dataset outputs (Scholes and Biggs, eds. 2004). Mayaux et al. (2004) found that the creation of a map of Africa based on the GLC 2000 dataset improved the state of knowledge about land cover in Africa and resulted in the most detailed regional map of the area to date, and this despite acknowledgement of the problems identified by Bartholomé (2004)."

(b) **Measurement Methods:** The basis of the Global Land Cover 2000 project is the VEGA 2000 data set. This is composed of 14 months (Nov. 1999 - 31 Dec. 2000) of daily 1-km resolution satellite data acquired over the whole globe by the VEGETATION instrument on-board the SPOT 4 satellite and delivered as multi-channel daily mosaics from 75°N to 56°S and from 180° W to 180° E. The data were interpreted by regional experts and harmonized into a global product.

4. ASSESSMENT OF DATA

(a) Data Needed to Compile the Indicator:

- JRC's Global Land Cover 2000.

(b) **National and International Data Availability and Sources:** European Commission's Joint Research Centre.

(c) Data References:

JRC (Joint Research Centre of the European Commission). 2003. Global Land Cover 2000. Available at http://www-gem.jrc.it/glc2000 (accessed on 28 February 2008).

(d) Costs of Updating the Indicator

As indicated in section 1(d), presently there are no globally comparable time series land cover data sets. The cost of creating an update to the GLC2000 using the same sensor and methodology for change measurement purposes would be substantial – and in fact, since regional teams were permitted to develop their own methods, regenerating a consistent product for 2005 might be impossible. On the other hand the GLOBCOVER data set, derived from European Space Agency's (ESA) Envisat data, will soon be released (September 2008). It uses the same LCCS classification scheme as GLC 2000, and represents a 2005 "picture" of land cover, though using different source data and methods (and hence not directly comparable for land cover change analysis). At approximately 300m resolution, it will be the most detailed portrayal of the earth's land cover ever, but it has yet to be extensively validated and peer reviewed. So, working on the assumption that the GEF will simply utilize the latest existing peer-reviewed data products, the marginal cost of obtaining and formatting these data for GEF needs are minimal.

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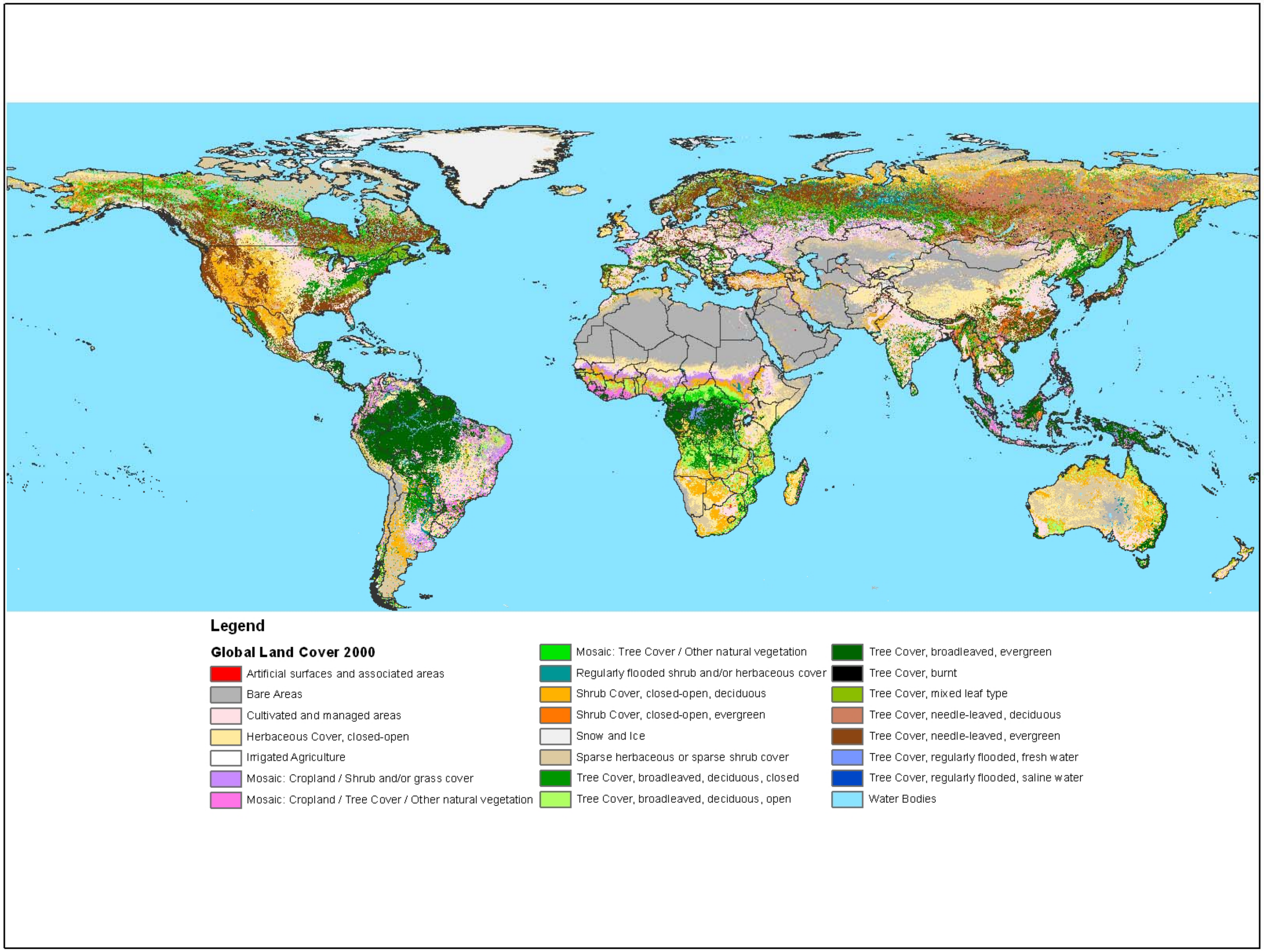
Figure 2. Global Land Cover 2000



Source: European Commission, Joint Research Centre.

