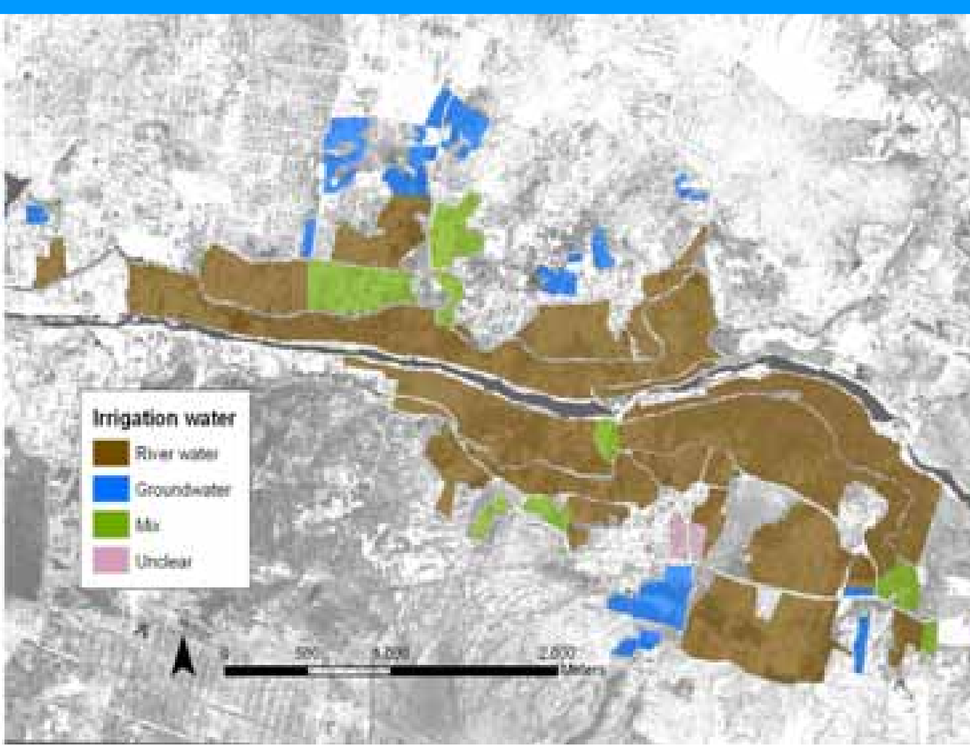
An Atlas of Water Quality, Health and Agronomic Risks and Benefits Associated with "Wastewater" Irrigated Agriculture

A Study from the Banks of the Musi River, India



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This manual is for distribution at the final project workshop only

Content

Acknowledgements

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Disclaimer

This report was prepared for the project *Ensuring Health and Food Safety from Rapidly Expanding Wastewater Irrigation in South Asia* funded by the German Federal Ministry for Economic Cooperation and Development (BMZ) and coordinated by the International Water Management Institute (IWMI). The statements, findings and conclusions are those of the authors and do not necessarily reflect the views of the BMZ and IWMI.

About the Atlas

This atlas provides information on the salient findings of the project entitled “Ensuring Health and Food Safety from Rapidly Expanding Wastewater Irrigation in South Asia” coordinated by the International Water Management Institute (Hyderabad office). The three year project funded by the German Federal Ministry of Economic Cooperation and Development (Bundesministerium für Wirtschaftliche Zusammenarbeit und Entwicklung - BMZ) was carried out in two countries, India and Pakistan, in collaboration with a number of international and local partners. This atlas highlights the findings from India.

The atlas comprises thematic maps and their corresponding descriptions highlighting the key findings of the project. The wastewater use in agriculture described here is associated with a polluted riverine system, due to all types of city discharges. As such, it can be expected that the water quality can change considerably in different stretches of the 40 km stretch of the river, with the head end being more polluted than the tail end. Therefore in order to avoid a rigid classification, the descriptions to the maps refer to the term “(Musi) river water”. In the rest of text, the term “wastewater” is used in the context of the chemical and biological attributes associated with agronomic and health risks in any given stretch of the river.

The atlas was prepared as a summary document of the key findings of the project, to promote a discussion on the wastewater use in agriculture, at the dissemination workshop held in October 2008.

Goals of the project

The **overall goal** of the project is to improve the health and safeguard wastewater-dependent livelihoods of resource-poor periurban and rural farmers, and consumers in developing countries.

How will the goals be achieved?

The goals of the project will be achieved by developing and promoting the uptake of a set of risk mitigation options based on a comprehensive assessment of risks and benefits associated with wastewater irrigation. These findings will be shared with relevant stakeholders for policy formulation, dissemination and intervention.

Project outputs

1. Framework of actors and interactions. Social and institutional map of the multiple actors (individuals and organizations) along the chain from wastewater source to end-use.
2. GIS database of urban and periurban agriculture and wastewater irrigation.
3. Evaluation of human health and agronomic risks from field to consumer.
4. Economic valuation of the direct and indirect livelihood benefits as well as the health and adaptation-related costs of wastewater irrigation.
5. Comprehensive assessment of tradeoffs, risks, costs and benefits at different levels along the chain from wastewater users to consumers of produce.
6. Concrete, actionable risk mitigation recommendations (based on outputs 1-5 above).

Major components and responsible persons of the project

Institutions and livelihood studies – Deepa Joshi (2006-2007)

GIS studies – Philipp Weckenbrock, Suryanarayana Gorji and Axel Drescher

Health studies - Priyanie Amerasinghe

Agronomic studies – Rob Simmons (2005 -2007) and Michael Blummel

Economic valuation of impact of wastewater irrigation – Jeena Srinivasan and Ratna Reddy

Partners

Freiburg University, Applied Geography of the Tropics and Sub-tropics (APT), Freiburg

International Livestock Research Institute (ILRI), Hyderabad

Centre for Economic and Social Studies (CESS), Hyderabad

Environment Protection Training and Research Institute (EPTRI), Hyderabad

Materials and Methods

Project site

Wastewater irrigated areas along a 27 km stretch of Musi River, comprising six villages grouped into periurban (three) and rural zones (three) were selected for the study. The Musi River, is one of the smaller tributaries of the Krishna River, and is located in the Deccan Plateau in southern India. The catchment of the River, is 11,300 km^2, constituting approximately 4% of the total Krishna River basin. Musi River has served as a source of irrigation water for downstream rural areas for centuries. Through a system of *anicuts* (weirs) and *ayacuts* (irrigation canal) the water is supplied for irrigation of agricultural land, each canal ending in a storage tank, served many a rural community. The river bifurcates the city of Hyderabad, and in the last 10-15 years, the city has grown rapidly, with the infrastructure not keep in pace with its growth. As such, much of discharges enter the river without much treatment. Currently, over 1000 MLD of wastewater generated from the city of Hyderabad (annual rainfall is 965 mm per year and temperature ranges from 6.1°C to 45.5°C depending on the season) reaches the Musi River, making it a perennial river, but a highly polluted water source.

GIS Studies

Land use/land cover in the study area was determined through a semi-supervised classification of the QuickBird satellite image (2006). For those agricultural village areas outside the satellite image, agricultural land use was mapped on the ground with the help of village assistants. Sources of irrigation water were determined through extensive ground truthing with local assistants from the respective areas.

Household listing and social maps

A household listing was carried out at the start of the study, identifying the basic demographic characteristics, main and subsidiary livelihood activities, and income generated from these activities. Social maps were drawn and focus group discussions were used to gather livelihood information in the villages.

Health Studies

Cross sectional health studies (health surveys and stool surveys) were carried out in randomly selected farming households engaging in wastewater agriculture along the banks of the Musi River (June 2006) after informed consent. Stool tests were performed using methods described in standard texts and ethical clearance was sought at the beginning of the study.

Soil and Crop Studies

Soil and crops (paddy rice and paragrass) from wastewater and groundwater (control) irrigated plots were sampled. Where relevant, concomitant soil and crop samples were collected and tested for elements given under the different headings below. Sample collection, preparation and analysis were undertaken following standard methods including the use of Quality Control Check Samples.

Soil

Soil samples were collected at 0-20 cm depth and determined for pH, Electrical Conductivity (ECe), Organic Carbon (Org-C) and Total (*Aqua Regia* Digested) Cadmium (Cd), Lead (Pb), Zinc (Zn), DTPA-Extractable Zn, Nitrate-N, Total mineralizable-N (Ammonium-Nitrogen (N)), Exchangeable-Potassium (Exch-K) and Available-Phosphorous (Olsen-P).

