Global Irrigated Area Mapping at IWMI – where we are now and where we go next.

The GIAM project began in 2001/2202 under Peter Droogers and really started to get moving in 2002/2003 with a steady increase in the number of partners and the recruitment of Prasad and Canisius to add some remote sensing horsepower. Since then, the team has expanded and a great deal of work has been done. This document arises out of recent discussions and a meeting held in November 2005 (see Annex 1).

Where we are now

Work has focused on the development of techniques and products, with techniques largely being used to develop the products we have. The DSP and GMIA website have been developed to store and give access to the products, the techniques and background information and much of the basic data (mainly processed data products, such as time series image files) that have been used in GIAM and in other related activities. The products developed and their associated techniques are summarized in Table 1a & b, below.

Table 1a. GIAM products. The global irrigated area mapping (GIAM) products by the International Water Management Institute (IWMI).

Product	Scale	Techniques	Key [1] people	Status
I. Global irrigated area mapping (GIAM) **Global Map of Irrigated Area (GMIA), (1999)** **Global map of rainfed cropland areas (GMRCA), (1999)** **Global map of land use/land cover areas**	1-10 km 10 km nominal	Mega-file of 139 bands: 10-km monthly AVHRR 1997-1999 + 1-km monthly Spot Vegetation 1999 + 50-km CRU Precepitation + 1-km DEM + 100-m JERS Radar. Multi-temporal unsupervised classification (3 yrs): spectral signature matching (SMTs) of time-series data; post classification class identification – 2-band multitemporal space-time spiral curves, brightness-greenness-wetness (BGW) plots, decision trees, principal component	PT, CB, MS, Team AH AR	On-line web portal (www.iwmigmia.org); + web map server of irrigated areas; documentation complete; development of global "groundtruth" database in DSP. Accuracy assessment in process. Simplified 5-7 class map ("happy map") in preparation. Refined version 2.0

[1] Full names are given in Annex 2.

(GMLULCA), (1999)		analysis. Sub pixel area estimation and cropping intensity 34 Class irrigated map refined using global LandCover imagery (Landsat ETM+ "maximum greenness" imagery, from NASA) and ground truth data		map of GMIA (in mid 2006)
II. Irrigated areas in river basin: **Ganges-Indus Irrigation Map**	500m	MODIS 500m – 7 band: Multi-temporal unsupervised classification (3 yrs): post classification class identification – 2-band multi-temporal space-time spiral curves	PT, MS, HT.	Completed. Groundtruthed; Journal Paper published (2004); fed development of Global Map. Products online in GMIA portal
Krishna Irrigation Map	500m	MODIS 500m – 7 band. Multi-temporal unsupervised classification (3 yrs): comparison with Mandal level census statistics of irrigation	TB, PT, MK, PG, HT	Completed. Journal paper under 2 stage review. Accuracy assessment completed. Products online in GMIA portal
Krishna Land use change	10km	AVHRR 20 year multitemporal series. Development of multitemporal signature matching (shape and magnitude) based on spectral correlation similarity, spectral similarity value of time series data. Sub-pixel area estimation technique developed and evaluated.	PT PG MK TB HT	Completed; ground truthed (2002 and 2005); journal paper under second stage review; techniques fed global map. Products online in GMIA portal
Global map of 2 crop irrigated area **prototype**	10km	AVHRR 20 year time series. Fourier analysis and signal extraction.	CF, HT	Paper submitted (2005). Refinement needed to identify 3 crop area and decision tree development needed to separate

		Determination of sub pixel area from magnitude of Fourier signal. Comparison to FAO statistics. Tested on 3 year MODIS 500m series for Krishna.		single irrigated crops from rainfed. Basis for 500m global map.
All-India Map of irrigated area	500m	MODIS 500m – 7 band and also based on 4 normalised difference indices . Ideal spectra generated based on extensive ground truth and matched with class spectra to identify and label classes. 3 year multi-temporal series. Comparison of techniques for accuracy and computation efficiency. Full accuracy assessment to be done.	VD, PT, HT, CB, PN	*In process*. Additional ground truth (2005). Unsupervised classification complete. Class grouping & naming in process based on the GT signatures with time series. Basis for 500m global map.
All India Map (2002)	500m	MODIS 500 and Aster (15m); Development of relationships between Vegetation Index (MODIS) and Vegetation Cover (Aster). Use of climatic, land use and topographic masks: temperature, Et, elevation, slope, latitude, soils, forest cover.	PD, PS	Completed. Regression relationships between VI and VC insensitive and very low R^2. Not used further. Use of masks contributed to all later techniques.
Hi Res irrigation map of Syr Darya **Hi Res**	30m 30m	Landsat 7 ETM + at 30m; with temporal information from Modis 500m Image segmentation, image fusion (high spatial and high temporal resolution), Fourier anlysis Image segmentation,	PT, CB JV PT,	Completed unsupervised classification, and GT data… Class identification and labeling in process. Basis for 30m global map Completed

irrigation map of Indian sub-continent		image fusion (high spatial and temporal resolution), secondary data (e.g., SRTM)	MV CB PN VD	mosaicking high resolution Landsat ETM+ images and MODIS temporal images