Land Productivity	
Category: *Land Productivity*	***Country Coverage:*** *Global*
Time Series: *2000-2007, 1981-2002; 1981-2003*	***Spatial Refinement*** *4km*
Placement Within SLM Framework: *Impact on Ecosystem Services*	***Status:*** *Will be available in 2008*

1. INDICATOR

(a) **Name:** Global Trend in Greenness (NDVI)

(b) **Brief Definition:** The International Soil Resources Information Centre (ISRIC), under a subcontract with FAO's Land Degradation Assessment in Drylands (LADA), has constructed a measure of greenness trend using the Global Inventory Modeling and Mapping Studies (GIMMS) normalized difference vegetation index (NDVI) time series (1981 to 2003) assembled by the University of Maryland. Trends are calculated in 11 year blocks, taking the most recent year of available data and the 10 preceding years (i.e. 1991-2002). Where greenness is limited by rainfall, the index is adjusted for rainfall variability using rain-use efficiency (RUE), the ratio of NDVI to rainfall. First, correlation between annual rainfall and NDVI is calculated, pixel-by-pixel. For those pixels that show positive correlation, station-observed rainfall is used to create a rainfall surface, and annual integrated NDVI values for a given grid cell are divided by the rainfall amounts for the corresponding time-unit. To obtain trends, the most recent year of available data and the 10 preceding years are used. Where RUE is positive, it is assumed that the greenness decline is caused by a declining trend of rainfall and those areas are screened from the other areas of declining greenness (see Figure 3). The remaining areas of declining greenness are expressed in terms of NPP to provide a single, tangible indicator: long-term trend of declining productivity which may be summed up as loss of NPP in tones C/ha.

(c) **Unit of Measurement:** sum NDVI, translated into absolute change in net primary productivity

(d) **Related Measures:** Beyond the trend measures, it is possible to generate state measures of current greenness (in a five-year moving average) for the most recent years for which NDVI data are available from MODIS or AVHRR sensors.

NDVI measures can be converted into biomass productivity (tons of carbon per sq. km) by integrating over time. However, to do so accurately requires information on vegetation structure and canopy height.

Using the GLC 2000 data set (see Land Cover profile), separate trends in rainfall-adjusted greenness for various land cover types (e.g. cropland) are isolated by creating masks by these land cover types. The data are less sensitive for forest because of saturation of the NDVI signal at high levels of greenness. The present GLADA product masks urban areas. However, trends in the urban land cover class could also be assessed, which might provide some indication of changes in the extent of urban agriculture in Africa.

2. POLICY RELEVANCE

(a) **Purpose:** To identify regions with declining greenness as an early warning of possible land degradation in a particular area. The indicators cannot be used to definitively conclude that land degradation has taken place, but they can help to identify areas that require more fine-scaled investigation.

(b) **Relevance to KM:Land Indicator Category:** Greenness trends help to identify areas in which there has been either an increase/decrease in vegetative cover or biomass productivity, net of the effect of rainfall.

(c) **International Conventions and Agreements:** UN Convention to Combat Desertification.

(d) **International Targets/Recommended Standards:** N/A

(e) **Comparison to Other Indicators and Strengths and Weaknesses:** Although the rainfall-adjusted greenness trend controls to some extent for the impact of rainfall variability, the global indicator is unable to fully distinguish between changes in NDVI resulting from land use change and those resulting from land degradation as ordinarily understood. This can only be assessed by following time series data for individual pixels, preferably at a higher resolution than the 8km GIMMS data. Another weakness is the paucity of rainfall measurement stations in some regions. Any rainfall surface derived from widely-spaced observations will not capture fine-scale variability. Nevertheless, this indicator can signal areas that require closer investigation and, as such, provides an early warning for land degradation.

The GLADA project has also employed the residual trends approach (see Herrmann *et al.* 2005, Wessels *et al.* 2007) at the regional and global level to provide an additional layer of information (see Figure 4). This identifies negative trends in the difference between observed ΣNDVI and the ΣNDVI predicted from rainfall. Areas where observed NDVI is significantly lower than expected would be areas of potential degradation.

As an alternative to NDVI, the Fraction of Absorbed Photosynthetically Active Radiation (fPAR) avoids some of the limitations of NDVI measures (see Section 3(a) below). fPAR data are available globally from the year 2000 at 1km-resolution.

3. METHODOLOGICAL DESCRIPTION

(a) Underlying Definitions and Concepts:

Quoting from Dent and Scholes (2008): "Land degradation may be defined as a long-term decline in ecosystem function and productivity, which may be measured by change in net primary productivity (NPP); deviation from the norm may be taken as an indicator of land degradation – or improvement.

"As a proxy indicator, normalized difference vegetation index (NDVI), calculated from the reflected near-infrared and red wavebands measured by earth-orbiting satellites, has been shown to be related to leaf area index and the fraction of photosynthetically active radiation absorbed by vegetation (fPAR), which control vegetation productivity and land/atmosphere fluxes, and to NPP. NDVI = (NIR-Red)/(NIR+Red). It compensates for some sensor drift, view angle, illumination and atmospheric effects. Shortcomings include: saturation at high leaf cover; soil interference with the signal at low leaf cover; unreliable measurements for cloudy areas; and variable, empirical calibration in terms of NPP. Consistent time-series data at resolutions from 20m to 8km are available from 1983 and, for this reason, it is the recommended indicator for immediate use (i.e. looking backwards).

"fPAR has the advantage of being a physically-defined quantity directly related to NPP. It is calculated from the same wavebands as NDVI using further, independent measurements, and it does not saturate at high leaf areas. Consistent time series data are available from JRC (MERIS ENVISAT) and NASA (MODIS) at 500m/1km resolution from year 2000. This is the preferred indicator for the future.[3]

"Greenness has been used to analyze vegetation dynamics at regional and global scales, either as an index (Anyamba and Tucker 2005, Olsson *et al*. 2005) or as one input to dynamic models (Nemani *et al.* 2003, Seaquist *et al*. 2003, Fensholt *et al.* 2006). However, a negative trend does not necessarily indicate land degradation, nor does a positive trend necessarily indicate improvement. Biomass depends on several factors including: climate – especially fluctuations in rainfall, sunshine, temperature and length of the growing season; land use; large-scale ecosystem disturbances such as fires; and the

[3] The Joint Research Centre's Institute for Environmental Sustainability has produced global FAPAR maps covering the period 1998 to 2003 using SeaWiFS data and from January 2003 onwards with MERIS data over Europe (JRC undated). FAPAR can be derived from other sensors, such as SPOT VEGETATION, MISR, and GLI.

global increase in nitrate deposition and atmospheric CO_2. To interpret greenness in terms of land degradation or improvement, the other factors in the equation must be accounted for. Globally, this may be accomplished for climatic variables for which consistent time series are available but not for land use and management - for which local interpretations are always needed.