Fodder grass

Paragrass (*Urochloa mutica*) samples were collected at the time of harvest in three periurban villages from four farmer plots. In each paragrass plot sampled (n = 12), eight 1 m^2 sub-plots were sampled and analyzed for Cadmium (Cd) and Lead (Pb), nitrogen (N) content and *in-vitro* organic matter digestibility (IVOMD) and biomass.

Rice straw and grain

Rice paddy samples were collected from three rural villages. In each village, three *O. indica* rice varieties namely, 1010, 1001 and IR64 were sampled from four farmer plots and four 1 m^2 subplots (n = 144).

Rice straw Cd, Rice straw N-content and straw *in-vitro* organic matter digestibility (IVOMD), rice straw yields and rice grain yields were investigated.

Vegetables

Bulk composite (1 kg 10 point composite) vegetable samples were collected from a total of 28 plots. Four main vegetable types irrigated with Musi River water, were sampled namely, Coriander (n = 5), Mint (n = 7), Spinach (n = 11) and Amaranth (n = 5). These samples were then analyzed for Cd, Pb and Zn.

A separate set of composite vegetable samples (n = 3 plots x 9 for each vegetable) of the same vegetables was analyzed for microbiological and parasitological contaminants (*E. coli* and helminth ova).

International standards for water quality

A variety of water quality parameters were tested at five stations along the Musi River. These were BOD, EC, Temperature, pH, TDS, Nitrates, ammonical N, DO, Total N, Total K, Total P, Boron, Cd, Zn, and Pb. Water quality was tested using Standard Methods (APHA, 2005). Microbiological and parasitological testing was carried out as described in Ayers and Mara, 1996. Irrigation water quality was assessed against the World Health Organization Guidelines (WHO 2006).

International standards for food additives and contaminants

Internationally recognized Maximum Levels (ML) for contaminants in foods are established by the Codex Committee on Food Additives and Contaminants (CCFAC) http://www.codexalimentarius.net. The current MLs for Cd and Pb in leafy vegetables are <0.2 mg Cd kg Fresh Weight^{-1} and <0.3 mg Pb kg Fresh Weight^{-1} respectively.

In addition, the Joint FAO/WHO Expert Committee on Food Additives (JECFA) http://www.who.int/ipcs/food/jecfa/en/ has established Provisional Tolerable Weekly Intake values for Cd and Pb of 0.007 mg Cd kg Body Weight^{-1} and 0.025 mg Pb kg Body Weight^{-1}.

The detailed methodologies followed in the different output studies will be described elsewhere.

1. Study zones along Musi River

The satellite image

A QuickBird satellite image from May 2006, covering an area of 89 km^2 was used. Six villages, along the river were grouped into two zones, relative to the city of Hyderabad. Although village maps were obtained from the authorities the boundaries had changed over time, and this was reflected in the satellite map once the ground truthing for village boundaries were done. However, most of the agricultural area of the six villages (92%) was covered by the QuickBird image. For the most part the descriptions refer to the satellite image area given in the map, unless otherwise stated.

Study site zones and villages

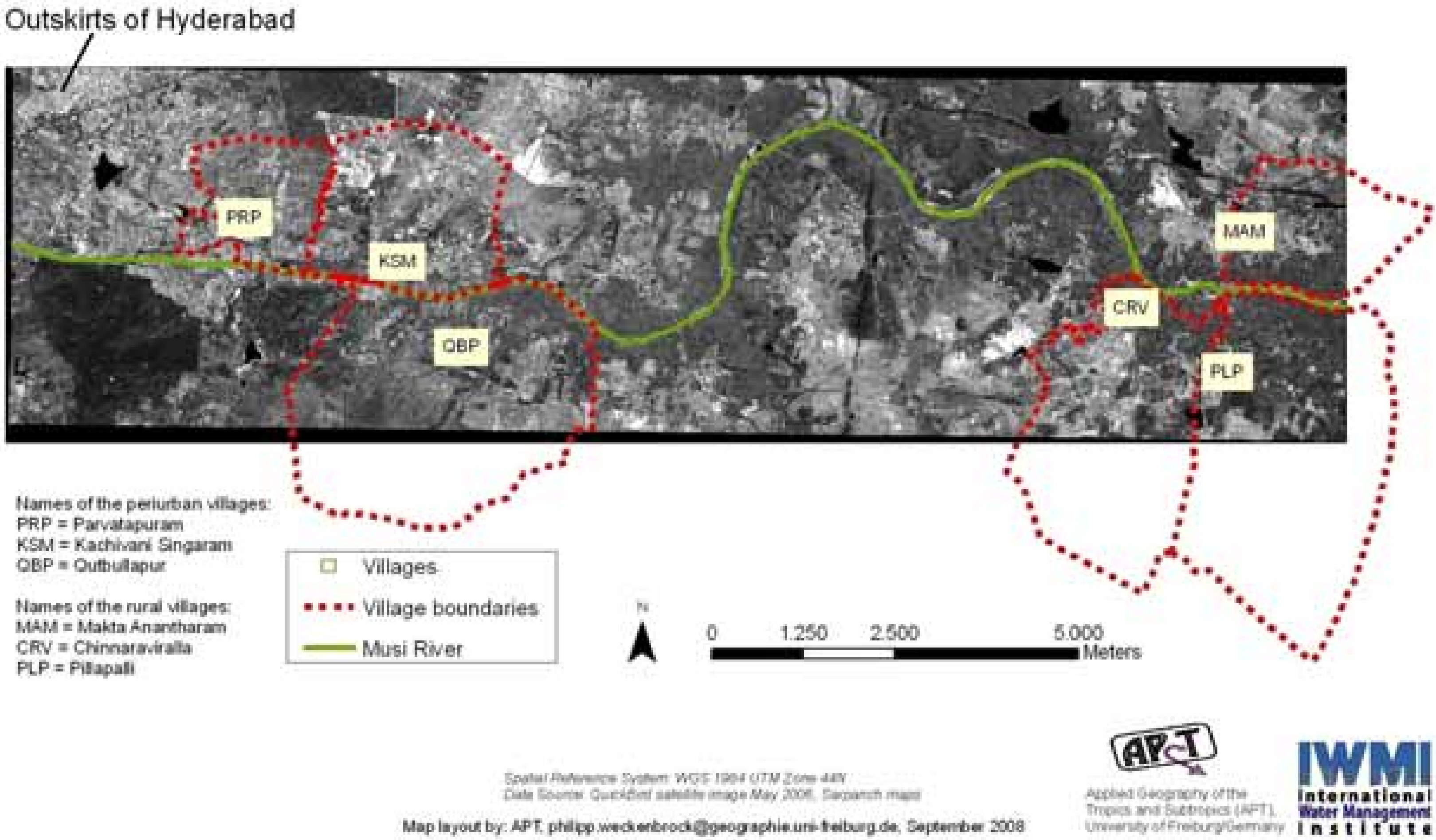
The periurban study zone close to the outskirts of Hyderabad city consisted of the three villages Parvatapuram, Kachivani Singaram and Qutbullapur. The population of these villages was approximately 6600 (2001 census) and the total area (with surrounding land) within the village boundaries was 1903 hectares.

The rural study zone was located 15 km downstream of the periurban zone. In the three villages Makta Anantharam, Chinnaraviralla and Pillaipalli, the population was approximately 5500. The total area within the rural village boundaries was 2211 ha.

Irrigation water

Irrigation water to the village was supplied by the Musi River via north and south bank irrigation canals. Ground water was also used to irrigate areas further away from the river.