Table 1b Techniques only – which also provide reference maps to check accuracy of lower resolution analysis.

Separat'n of rainfed from irrigated rice in tropical conditions	1km	Spot Vegetation 1km: 3 year time series; signal processing using Maximum Local Fitting; development of algorithm to classify based on lag correlation between peak NDVI and peak rainfall. Development of automated "Peak Classifier".	AIT KH, DK, HT	Completed: paper published (2005). PhD awarded. Technique works better in some rainfall conditions than others – tested across central, north and southern Thailand.
3 date Pan classific'n	15m	3-date Pan classification of Landsat ETM+ data. Requires carefully selected dates to represent conditions in characteristic parts of three seasons. Uses multi-scale segmentation prior to unsupervised classification: classes defined with groundtruth.	CF, HT, LY	Development of reference maps at high resolution for Hyderabad, Nagarjuna Sagar and Krishna Delta (India) + Ruhuna and System C in Sri Lanka.
Fusion of MODIS and LS imagery	30m-500m	MODIS 500 and Landsat ETM+ Radar-based technique to preserve spectral characteristics of fused imagery, to allow classification of fused image.	CF, HT	Conference paper (2003). Too demanding for general application and for modest improvement in accuracy.
Single date, multi season irrigation classific'n	15-30m	Landsat ETM+; Unsupervised classification followed. Class identification using NDVI, band information, bi-spectral plots of R:NIR and NIR:MIR. Detailed groundtruth. Classification accuracy >85% achieved	NG, Mobin, HT	Maps created for Rechna Doab and Upper Swat Canal in Pakistan for Rabi and Kharif. Conference paper (ACRS, 2005). Journal paper in preparation.

Object oriented classific'n of multi-temporal data	250m	MODIS 250m Musi/Hyderabad. Initial comparison of unsupervised classification based on multitemporal series with and without initial image segmentation. Ref to Landsat ETM	LY	Segmentation approach looks promising – with higher accuracies. Better geographic definition.

Where to next?

There are six components to consider:

1. Accuracies, Areas, and synthesis of GMIA;
2. GMIA version 2.0: Refinement of GMIA based on GT data;
3. Implications: Analysis and presentation of the implications of the remote-sensing based analysis of global irrigated area.
4. Synthesis publications
    a. Research report giving the big picture,
    b. A CA book giving the big picture backed up by a summary of the techniques and products listed in the first section of this note.
5. Collaborative approach: Development and improvement of actual mapping of irrigated area, following a regional collaborative approach.
6. Methodology advances: Further development and testing of methodologies at IWMI, focused on automated classification techniques.
7. GMIA-high resolution: Irrigated area mapping in Africa, Indian sub-continent, Central Asia, and China at high resolution (30m).

The team will continue to write journal papers for publication in top-quality remote sensing journals. There is already a commendable output, but this needs to continue, both as documentation and to bolster the scientific credibility of our work.

1. The implications of the global map of irrigated area.
Although the scale of the global map (10km) and the skew in detailed groundtruth (biased towards the Indian sub-continent) allow room for detailed criticism, the map present and convincing picture and reveals that global irrigated cropping intensity is higher than previously understood or implied by the available statistics of equipped area.

This poses important questions about (1) whether irrigation provides more or less of the world's food than currently estimated (40% from 17-18% of global cropped area) and (2) what it implies for the relative productivity of irrigation compared to rainfed agriculture. It also has implications for the potential for future intensification (increasing cropping intensity) and its associated water use in meeting the world's future food requirements.

This analysis moves away from a discussion of mapping and remote sensing technology, to a comparison of statistics from different sources, and a re-evaluation of food production statistics in relation to cropped areas and types of production system. Since this will be difficult to do at a global scale, there will have to be some selected regional focus – most likely Indian sub-continent and China.