"Where productivity is limited by rainfall, rain-use efficiency (the ratio of NPP to precipitation) accounts for variability of rainfall and, to some extent, local land and soil characteristics. The combination of satellite-based NPP and station-observed rainfall has been used successfully to assess land degradation at various scales (Holm *et al.* 2003, Prince *et al.* 2007, Bai *et al.* 2008a). It is recommended that, for those areas where there is a relationship between rainfall and productivity, rain-use efficiency or RESTREND (Wessels *et al.* 2007) is used in conjunction with the greenness indicator;[4] where appropriate, energy-use efficiency based on greenness and accumulated temperature may also be used - as in the GEF-UNEP-FAO LADA program."

(b) **Measurement Methods:**

The Global component of the Land Degradation Assessment in Drylands (GLADA) used annual sums of NDVI from the MODIS 16-day maximum at 500 m resolution. From this it is possible to create a five year moving average (i.e. the 2005 average represents an average of the NDVI for the years 2003-2007).

The Global Inventory Modeling and Mapping Studies (GIMMS) data set is a normalized difference vegetation index (NDVI) derived from imagery obtained from the Advanced Very High Resolution Radiometer (AVHRR) sensor onboard National Oceanic and Atmospheric Administration (NOAA) satellites. The GIMMS dataset was corrected for distortions due to instrument calibration, view geometry, volcanic aerosols, and other effects unrelated to vegetation change (University of Maryland, undated). GIMMS is available globally for a 21-year period from 1981 to 2002 and is also updated annually on a regional basis.

The rainfall-adjusted greenness indicator uses the greenness trends derived from the GIMMS dataset. It takes the ratio of ΣNDVI values and sum of annual rainfall values from the Variability of Surface Climate Observations (VASClimO) dataset developed by the German Meteorological Service.

4. ASSESSMENT OF DATA

(a) **Data Needed to Compile the Indicator:**

[4] Where there is no relationship between greenness and rainfall (i.e., irrigated areas, wetlands, groundwater-fed vegetation like oases, and the much larger areas where there is surplus rainfall), rain-use efficiency or RESTREND are not appropriate indicators.

- MODIS NDVI product for a five-year moving average centered on 2005
- GLADA trend data derived from GIMMS
- VASClimO annual rain fall data

(b) **National and International Data Availability and Sources:** All data sets are already available from GLADA. An updated global GIMMS will be available later in 2008.

(c) **Data References:**

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(d) **Costs of Updating the Indicator**

Assuming that the ISRIC's global contribution to the LADA will continue to produce periodic updates using MODIS annual NDVI, and assuming that MODIS remains an operational mission, the marginal cost of producing this indicator would be minimal. However, neither assumption is entirely realistic. In the event that this becomes an operational indicator for allocating GEF resources in the land degradation portfolio, some level of support would be required for producing the indicator, probably on the order of $50,000 per year. In the event that MODIS goes out of service, the methodology is portable to other sensors, but there would be costs inherent in re-calibration.