Study Sites along the Musi River, India

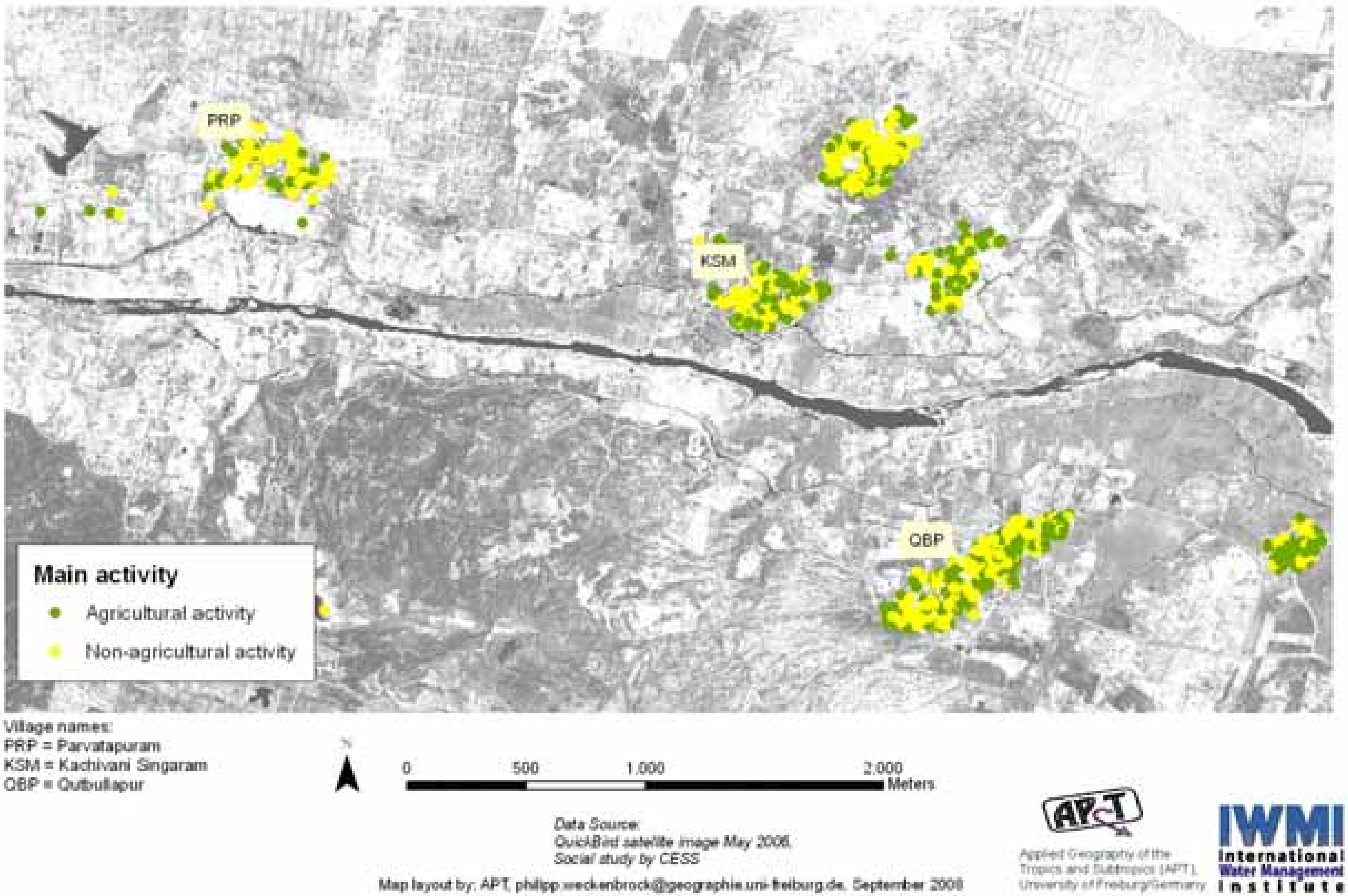


2. Agriculture was not the predominant livelihood of households in the periurban zone

Overall, the initial household listing captured information from 1319 periurban households. Of these, only 38% of household heads reported agriculture as their main livelihood activity. Agricultural activities included farming, dairy production, *Toddy* tapping and sheep rearing). The rest (63%) were involved in non-agricultural activities. Non-agricultural activities included persons such as government employees, business persons, pensioners, carpenters, stonecutters, basket makers, tailors, dhobis, medical practitioners, goldsmiths, servants, pot makers, barbers and weavers.

There were other households that recorded agriculture as a subsidiary activity, which raised the households engaging in agriculture to 50%. Being close to the city, this zone was a dynamic zone, and in general, people engaged in mixed livelihoods. It was also noted that this group was a highly mobile group moving in and out of the city looking for work.

Main Activities of Household Heads in the Periurban Villages

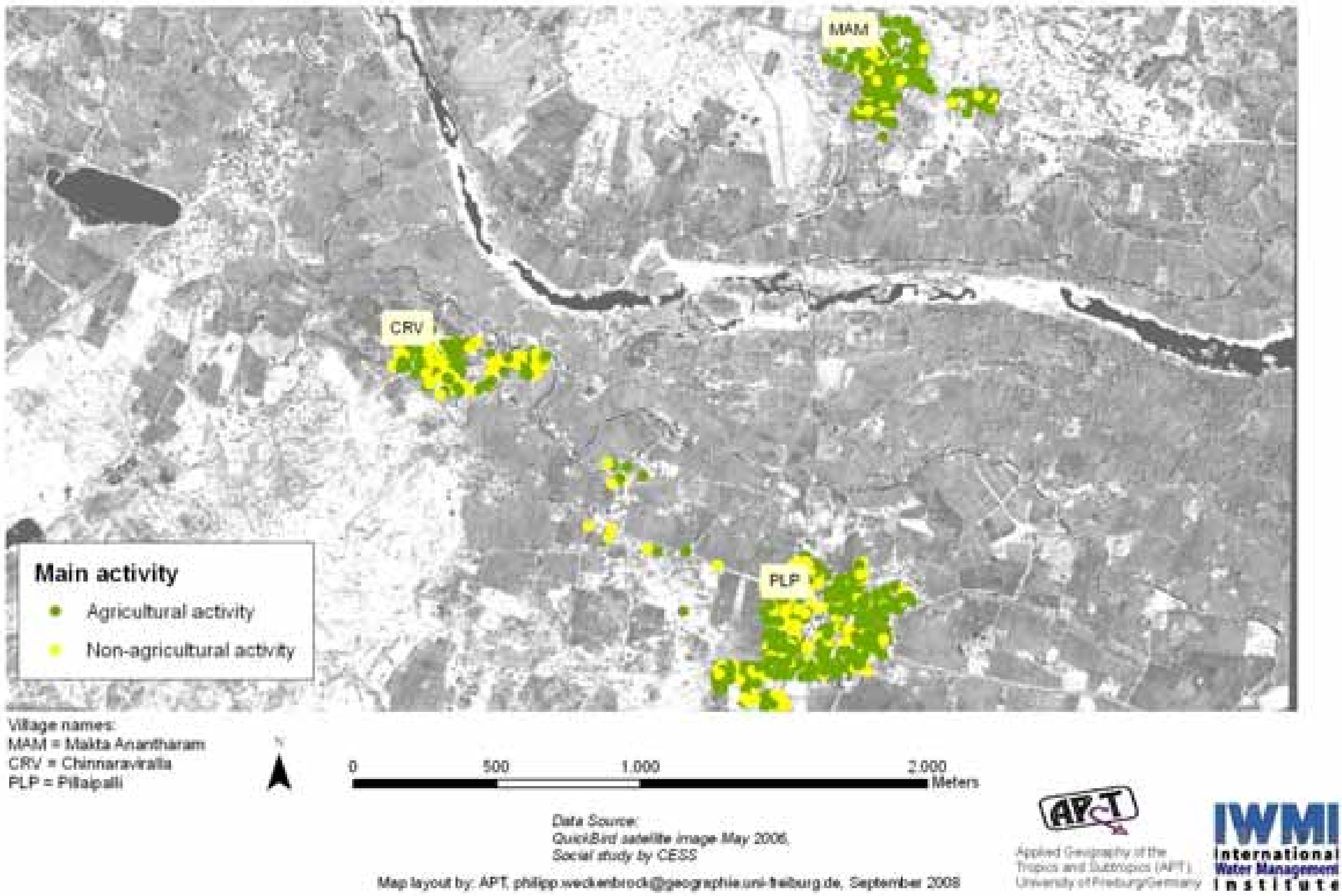


3. Predominant livelihood of the rural communities was Agriculture

Overall, the initial household listing captured information from 1064 rural households. 57% of the households reported that the main livelihood activity of the household head was agriculture. Agricultural activities included farming, *Toddy* topping, dairy production and sheep rearing. The non-farming livelihood activities (30% of the household heads) comprised persons such as government employees, business persons, stone cutters, pensioners, pot makers, weavers, dhobis, tailors, carpenters, basket makers, fuel-wood collectors, goldsmiths, barbers, mat makers, priests and servants.

When the secondary activities were included, the above percentages increased from 57% to nearly 90%. During the harvesting season, migrant labour from other villages moved in temporarily. Similarly farming communities from the study villages moved to neighbouring villages in search of work to supplement their income. This was more common in the rural villages.