Key elements in taking this forward are:

1. Completion of accuracy analysis of global map in different regions compared to established and detailed groundtruth sets and statistics (in process by Chandru).
2. A comparable exercise for the University of Frankfurt-FAO map of equipped irrigated area and interpretation of available data on cropping intensity (in process by Chandru).
3. Establish crop calendar (cropping season) and hence cropping intensity for individual class and increase accuracy of sub-pixel area estimation
4. Comparison of IWMI's remote sensing derived map with the UF-FAO map to understand where there are similarities and differences and explain the reasons why (in collaboration with Stefan Siebert (UF), FAO (JM Faures and Jippe Hoogeveen), and IWMI (PT, CB, HT, DM).
5. Comparison of sub-sets of the global map with higher resolution products (MODIS 500m) – all India map, UNH maps of rice area (Xiao).

2. Synthesis

HT will be responsible for putting together the final RR summarizing the big picture and this needs to account for all the work undertaken in point 1. The whole team will be responsible for the production of a book on Global Irrigated area mapping, and different chapters will be allocated to different authors by HT and PT. The immediate publications (2006) will be GMIA RR on methods (PT, CB, HT), CA book chapter on big picture (HT, PT, CB), GMIA journal paper (PT, CB, HT), and GMRCA journal paper (CB, PT, HT). Detailed workshop materials (on how to do? By PT, CB, HT, and team) will also be developed and published. All these efforts should lead to a synthesis book in 2007-2008. There is no need to do extensive technical documentation, as the DSP and GIAM website provide this in some detail and are "living documents". Clearer guidelines will be developed by DM, HT and PT.

3. A new collaborative approach

The irrigated area mapping project will now move into a new phase, in which we will work more closely in partnership with key organizations in different parts of the world. As the resolution of analysis increases, the amount of work increases, and the benefit of detailed local groundtruth becomes increasingly apparent.

IWMI will engage willing partners to make use of and refine the techniques developed so far. This will be done through (1) a series of workshops in 2006, beginning with a consultation early in the year in India, and followed by an international workshop in Colombo mid year; (2) targeted travel to make presentations and engage key partners in:

China (CAAS); Iran (Tarbiet Moderes University), India (National Remote Sensing Agency with 2-3 scientists from NRSA\NNRMS\ISRO), USA (Gabriel Senay, USGS/South Dakota State University; Seelan Santhosh Kumar, University of North Dakota), Australian (UNSW research students?), Malaysia (partner to be identified), Tunisia (ask Akissa Bari for reference), Eastern Africa (identify a bright African student), Ghana (identify a bright African student), and Central Asia (Identify a bright Central Asian student)…

Further homework is required to identify and follow up on potential partners, especially since we aim to interest them in doing and funding this work themselves.

Partners will work on groundtruth, crop patterns, image analysis and classification, and refinement of irrigated class definitions at national and regional scales, at resolutions of 500m or better using MODIS data.

Frank Rijsberman, Hugh and Prasad will collaborate closely on getting this new mode established, beginning with follow up on partnership in China and the hosting and running of workshops (see PT's earlier note for 2006 work programme). Further news on this is expected following CGIAR AGM in Morrocco next week.

4. Further methodological development at IWMI

The team has pursued parallel paths of developing interactive and more automated techniques of image analysis. We have made more rapid progress with interactive techniques and can usefully do more work on automated approaches. The longer term attraction of automated procedures is their repeatability. These methods and techniques This work will focus on:

1. Ideal spectra and optimal indices: Concept of Ideal spectra, optimal two band vegetation indices (TBVI's) are currently used in the sub-continental irrigated area mapping. The approach involved matching class spectra with ideal spectra to identify and label classes;
2. Data Fusion of high-temporal resolution with high-spatial resolution: Combination of multi-temporal signatures derived from MODIS 500 and MODIS 250 with high resolution Landsat imagery (15-30m), to define both irrigated areas and irrigated crop types. This work is most advanced in Central Asia and will continue as part of the EU funded work programme there in 2006, coupled with work on development of methods to assess crop water productivity using remote sensing, which itself requires detailed crop identification. Use of segmentation with intermediate scale imagery (150-250m – MODIS, WIFS etc) to obtain better geographical definition and separation of classes prior to unsupervised classification and application of classing techniques.
3. Fourier analysis: Application of Fourier analysis to define irrigated areas based on one, two, and three peak signals reflecting vegetation phenology. Canisius has made a good start, and recently submitted a paper, but Prasad's former colleague Roland also has experience and published track record on Fourier analysis for

more general land use mapping. Chandru and Jagath have become seriously interested in this approach and will take it further in 2006.