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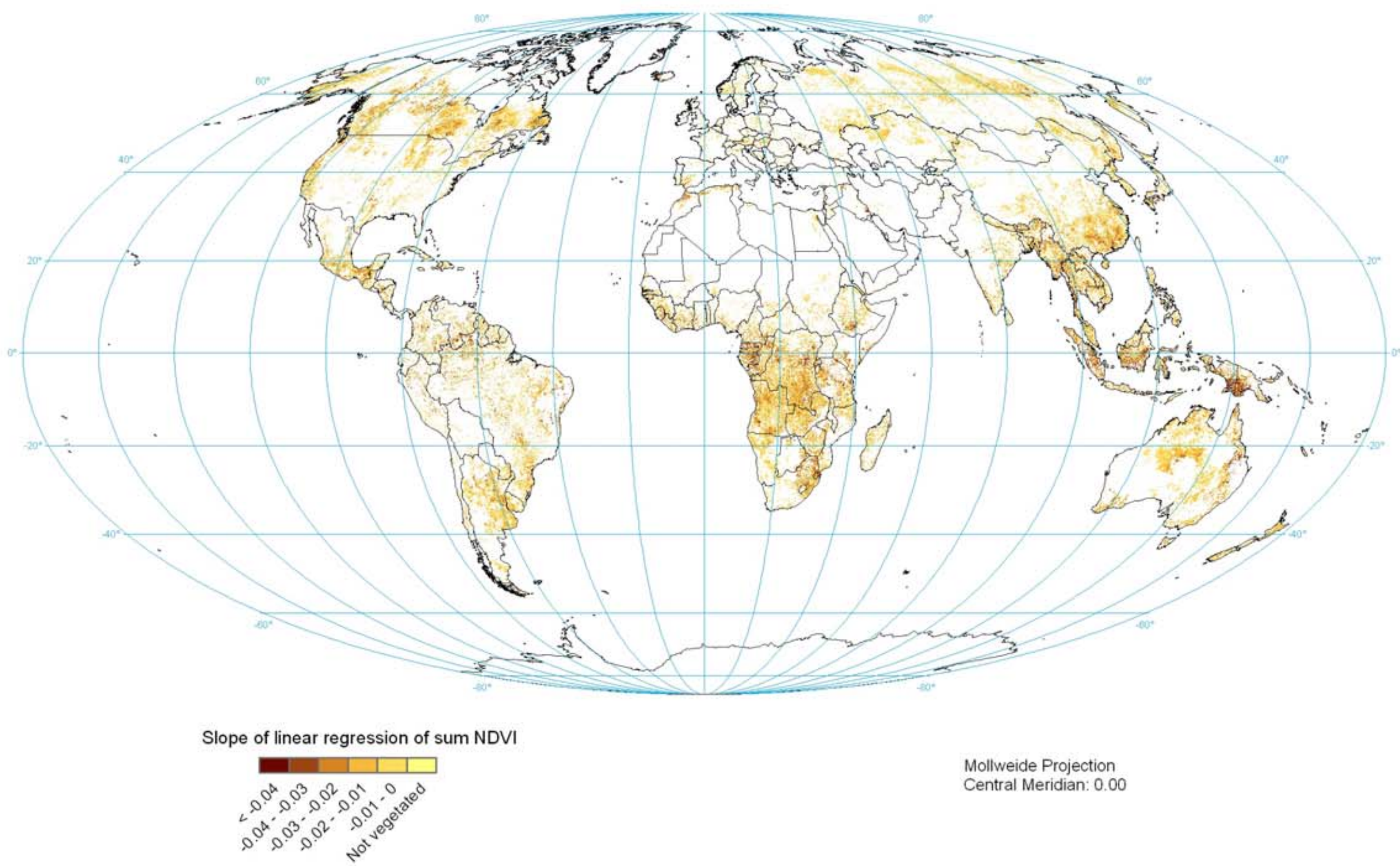
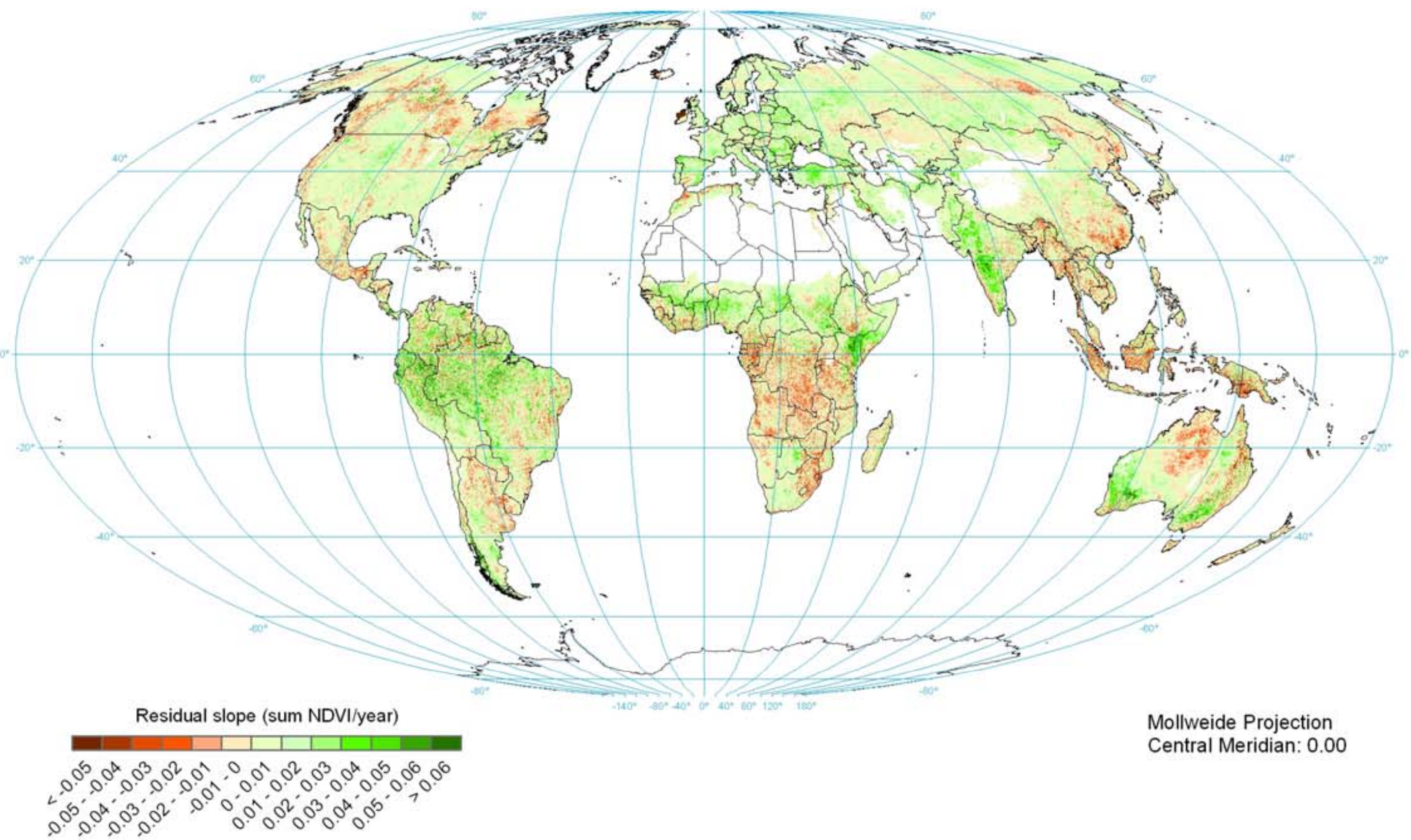
Figure 3. Global negative trend in RUE-adjusted NDVI, 1981-2003



Source: Bai et al.*,2008b, p. 15.*

Figure 4. Residual trends of sum NDVI (RESTREND), 1981-2003



Source: Bai et al.*,2008b*, *p.17*

Water Stress	
Category: *Water availability*	***Country Coverage:*** *Global*
Time Series: *UNH-WSAG model run for 2000*	***Spatial Refinement*** 0.5° (30 arc-minute) grid
Placement Within SLM Framework: *Pressure and Impact on Ecosystem Services*	***Status:*** *Indicator ready*

1. INDICATOR

(a) **Name:** Water Stress

(b) **Brief Definition:** This indicator measures the ratio of withdrawals to availability, a conventional indicator of water stress. Water stress is a measure of the amount of pressure put on water resources and aquatic ecosystems by the users of these resources, including domestic users, industries, power plants and agriculture. Water withdrawals are defined as the amount of water taken out of rivers, streams or groundwater aquifers to satisfy human needs for water. A river basin is water stressed if annual withdrawals are between 20 and 40% of annual supply, and severely water stressed if this figure exceeds 40%. Figure 5 shows water stress on a pixel basis, developed by the Water Systems Analysis Group (WSAG) at the University of New Hampshire.

(c) **Unit of Measurement:** This indicator measures the ratio of withdrawals to availability on a 0.5° grid. Grid cells in which withdrawals are >40% of supply are considered stressed.