Main Activities of Household Heads in the Rural Villages

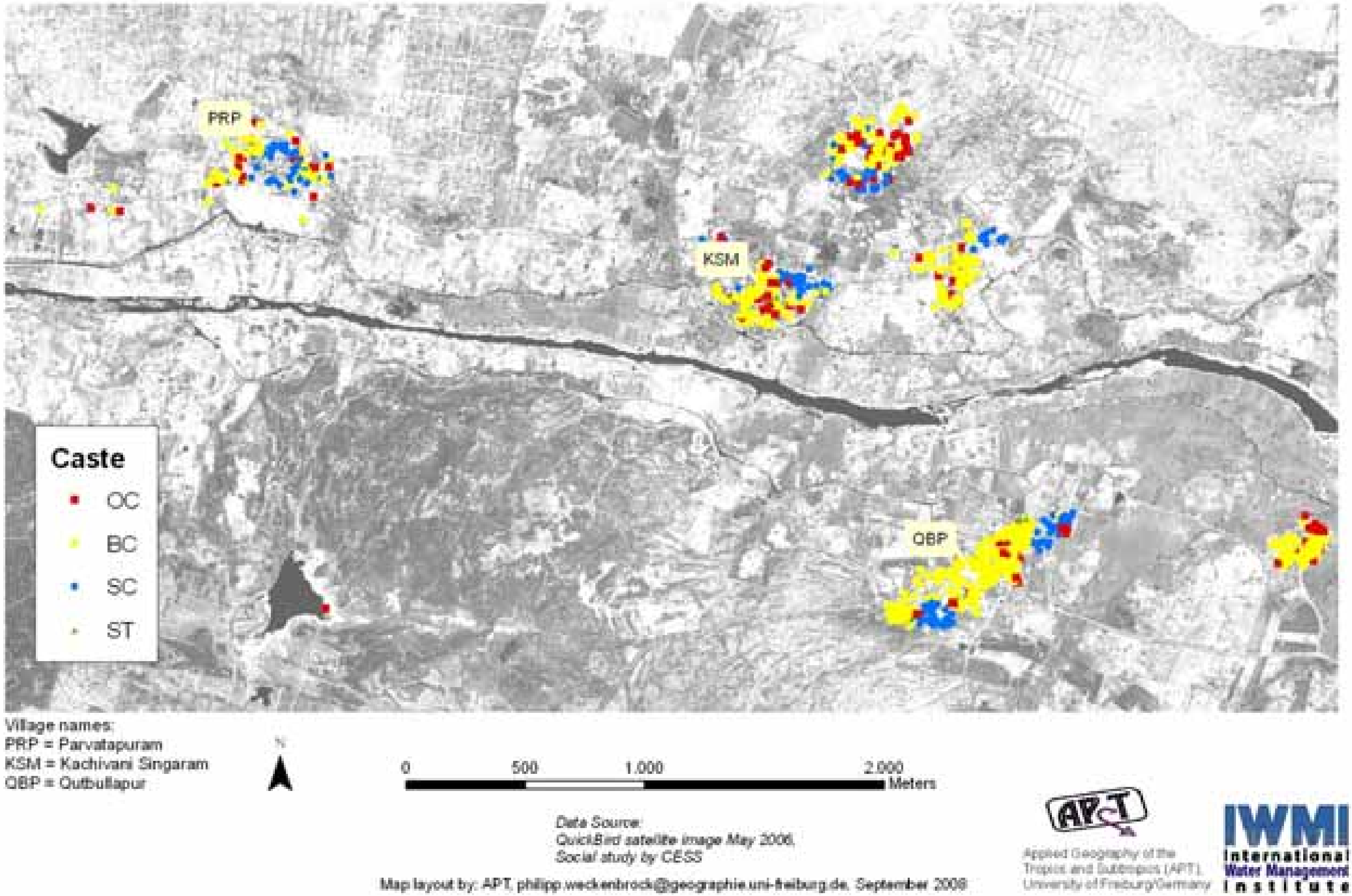


4. Majority of the communities in the periurban zone were from backward castes

Caste distribution based on the household heads in the periurban zone was as follows. Backward castes (BC) 58%, other castes (OC) 16.3%, scheduled castes (SC) 23.1% and scheduled tribes (ST) 2%. The scheduled caste communities were often found clustered.

Overall, 60.9 % of household heads were literate. In general, literacy rates were higher among those household heads whose main occupation was non-agricultural activities.

Castes of Household Heads in the Periurban Villages



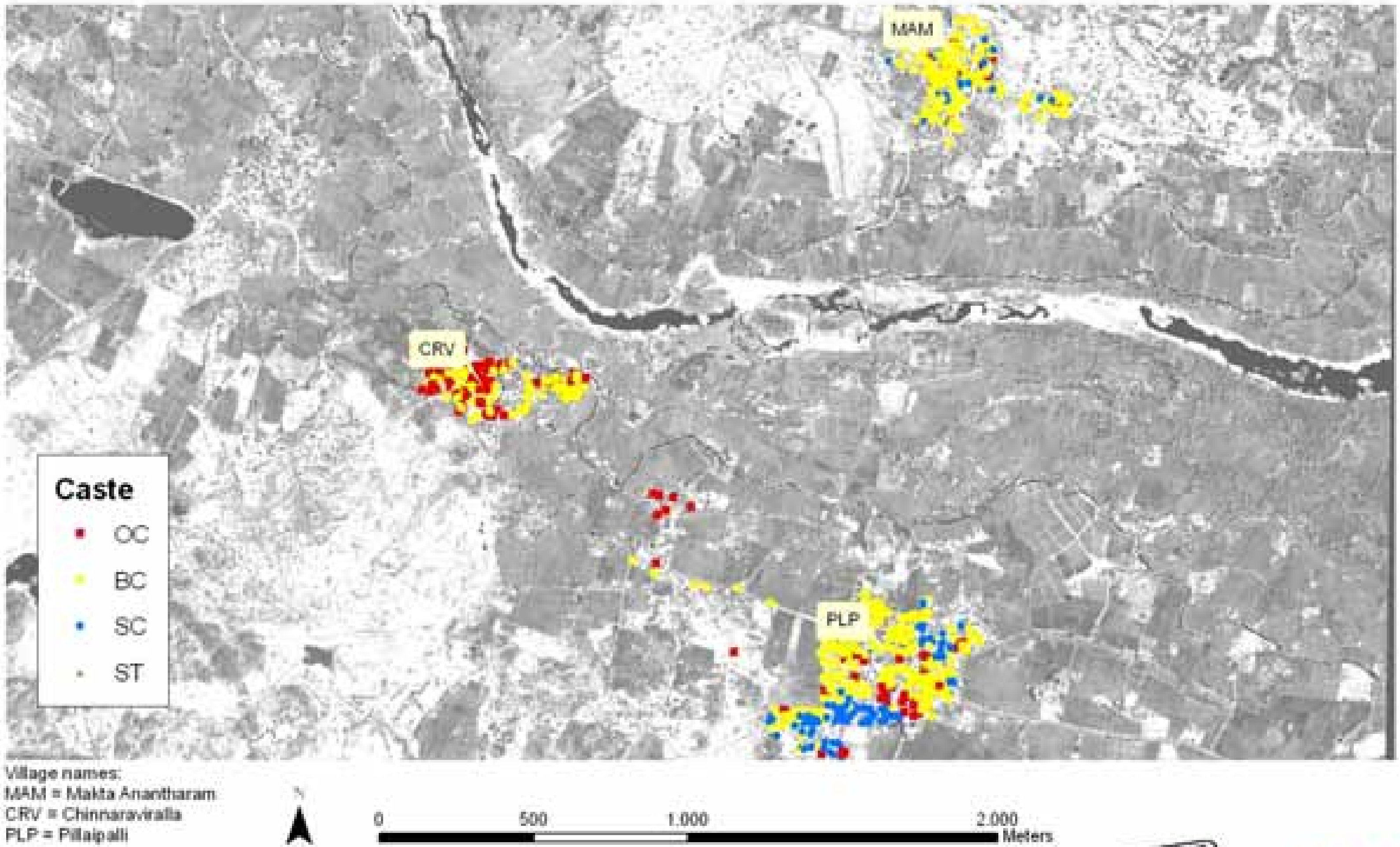
5. Majority of the communities in the rural zone were from the backward castes

Caste distribution in the periurban zone was as follows. Backward castes 65.4%, other castes 15.8%, scheduled castes 17.6% and scheduled tribes 1.2%. The scheduled caste communities were often found clustered, with the exception of the village Makta Anantharam, where these households appeared to be spread relatively evenly.