4. Decision tree advances: Development of formal decision tree analysis based on statistical training of high resolution class recognition. This work owes a lot to the work of de Fries and her team on global forest cover mapping at the University of Maryland. Outputs by Canisius and HT are incomplete, but they will continue to work on this in 2006, and if possible Canisius will spend 4-6 weeks at IWMI. We can usefully expand the number of people working on this approach too.
5. Sub-pixel decomposition technique refinement: Refinement of sub-pixel area estimation, using Prasad's existing approach at higher resolution and using Canisius' efforts using Fourier transform magnitude.
6. Multi-sensor data fusion and synthesis: Possibly, combination of radar, optical and thermal data in detailed crop classification and use of Eta (from SEBAL, or other simpler techniques).

5. Irrigated area mapping in Africa

Africa was deliberately "neglected" in the previous work in GIAM, because the amount of irrigation in Africa is small compared to Asia and the rest of the world, and because it is often at a small scale that requires the use of high resolution imagery, which is expensive and also a better understood technology.

However, there is now a need to make some progress and we had initially thought of working closely with Bancy Mati to conduct pilot irrigated area mapping in Kenya and Ethiopia. However, we were not convinced of Bancy's ability to do this without considerable help and, in the end, she has other commitments. The techniques developed in Central Asia, Pakistan and India can be used to complement techniques that are well described in the literature. A complication in Africa comes with the need to assess cropping intensity, which requires multiple (probably hi-res) imagery and the confounding effects of cloud on observability with low frequency hi-res imagery (already evident in Tanzania – Ruaha). A second issue is that significant amounts of irrigation occur in wetlands in Africa and so there is potential synergy with the Wetland Mapping exercise at IWMI.

It is unlikely that we can find collaborators in Africa who will be self-funding, except possibly through collaboration with South African universities, or INA in Tunisia. We therefore have two options: 1) begin work in direct collaboration with an African partner, using GIAM funds from IWMI (in such a case identify 1-2 strong candidates in RS/GIS image processing skills) or 2) seek external funding for a project in Africa, which requires the development of a good concept note and supporting proposal, with budget.

A key part of irrigated area mapping in Africa will be low-cost ground truth data collection – we already have experience of wetland mapping in southern Africa, on which we can draw, but rapid, GPS based surveys will be a necessary part of the methodology - to identify areas where we need to acquire imagery.

In either case, it would make sense to collaborate with an Ethiopian partner and leverage GIS and remote sensing capabilities at ILRI or ICRAF. Develeoping connections with Dr. Gabriel Senay and UND (USA) would also be helpful in this regard. It should be possible to collaborate with an Ethiopian University (which one?) and develop a small Africa team at the ILRI campus, with the injection of appropriate hardware, software and some training effort. An alternative would be to do the same in West Africa, based around Ghana and Burkina Faso, where IWMI is already well established.

We might also usefully collaborate more closely with FAO and other CG centres based on 1) Jippe Hoogeveen's GIS-based analysis of irrigation in Africa (FAO – Land and Water Bulletin No. 4) and 2) the AfriCover product. Further detail can be worked out in a formal project proposal.

In the longer run moving from mapping existing irrigated area to developing remote sensing as a tool to assess irrigation potential would be useful for Africa, where there is still considerable scope for well-advised development. There are a number of technical challenges for remote sensing, relating to soils and the relationship between land use and land use potential, which has traditionally been done by "sages" using aerial photographs at 1:25,000 scale or better. It is unlikely that remote sensing can say very much of use in the estimation of available water resources for irrigation, but GIS can be useful in conjunction with RS to define land suitability for enhanced rainfed agriculture.

6. High resolution mapping of irrigation in India
The team has already (2005) assembled a Landsat mosaic of the whole Indian sub-continent at 15-30m scale, using the publicly available images used to create GeoCover. The file is an amazing 150 GB! This potentially allows a continental analysis at high resolution for a nominal year of 2000. This would allow for some interesting methodological development and also comparative studies with existing statistics and the 500m, 1 km and 10 km products.

Concluding remarks

The costs of time, travel and material for these options needs to be worked out in some more detail (please refer to Prasad's earlier work plan to get a framework), and broader discussion held to establish priorities, since there is rather more slated here than could be reasonably accomplished in 2006. Hopefully, it is a reasonable start to a new focus of work and activity over the next two years.

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Hugh Turral and Prasad Thenkabail, December 4, 2005.

Annex 1 Discussions/agreements on Global Map of Irrigated Areas (GMIA V1.0)

Notes on a meeting attended by: Hugh Turral, David Molden, Prasad Thenkabail, Chandrashekkar Biradar, and Venkateswarlu Dheeravath, November (4) 2005.