(d) **Related Measures:** Other measures would include the percentage of territory that is under water stress, which CIESIN also has available. An additional indicator that has been calculated by CIESIN is the percentage of irrigated area in water stressed regions of a country, using water stressed regions developed by WSAG and irrigated areas defined by Siebert *et al.* (2005a).

2. POLICY RELEVANCE

(a) **Purpose:** To measure the stress on water resources.

(b) **Relevance to KM:Land Indicator Category:** Since agriculture accounts for approximately 70% of water withdrawals (Siebert *et al.*, 2005b), stress on water resources is highly correlated with water management in the agricultural sector. The higher the ratio of withdrawals to availability, the more often the water in a basin is used and the more it is degraded or depleted, therefore limiting further use of these water resources to downstream users. In several developing countries, irrigation represents up to 95 percent of all water withdrawn, and it plays a major role in food production and food security.

(c) **International Conventions and Agreements:** The UN Watercourses Convention, adopted in May 1997, and ratified to date by six Parties, is a global framework agreement with the goal to "ensure the utilisation, development, conservation, management and protection of international watercourses" and the promotion of their optimal and sustainable utilisation for present and future generations. In line with this, the Convention requires that "an international watercourse shall be used and developed by watercourse States with a view to attaining optimal and sustainable utilisation thereof and benefits therefrom, taking into account the interests of the watercourse States concerned, consistent with adequate protection of the watercourse. "

(d) **International Targets/Recommended Standards:** United Nations Commission on Sustainable Development (UN CSD) suggests that a country is water scarce if annual withdrawals are between 20 and 40% of annual supply, and severely water scarce if this figure exceeds 40% (Raskin et al., 1997).

(e) **Comparison to Other Indicators and Strengths and Weaknesses:** The advantage of this metric is that it is available at a sub-national level. A disadvantage is that it could be quite costly to update it, owing to problems in obtaining input data for global hydrological models (see sections 3(a) and 4(d) below).

Alternative metrics include the Water Stress Index (Falkenmark et al., 1989), which proposes 1,700 m^3 of renewable water resources per capita per year as a threshold for adequate water availability, based on estimates of water requirements in the household, agricultural, industrial and energy sectors, and the needs of the environment. Countries below this threshold are said to experience water stress. When supply falls below 1,000 m^3/person a country experiences water scarcity, and below 500 m^3/person absolute scarcity. Water availability per capita could be calculated on the basin level, and even potentially on a per-pixel basis, though it's meaning at that level is less certain since a population far from a river or water source may still benefit from water that is transported overland in pipes/canals or extracted from underground aquifers.

3. METHODOLOGICAL DESCRIPTION

(a) Underlying Definitions and Concepts:

The documentation associated with the 'mean annual relative water stress index' data set (Figure 5) developed for the *World Water Development Report II* by the University of New Hampshire's Water Systems Analysis Group describes the following methods used to develop the data: "Gridded fields of water stress indicators based on the ratio of human water use (sum of domestic, industrial and agricultural = DIA, in km^3 per year) to renewable water resources (Q) for 1995 (in km^3 per year) at 30 minute (latitude by longitude) resolution (UNH WSAG, 2006).. Sectoral water use statistics were from WRI (1998). Domestic water demand was computed on a per capita basis for each country and distributed geographically with respect to the 1-km total population field (Vorosmarty et al., 2000). Industrial usage was applied in proportion to urban population. Country-level irrigation withdrawals were distributed over irrigated lands (aggregated from Döll and Siebert, 2000) based on estimated irrigation need (see Irrigation water use metadata). Irrigation need was computed as the difference between potential evapotranspiration (PET, which represents the crop water requirements under optimal conditions) and actual evapotranspiration (AET, see Irrigation water use metadata for details). Grid-based aggregates at 30′ resolution were then determined for agricultural plus domestic plus industrial water demand. Discharge (Q) was computed as flow-accumulated composite runoff (Fekete et al., 2002) along a 30-min (latitude by longitude) digital river network (Fekete et al., 2001). A ratio of 0.4 or greater indicates conditions of water stress (Vorosmarty et al., 2000; UN CSD, 1997)."

Creating a time series indicator based on real changes in global hydrology and water use presents a complex and challenging picture. According to Charles Vorosmarty of the WSAG (personal communication, 5 April 2008), the Global Terrestrial Network-Hydrology (GTN-H) intends to work on developing better time series data on water supply (Q). The City College of New York (where the WSAG is relocating) will coordinate the GTN-H, and the following partners will be involved: the Global Runoff Data Center (river discharge and runoff); Global Precipitation Climatology Center, Global Precipitation Climatology Project, of the US National Climatic Data Center (rainfall and snowfall); National Snow and Ice Data Center, World Glacier Monitoring Service (snow and ice cover); FLUXNET (evaporation and evapotranspiration); ESA's Soil Moisture and Ocean Salinity mission (soil moisture); International Groundwater Resource Assessment Center (groundwater); International Data Centre on the Hydrology of Lakes and Reservoirs (lake/reservoir levels); World Meteorological Center (water vapor); International Atomic Energy Agency (isotopes); and UNEP/GEMS (water quality). On the use side, GTN-H's partner is FAO/AQUASTAT.

Despite this impressive partnership, the ability to effectively coordinate it will immediately meet the limits imposed by varying levels of capacity and varying levels of commitment to collect and stage the integrated data streams. For example, the Global Runoff Data Center (GRDC) is overstressed with respect to its ability to collect unbroken time series of discharge data, which is the mainstay of GTN-H's capacity to monitor the state of world water resources. The problem arises from several factors: the basic logistical challenge of having to contact numerous data holders in any one country (all with varying commitments to share data); staffing shortages at GRDC; decline in the number of operating stations, especially in the developing world; prohibitions against data release, forced by agency cost-recovery concerns and national policy based on strategic concerns; and, even where the data are available, substantial delays in data processing and release.

On the water use side, there are many difficulties in assembling water use data . In the case of irrigation, there are definitional problems as well as under/over reporting for political and economic ends. Other water use data sets are outdated and standardized methods for collecting the information are not applied. This presents a highly patchy picture in which substantial educated guesswork is required.