In these villages, most of the households belonging to the scheduled castes are agricultural labourers and those from other castes are cultivators who own land.

Overall, 55.8% of household heads were literate. Literacy rates were higher among those household heads whose main occupation was non-agricultural activities.

Castes of Household Heads in the Rural Villages



Village names:
MAM = Makta Anantharam
CRV = Chinnaraviralla
PLP = Pillaipalli

Data Source:
QuickBird satellite image May 2006,
Social study by CESS

Map layout by: APT, philipp.weckenbrock@geographie.uni-freiburg.de, September 2008

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International Water Management Institute

6. In the urban fringes, rice was replaced by fodder grass

Most of the agricultural land was distributed along the Musi River. The general cropping pattern showed the cultivation of fodder grass, mostly paragrass (*Urochloa mutica*), in the urban fringes (10-15 km from the city) and rice further downstream. This pattern was reflected in the study villages with paragrass being the main crop in the periurban study villages (59.0%, 453 ha) and rice the dominant crop in the rural study villages (96.2 %, 1097 ha). Multiple contributory factors can be suggested for these adaptive changes: poor water quality, high demand for paragrass in the dairy industry and prohibitive transport costs for paragrass production in the rural areas.

Main crop types cultivated: areas in hectares (percentage)

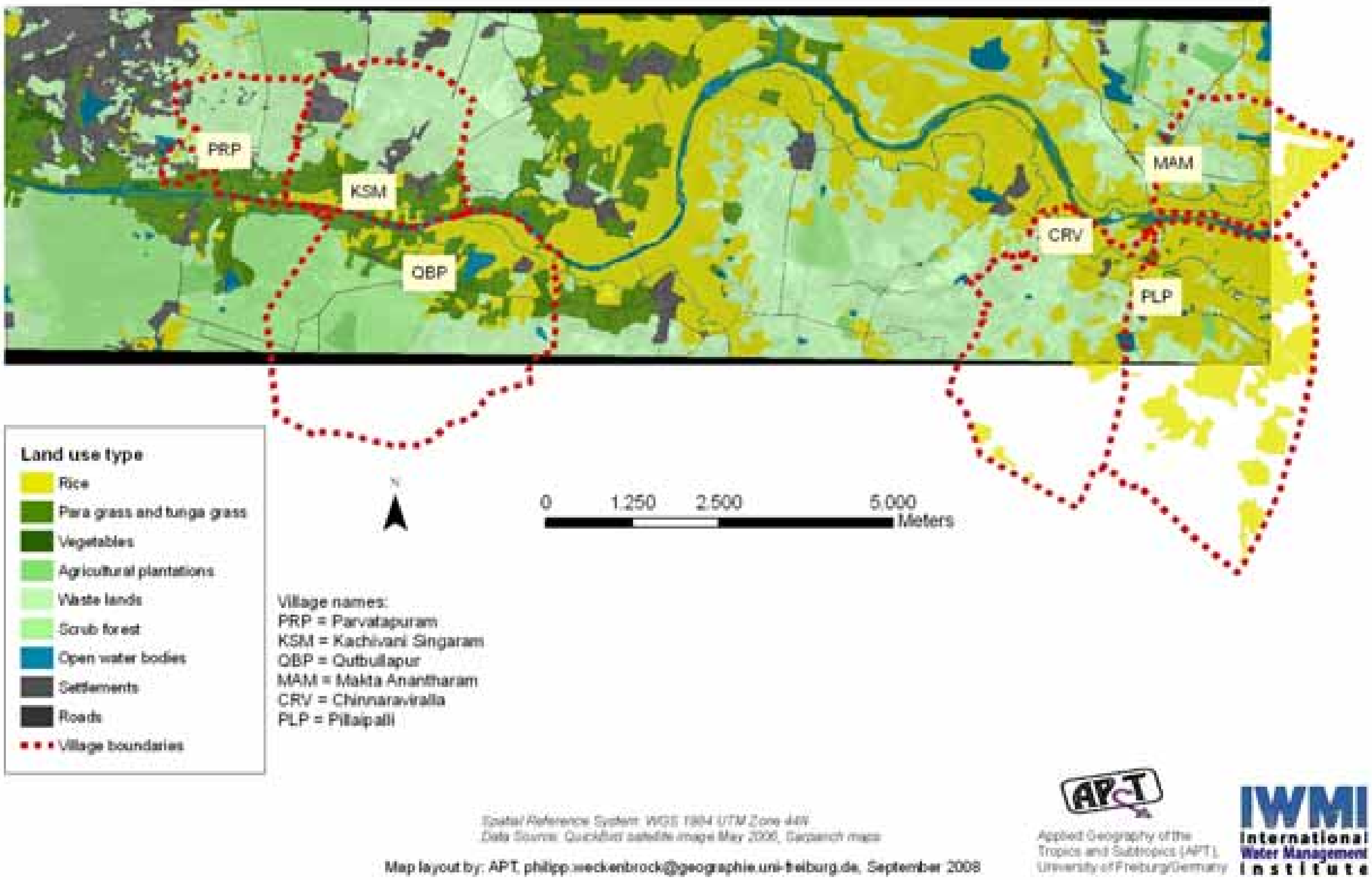
Crop type	Overall area (%)	Periurban villages (%)	Rural villages (%)
Rice	2790 (69.9)	296 (38.6)	1097 (96.2)
Paragrass	1024 (25.6)	453 (59.0)	32 (2.8)
Vegetables	19 (0.5)	1 (0.1)	-
Others	161 (4.0)	18 (2.4)	12 (1.0)

Vegetables are produced mainly in locations very close to the city. While cultivated only in a limited area, they provided important livelihood benefits, in particular for women of low-income groups.

Most of the vegetables grown in the periurban areas along Musi River are green leafy vegetables.

As the city expanded into agricultural areas, land use often followed a pattern of rice cultivation being replaced by paragrass cultivation, sometimes replaced by vegetable production and finally construction of buildings.

Overview on Land Use in the Study Area



7. River water is the main source of irrigation water in the periurban villages

The map shows areas under irrigation with different sources of water.

Sources of irrigation water were divided into three main categories:

River water: water was not taken directly from the Musi River but from irrigation canals on the left and the right bank of the river. Between the canals and the river, the natural slope was used for gravity flow ('direct') irrigation. To irrigate the land above the canals, water was extracted with electrical pumps ('lift' irrigation).