As a result of the recent comments and criticism on IWMI's GMIA, we conducted a discussion forum to determine the way forward. The conclusion was to address the issues and forge ahead to make IWMI GMIA a widely accepted product across the globe. Here are the issues discussed and suggested actions:

1. **Definition issues**

Supplemental irrigation

Currently GMIA has, in a number of classes, predominantly ground water irrigated areas as "supplemental irrigated areas". These classes need to be re-labeled as Irrigated areas-especially for tropics (e.g., India). Also, the sprinkler irrigation in rainfall deficit areas in regions such as Kansas in United States fall into "irrigation category".

David Molden and Hugh Turral call a class "supplemental" when in a: (a) predominantly rainfed areas irrigation is supplied a few times to sustain crop water requirements as case of, for example, Argentina; (b) when ET low as in temporal climates such as, for example, Europe, where nominal ET of crops is around 550 mm per year.

Another way of defining "supplemental irrigation" will be to look at climate data and see areas where ET/R is > 1. To see in how many months that happens during crop growing season. This is indicative of water demand for crop growth apart from rainfall (R).

2. **Class naming issue**

It was decided to have a simplified map ("happy" map) with simplified names so that a broad spectrum of people will understand map labels better.

- Irrigated, surface water, large scale
- Irrigated, surface water, small scale
- Irrigated, ground water
- Irrigated, supplemental
- Irrigated, conjunctive use
- Irrigated, rice

3. **GMIA version 1.0 release**

This was discussed and the consensus is to release the map for a wide spectrum so that feedback comes in for the next, bigger, release. David mentioned that the release should have some kind of a note (prominent) that says (I have added the following for discussions):

"The International Water Management Institute (IWMI) is happy to release the very first Satellite Sensor Based Global Map of Irrigated Areas Version 1.0 (GMIA v1.0). Please be aware that we are releasing this map to solicit opinions and feedback so that we can refine and improve it to become version 2.0 map in late 2006. We particularly seek

feedback on the spatial accuracy of mapping, percentages of irrigated area and class definitions in regions outside the Indian sub-continent, for which we have had relatively less groundtruth data."

4. **Buy-in and Collaboration**

It was agreed that greater emphasis should be placed on "buy-in" form National partners and collaboration with FAO (Contacts: Jean Marc Faures, Jippe Hoogeveen and Stefan Siebert). For "buy-in" the National workshops is a good idea. It was thought that greater collaboration with FAO maybe needed before the suggested International workshop in Colombo planned for mid-2006.

5. **Accuracies and areas**

It was decided that one of the highest priorities is to perform accuracy assessments and calculate areas. In this regard, **accuracies** will be established by Chandru for:

- IWMI GMIA map with GT data
- FAO/Frankfurt university map with GT data
- Comparison of GMIA vs. FAO maps

Areas will be calculated for:

- Major irrigated area countries
- Continent-by-continent

6. **Sub-continental irrigated area mapping at 500-m**

This work was reviewed and Venkat was asked to produce the synthesized class names of all irrigated area classes from the recent India GT mission as well as previous GT missions for Ganges and Krishna. This work will be subjected to detailed accuracy assessment and compared back to the India classification in the global map.

7. **Class definitions**

When next set of classes are produced, it is important to define class names. So every class will have a complete definition and these will be circulated for discussion and finalization, amongst IWMI and its partners.

8. **Maps for CA book**

David was very interested in getting some GMIA maps for the CA book. This is possible and will be produced by February. HT will have overall responsibility for seeing this through, as he is also involved as an author of the Irrigation Chapter.

9. **ET from land cover classes**

David was interested not only in GMIA map but in the Global map of rainfed croplands (GMRCA). He asked whether we can produce ET from cropland and land cover classes. He mentioned of Peter Droogers work on rainfed area potential, based on a combination of remote sensing and regionalized soil water balances. This will be investigated.

Annex 2 Index of people involved in GIAM

Initial	Person
PT, CB, MS, Team, AH, AR	Prasad Thenkabail Chandrashekhar Biradar (Chandru) Mitch Schull Praveen, Sarath, AD Ranjith, Shakoor Asghar Hussein (Pakistan) Ata Rehman (Pakistan)
HT	Hugh Turral
TB, MK, PG	Trent Biggs Murali Krishna Parsadhi Gandagarao
CF, LY	Canisius Francis Ly Yuanjie
VD, JV	Venkateswarlu Dheeravath Jagath Vithanage
PD, PS	Peter Droogers Pervez Shariah
NG, Mobin	Nilantha Gamage Mobin ud-Din Ahmad