Summing up, indicator sets are only as robust as the data sets from which they are derived. The challenges laid out above are thus intrinsic to the problem at hand. It would take on the order of a few million US dollars (USD) to create a functioning in situ network of global discharge stations to monitor the water resource base. The alternative is a satellite-based system on the order of 100-200M USD each, with a few years of life expectancy, to detect river/lake levels/area inundated (then use these space-derived variables together with hydraulic functions to infer river flows). GTN-H is working in conjunction with the Global Earth Observation System of Systems (GEOSS) process to produce some end-to-end demonstrations of the value of these coordinated data sets. It is hoped that these demonstrations will help to mobilize the needed resources for a major global monitoring effort.

(b) **Measurement Methods:** There are two widely used models that could be used to compute this measure, the University of Kassel's WaterGAP 2.1 model and a water model developed by the University of New Hampshire Water Systems Analysis Group (UNH WSAG, 2006). Both are at a 30-minute (half degree) resolution, but the water stress indicator produced by Kassel is measured on the basin rather than the pixel basis. The indicator described here was produced by WSAG, which is measured on a pixel rather than a basin basis. In the future it may be useful to aggregate to the sub-basin or watershed level.

4. ASSESSMENT OF DATA

(a) **Data Needed to Compile the Indicator:**

- UNH Water Systems Analysis Group's mean annual relative water stress index (unitless ratio per grid cell)

(b) **National and International Data Availability and Sources:**

(c) **Data References:** See 4(a)

(d) **Costs of Updating the Indicator**

As described in section 3(a), the Global Terrestrial Network for Hydrology (GTN-H) is seeking to move from hydrological models that are based on the 30-year "climate normal" period of 1960-1990 to ones that reflect changes in annual hydrograph data. The models would thus increasingly reflect on-the-ground annual changes in hydrology. The investment in this effort is on the order of several millions of dollars. Should these data streams eventually become available (the GTN-H will take several years to implement), it would not be terribly costly (on the order of $50,000) to run the models every two years to produce updated water stress indicators. This would address the "Q" side of the equation. A larger investment would probably be required to update the "DIA" (domestic, industrial, and agricultural uses) estimates to reflect changes in population distribution, agricultural cropping patterns, irrigated areas, and industrial activities. This could run on the order of $100,000-$150,000 every two years. The total would be approximately $200,000 every two years.

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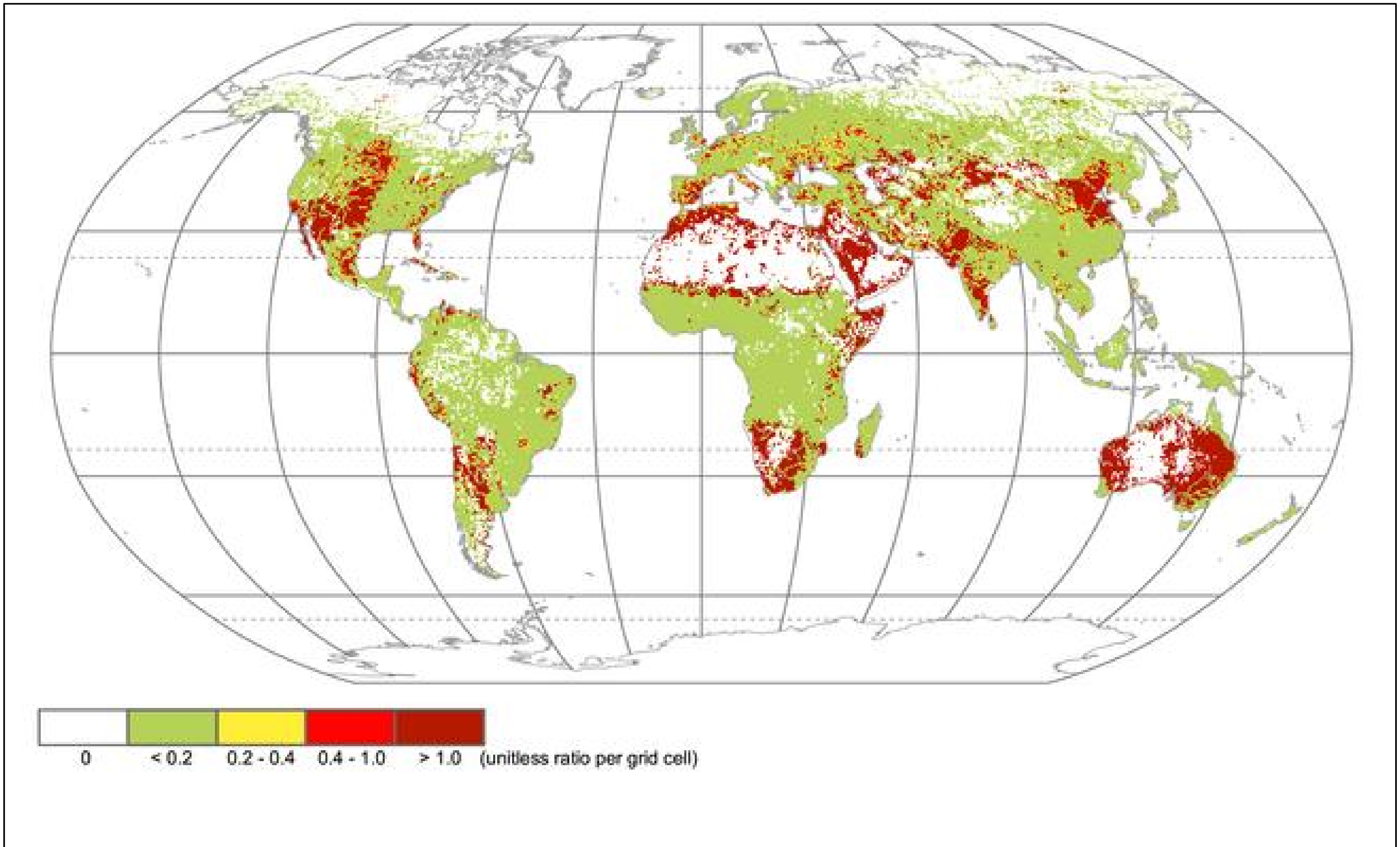
Figure 5. Mean Annual Relative Water Stress Index



Source: University of New Hampshire Water Systems Analysis Group.