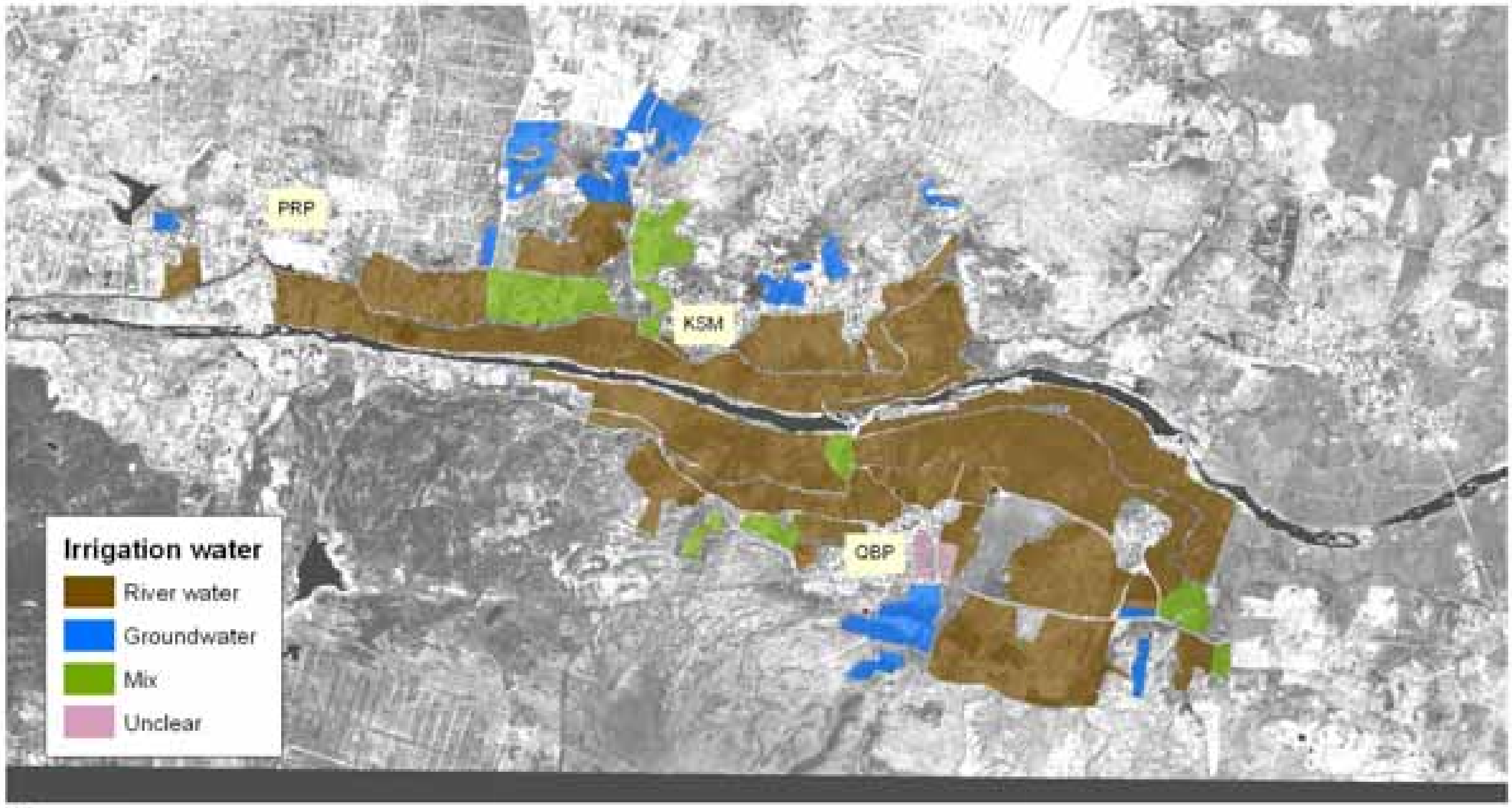
Groundwater: groundwater was extracted from bore wells and open wells (to a lesser extent)

Mix: this comprises a mixture of river- and groundwater (for example, a mixture of river- and bore well water or water from open wells partly refilled with river water).

In the periurban villages, river water was used in 81.1% of the agricultural area (354 ha). Groundwater accounted for 9.3% (41 ha) and a mixture of river- and groundwater 8.8% (38 ha). 0.7% (3 ha) were unclear.

In general, the pattern of irrigation showed the following sequence: 'direct', 'lift' and groundwater irrigation as the distance from the Musi River increased.

Sources of Irrigation Water in the Periurban Villages



Village names:
PRP = Parvatapuram
KSM = Kachivani Singaram
QBP = Qutbullapur

N

0 500 1.000 2.000 Meters

Spatial Reference System: WGS 1984 UTM Zone 44N
Data Source: QuickBird satellite image May 2006, Sarpanch maps

Map layout by: APT, philipp.weckenbrock@geographie.uni-freiburg.de, September 2008

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International Water Management Institute

8. River water the main source of irrigation water in the rural villages

The map shows areas under irrigation with different sources of water.

Sources of irrigation water were divided into three main categories:

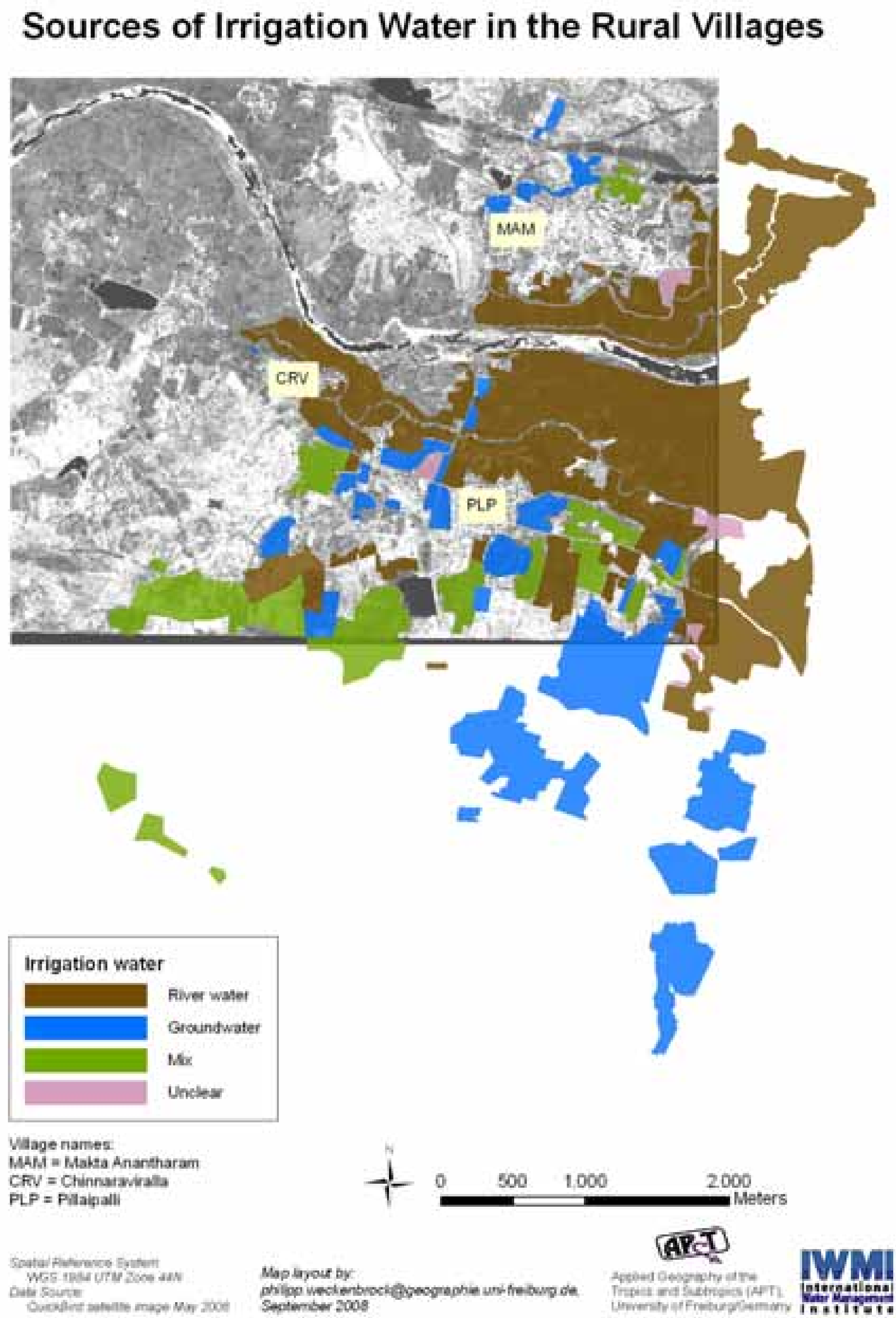
River water: water was not taken directly from the Musi River but from irrigation canals on the left and the right bank of the river. Between the canals and the river, the natural slope was used for gravity flow ('direct') irrigation. To irrigate the land above the canals, water was extracted with electrical pumps ('lift' irrigation).

Groundwater: groundwater is extracted from bore wells and open wells (to a lesser extent)

Mix: this comprises a mixture of river- and groundwater (for example, a mixture of river- and bore well water or water from open wells partly refilled with river water).

In the rural villages, river water was used in 61.1% of the agricultural area (594 ha). Groundwater accounted for 25.9 % (252 ha) and a mixture of river- and groundwater 11.1 % (107 ha). 1.9 % (19 ha) were unclear.

In general, the pattern of irrigation showed the following sequence: 'direct', 'lift' and groundwater irrigation as the distance from the Musi River increased.


Sources of Irrigation Water in the Rural Villages
MAM
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Irrigation water
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International Water Management Institute

9. Irrigation water quality improved with increasing distance from the city

Water quality at five stations in the Musi River was measured from October 2005 – April 2007 (18 months).

The water reaching the sampling points were considered as partially treated, as the Amberpet Sewage Treatment Plant (STP) discharged its contents at a point before the first sampling point. Overall, microbiological and parasitological analyses showed that Biological Oxygen Demand (BOD) and helminth ova levels were relatively higher in the first two than the rest of the sampling points. BOD levels ranging from 90 – 266 mg L^{-1} and helminth ova 13 - 66 ova L^{-1} respectively were recorded at the first sampling point, which could be expected as excess untreated sewage was discharged into the river. Based on WHO guidelines, this water quality is not suitable for irrigation.