Rural Poverty Rate	
Category: *Rural Income*	***Country Coverage:*** *73*
Time Series: *1990-2004* *(approximately 2 data points per country)*	***Spatial Refinement*** *Rural*
Placement Within SLM Framework: *Human Wellbeing and Poverty Reduction*	***Status:*** *Indicator ready (non-comparable indicator based on national poverty line)* *Indicator in development (comparable indicator based on international poverty line)*

1. INDICATOR

(a) **Name:** Rural Poverty Rate

(b) **Brief Definition:** The rural poverty rate is the percentage of the rural population living below the national rural poverty line.

(c) **Unit of Measurement:** Percent of population below the poverty line

(d) **Related Measures:** The poverty rate is part of a suite of decomposable poverty measures referred to as the Foster, Greer, and Thorbecke (FGT) Poverty Measures (Foster *et al*., 1984), that also include the poverty gap and the poverty severity measure. The inputs required to produce these measures include a population estimate, a poverty line/threshold, and a welfare estimate.

2. POLICY RELEVANCE

(a) **Purpose:** The rural poverty rate measures the percent of the population in rural areas living in poverty. Individuals whose consumption (or income, when consumption is unavailable) falls below the rural poverty line are considered poor.

(b) **Relevance to KM: Land Indicator Category:** Country specific rural poverty lines are used to measure welfare levels in rural areas, target poverty alleviation interventions, and monitor progress in poverty reduction.

(c) **International Conventions and Agreements:** Millennium Development Goals (MDGs).

(d) **International Targets/Recommended Standards:** The United Nations Millennium Project set a target to reduce the proportion of the population living in poverty by half between 1990 and 2015.

(e) **Comparison to Other Indicators and Strengths and Weaknesses:** The poverty rate is one of the most widely used indicators of poverty, but it has the draw back that, unlike the poverty gap or severity of poverty measure, it does not provide any details on how poor (i.e., how far below the poverty threshold) the poor are. As an alternative, the poverty gap is used as an estimate of the depth of poverty.

3. METHODOLOGICAL DESCRIPTION

(a) Underlying Definitions and Concepts:

The FGT suite of poverty measures are best suited for within country assessments of poverty, rather than international comparisons. Definitions of poverty, methods of measuring consumption (or income), and data quality and design of household surveys, all vary across countries, making international comparisons of poverty difficult.

Different poverty lines are used in urban and rural areas to reflect differences in consumption patterns, prices, and availability of goods and services. The adjustments are intended to capture differences in the cost of living in these areas (so typically urban poverty lines are set higher than rural poverty lines), however there is limited consensus on how much to adjust the poverty lines to properly account for these cost of living differences. On average, urban poverty lines are typically set about 30 percent higher than rural poverty lines; but the actual amount can vary substantially across regions. (Ravallion *et al*., 2007).

Consumption or income based definitions of welfare reflect only one dimension poverty, and fail to account for non-monetary dimensions of welfare. Additionally, by deriving a per capita measure of poverty it is assumed that household level consumption (or income) is equally shared among household members (regardless of age, gender, or relationship to the head of household). Thus, other welfare measures, such as infant or child mortality, should be used in conjunction with monetary poverty measures, to provide a fuller picture of living conditions (Ravillion *et al.,* 2007).

(b) Measurement Methods:

Information on household consumption (or income) is gathered through living standards measurement and household surveys that contain detailed responses to questions regarding household spending habits and sources of income. The data captured in the surveys is used to estimate rural poverty rates for inclusion in country-specific Poverty Assessments. If a rural household's per capita consumption (or income where unavailable) is below the rural poverty line, then all the individuals in that household are considered poor. The number of rural poor is later divided by the total rural population, to derive an estimate of the proportion of the population living in poverty in rural areas.

4. ASSESSMENT OF DATA

(a) Data Needed to Compile the Indicator:

- National level rural poverty rates, based on national poverty lines, are in the public domain. For selected countries data are also available at the sub-national level (see SEDAC's Poverty Mapping Project web site at http://sedac.ciesin.columbia.edu/povmap).
- National level rural poverty rates, based on an international poverty line, which enables comparisons across countries, are not yet in the public domain.

(b) **National and International Data Availability and Sources:** Data for 73 countries are available for download from the United Nations Statistics Division Millennium Development Goals Indicators Database.

(c) Data References:

1. United Nations. *Millennium Development Goals Indicators Database*. Statistics Division Internet site. Available at: http://mdgs.un.org/unsd/mdg/ (Accessed on February 21, 2008).

(d) Costs of Updating the Indicator

There would be no cost to GEF to update this indicator, since the indicator is part of the existing data collection and reporting efforts in support of the MDGs.

5. REFERENCES

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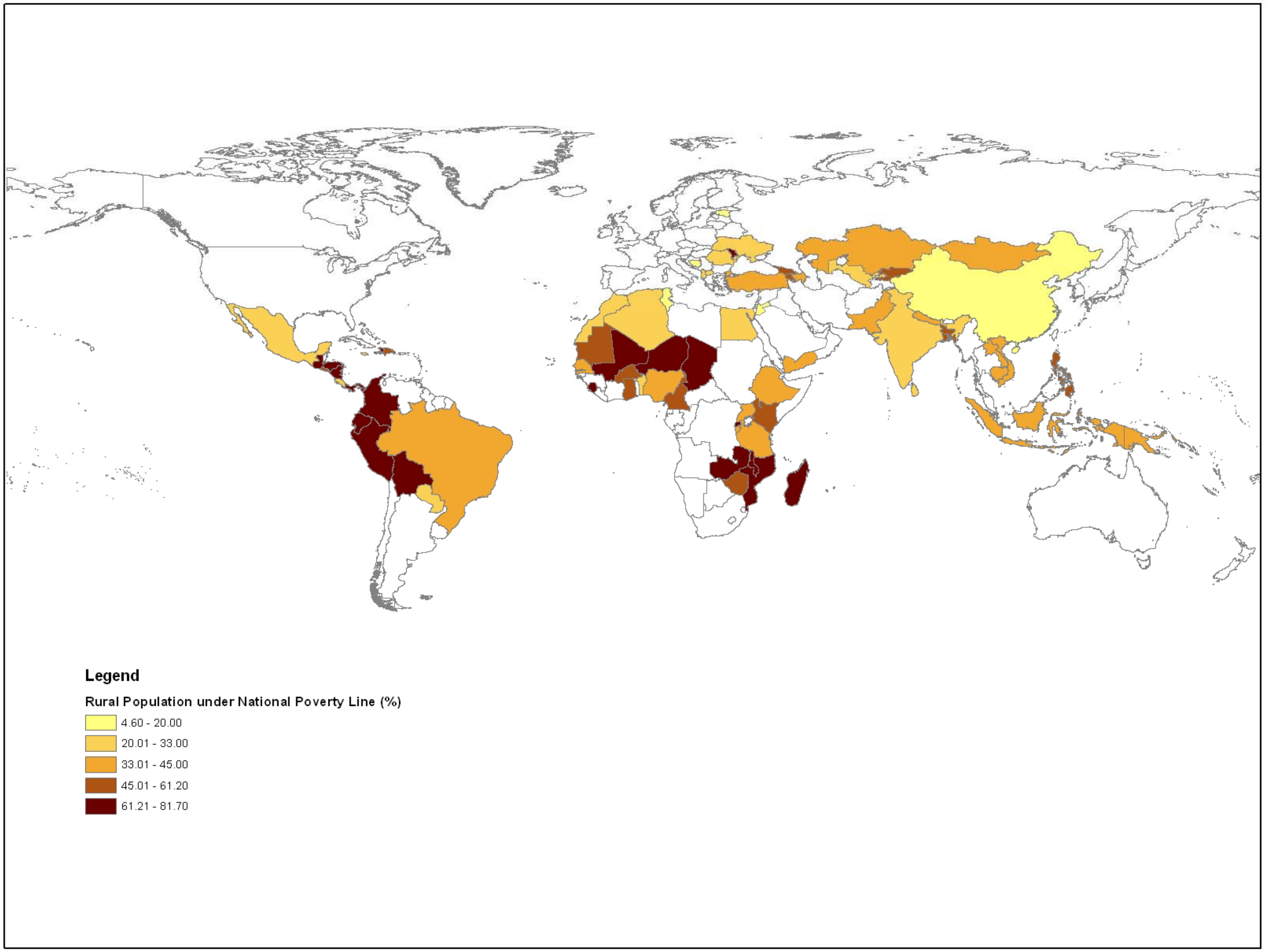
Figure 6. Rural Poverty Rate



Note: Countries in white have no data on the rural poverty rate.

Income Distribution	
Category: *Rural Income*	***Country Coverage:*** *127*
Time Series: *1990-2004* *(approximately 3 data point per country)*	***Spatial Refinement*** *National level only*
Placement Within SLM Framework: *Human Wellbeing and Poverty Reduction*	***Status:*** *Indicator ready*

1. INDICATOR

(a) **Name:** Income Distribution (Distribution of Per Capita Income)

(b) **Brief Definition:** This indicator measures the poorest fifth's share of national income (or consumption).

(c) **Unit of Measurement:** Percentage of national income

(d) **Related Measures:** Related measures include the Rural Poverty Rate (see separate profile) and inequality measures such as the Gini coefficient, Generalized Entropy Measures and Coefficient of Variation, which describe how resources are distributed across a population.

2. POLICY RELEVANCE

(a) **Purpose:** Income Distribution is a measure of relative levels of inequality across different segments of the population, as expressed by the poorest fifth's share of total national income.

(b) **Relevance to KM: Land Indicator Category:** This measures the relative share of total national resources of those that are among the poorest segments of society. It addresses the problem inherent in the Rural Poverty Rate, which is that knowing the percentage of the population that falls below the national poverty line does not provide sufficient information on the *depth* of poverty in the country.

(c) **International Conventions and Agreements:** Millennium Development Goals (MDGs).

(d) **International Targets/Recommended Standards:** The United Nations Millennium Project set a target to reduce the proportion of the population living in poverty by half between 1990 and 2015.

(e) **Comparison to Other Indicators and Strengths and Weaknesses:** Income (or consumption) based definitions of welfare reflect only one dimension of poverty, and fail to account for non-monetary dimensions of welfare. Additionally, by deriving a per capita measure of welfare it is assumed that household level income is equally shared among household members (regardless of age, gender, or relationship to the head of household). Thus, other welfare measures, such as infant or child mortality, should be used in conjunction with monetary welfare measures, to provide a fuller picture of living conditions (Ravallion *et al*., 2007).

3. METHODOLOGICAL DESCRIPTION

(a) Underlying Definitions and Concepts:

Calculations of the poorest fifth of the population's share of national income are made in local currency, and there is no adjustment made for differences in costs of living or exchange rates, definitions of income (or consumption), or data quality and design of standardized surveys across countries.

Where possible consumption is used over income, because it is considered a better indicator of welfare, and it is more consistently defined across household surveys. Differences in household composition, consumption patterns, and in welfare measures used (income is typically more unequally distributed than consumption) can bias comparisons across countries.

(b) Measurement Methods:

Information on household income (or consumption) is gathered through living standards measurement and household surveys that contain detailed responses to questions regarding household spending habits and sources of income.

An income measure (or consumption aggregate) is estimated for the entire household, and then is divided by the number of people in the household to estimate income per person. The population is ranked according to income, and then grouped into quintiles. The income of the poorest fifth is divided by the total population's income, and expressed as a percentage of total income.

4. ASSESSMENT OF DATA

(a) Data Needed to Compile the Indicator:

Country specific estimates of income per capita distribution are in the public domain.

(b) National and International Data Availability and Sources:

Data for 127 countries are available for download from the United Nations Statistics Division Millennium Development Goals Indicators Database.

(c) Data References:

1. United Nations. *Millennium Development Goals Indicators Database*. Statistics Division Internet site. Available at: http://mdgs.un.org/unsd/mdg/ (Accessed on February 21, 2008).

(d) Costs of Updating the Indicator

There would be no cost to GEF to update this indicator, since the indicator is part of the existing data collection and reporting efforts in support of the MDGs.

5. REFERENCES

Ravallion, M., S. Chen, and P. Sangraula (2007). New evidence on the urbanization of global poverty, *Policy Research Working Paper Series 4199*, The World Bank

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Figure 7. Percentage Share of National Income of the Poorest Fifth of the Population