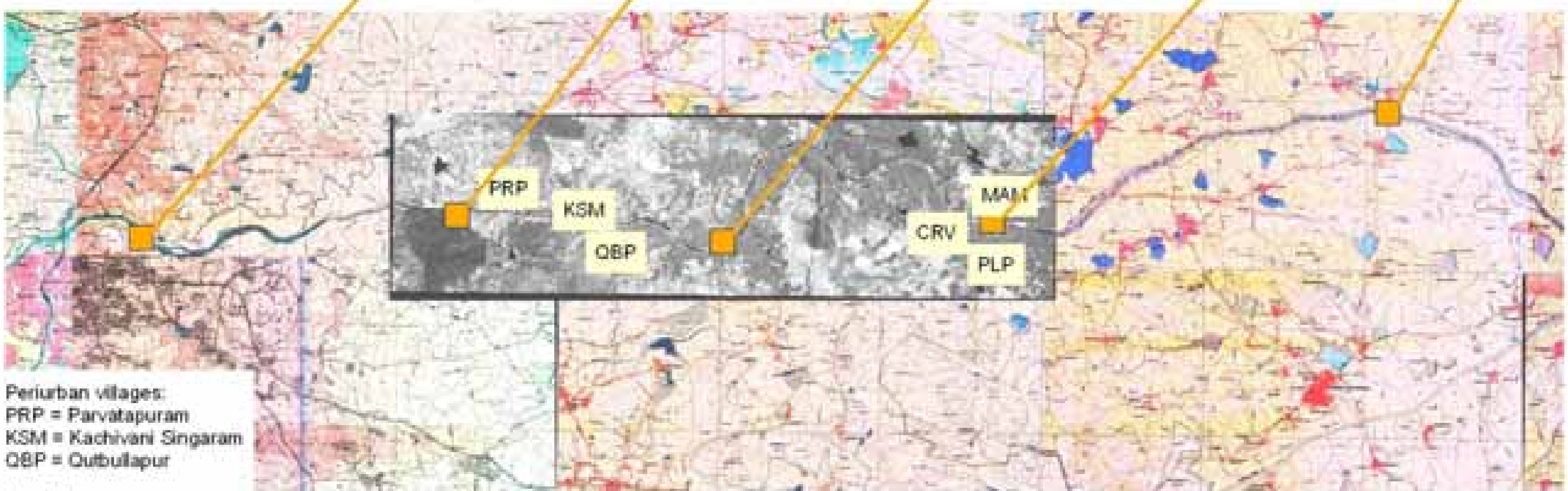
With increasing distance from the city, an improvement in water quality was evident. Moving downstream the river, BOD and helminth ova levels dropped drastically, ranging from 28 – 49 mg L^{-1} and 0 L^{-1} respectively. Hook worm levels were low even at the first sampling point where only 0.7 ova L^{-1} were recorded.

A decreasing trend in *E. coli* levels was also noted but the values (2.16×10^6 to 5.73×10^3 cfu l^{-1}) remained above the permissible level. *E. coli* levels of 1000 cfu l^{-1} and ≤ 1 ova l^{-1} were set as the permissible levels for irrigation water (WHO guidelines, 2006). Fluctuations of *E. coli* levels across the sampling points were observed. These could be associated with cattle bathing.

The system of *anicuts* (weirs) appeared to have had a “treatment function” where the bacteria and ova were sedimented and removed from the river water.

Water Quality in the Musi River: Microbiology and Parasitology

Indicator \ Water sampling point	Amberpet	Peerzadeguda	Gourvelli	Pillaipalli	Battigudam
E. coli (CFU 100 ml^{-1})	2.16 * 10^{6} (1.73 * 10^{6})	1.31 * 10^{5} (1.00 * 10^{6})	1.53 * 10^{5} (1.60 * 10^{5})	4.33 * 10^{5} (4.54 * 10^{5})	5.73 * 10^{3} (7.50 * 10^{3})
Nematode eggs litre^{-1}	19.5 (20.6)	17.2 (17.8)	2.0 (2.8)	0.0 (0.2)	0 (0.0)
Hookworm eggs litre^{-1}	0.7 (1.0)	0.8 (1.0)	0.1 (0.2)	0.0 (0.0)	0 (0.0)



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Water sampling points
Villages

N

0 2,5 5 10 Kilometers

Data Source: QuickBird satellite image May 2006, merged topographic maps, water sample analysis

Map layout by: APT, philipp.weckenbrock@geographie.uni-freiburg.de, September 2008

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10. With increasing distance to the city, total Nitrogen and BOD levels in the river water decreased significantly while Electrical Conductivity (EC) increased

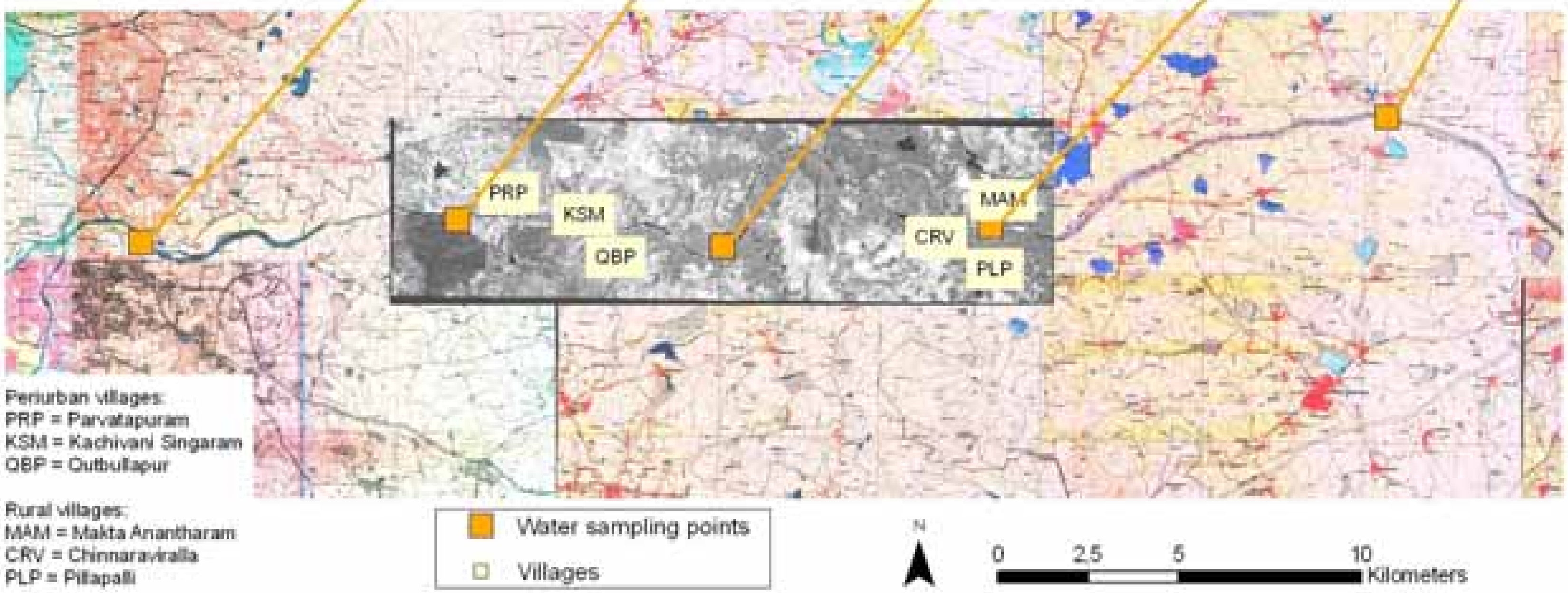
Water quality at five stations in the Musi River was measured from October 2005 – April 2007 (18 months).

Results of selected physico-chemical parameters are presented here. Along a 40 km stretch of the Musi River, total Nitrogen (35.19 – 14.88 mg l^{-1}) and BOD (180.8 – 25.9 mg l^{-1}) levels decreased significantly, whereas EC levels (1272.1 – 1672.4 µS cm^{-1}) increased.

The major contributor to total Nitrogen was Ammonia, which probably evaporated as the water flowed, which could account for the reduction in total Nitrogen levels. High EC levels downstream could be due to evaporative water loss, and run-off from agricultural fields with high levels of chemical fertilizers.

Water Quality in the Musi River: Physico-Chemical

Indicator / Water sampling point	Amberpet	Peerzadeguda	Gourvelli	Pillaipalli	Battigudam
BOD (mg l^{-1})	180.8 (53.2)	103.9 (38.1)	70.7 (41.7)	37.8 (13.3)	25.9 (10.1)
EC (µS cm^{-1})	1272.1 (209.8)	1800.4 (182.5)	1575.7 (157.0)	1628.2 (156.7)	1672.4 (158.0)
Total N (mg l^{-1})	35.19 (7.68)	32.31 (7.94)	31.80 (7.38)	29.38 (6.14)	14.88 (4.62)



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11. Overall, Cd levels in periurban soils were below international standards and high soil pH prevented uptake to leafy vegetables

In January 2007, bulk composite vegetable samples were collected of the four main vegetable types irrigated with Musi River Water namely, Coriander, Mint, Spinach and Amaranth. A total of 28 plots were sampled.

Key Findings:

- Lead: For the plots sampled, all total soil Pb concentrations were significantly lower than the EU Maximum Permissible (MP) level for Pb in sludge amended soils of <300 mg Pb kg^{-1*} for soils with a pH >7.0.
- Zinc: With the exception of four plots, soil Zn concentrations were significantly lower than the EU MP level for Zn in sludge amended soils of <300 mg Zn kg^{-1}* for soils with a pH >7.0.
- Cadmium: With the exception of three plots, soil Cd concentrations were significantly lower than the EU MP level for Cd of <3.0 mg Cd kg^{-1}* for soils with a pH >5.5.
- Alkaline soil pH limits uptake of Cd to vegetables: Trace levels of Cd found in leafy vegetables is primarily due to the high soil pH (>8.0) found across all plots. Alkalinity significantly affects the phyto-availability of soil Cd.
- Source of elevated Zn, Pb and Cd: Results indicate that for those plots with total soil Zn, Pb and Cd exceeding or close to the EU MP levels metal concentrations are strongly correlated with soil Org-C. This suggests that Cd, Zn and Pb contamination in the aforementioned plots may in large part be due to the application and incorporation of a ‘contaminated’ organic amendment.

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* EU Maximum Permissible (MP) level, directive 86/278/EC

Cadmium in Periurban Soils

Data Source:
QuickBird satellite image May 2006,
Soil study Dr. R. Simmons

Map layout by: APT, philipp.weckenbrock@geographie.uni-freiburg.de, September 2008

Applied Geography of the Tropics and Subtropics (APT), University of Freiburg/Germany

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12. Cd levels in 50% of rural soils sampled exceeded international standards but high soil pH prevented uptake to rice straw

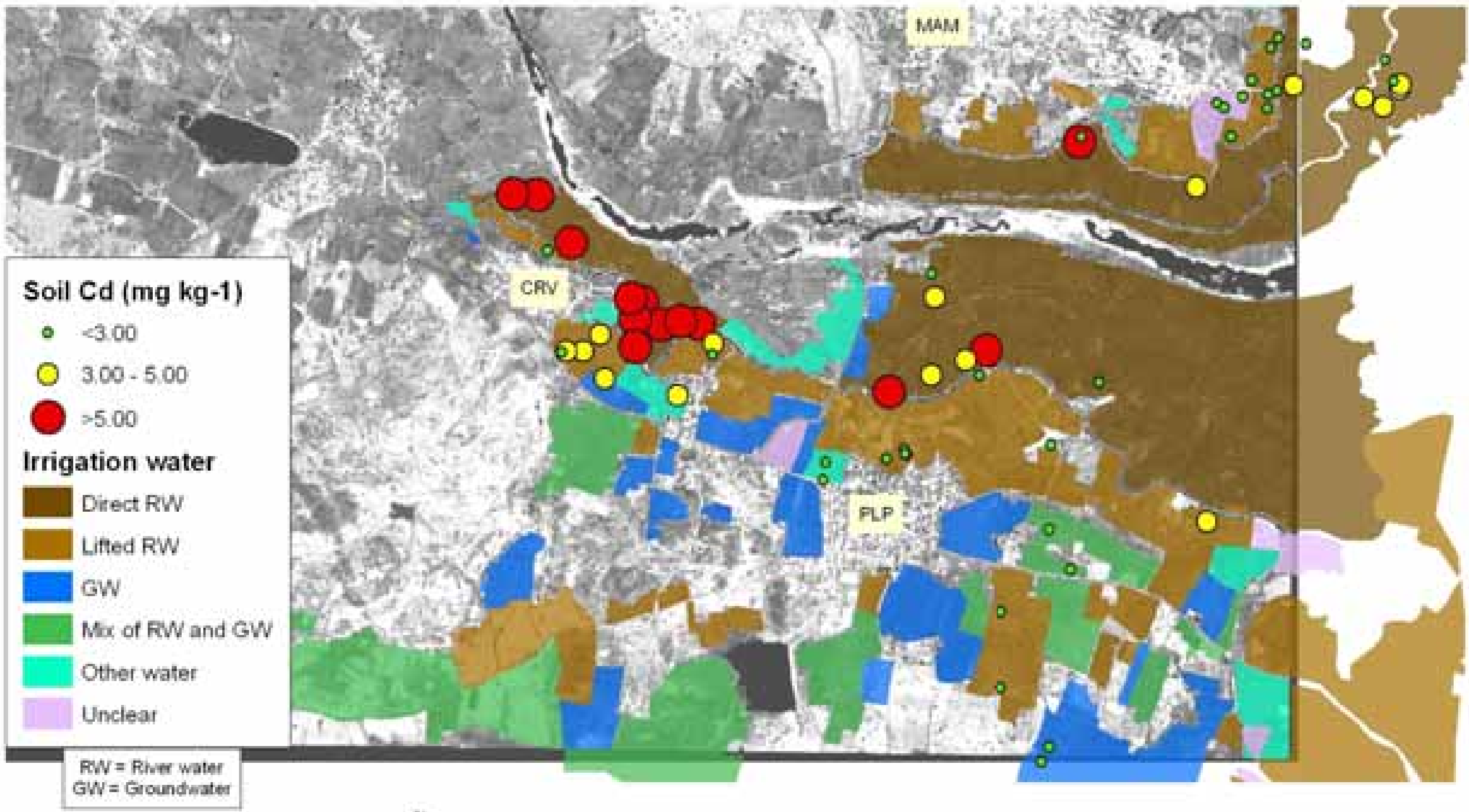
In 2006 concurrent rice and soil samples were collected from 64 rice paddy plots from three rural villages. In each village, three *O. indica* rice varieties namely, 1010, 1001 and IR64 were sampled from four farmer plots (n = 36).

Key Findings:

- Irrespective of irrigation type, all total soil Pb and Zn concentrations were significantly lower than the EU MP level for Pb and Zn in sludge amended soils of <300 mg kg^{-1}[*] for soils with a pH >7.0.
- For the plots sampled, total soil Cd, Zn and Pb concentrations were significantly higher under 'direct' as compared with 'lift' and 'control' irrigated plots.
- Of the 64 plots sampled, over 47 % had total soil Cd concentrations >3.0 mg Cd kg^{-1}. However and critically, all rice straw Cd levels were orders of magnitude below the EC MP levels.
- Zinc deficiency: Of the 64 plots tested, over 30% were associated with DTPA-Extractable Zn concentrations less than the critical threshold of 0.8 mg Zn kg^{-1} below which Zn deficiency symptoms would be expected in rice. This is supported by the fact that over 95% of the rice straw samples contained Zn concentrations of <15 mg kg^{-1} DW[†] which is considered as a reliable indicator of Zn deficiency.
- High soil pH in the study area (>pH 8.0) and high P-status seriously reduces Zn bio-availability. It is recommended that farmers apply supplemental Zn-fertilizer at critical growth stages to alleviate the inherent Zn deficiency of these soils.

[*] EU Maximum Permissible (MP) level, directive 86/278/EC
[†] Dry weight

Cadmium in Soils of the Rural Villages



Village names:
MAM = Makta Anantharam
CRV = Chinnaraviralla
PLP = Pillaipalli

Data Source:
QuickBird satellite image May 2006,
Soil study Dr. R. Simmons

Map layout by: APT, philipp.weckenbrock@geographie.uni-freiburg.de, September 2008

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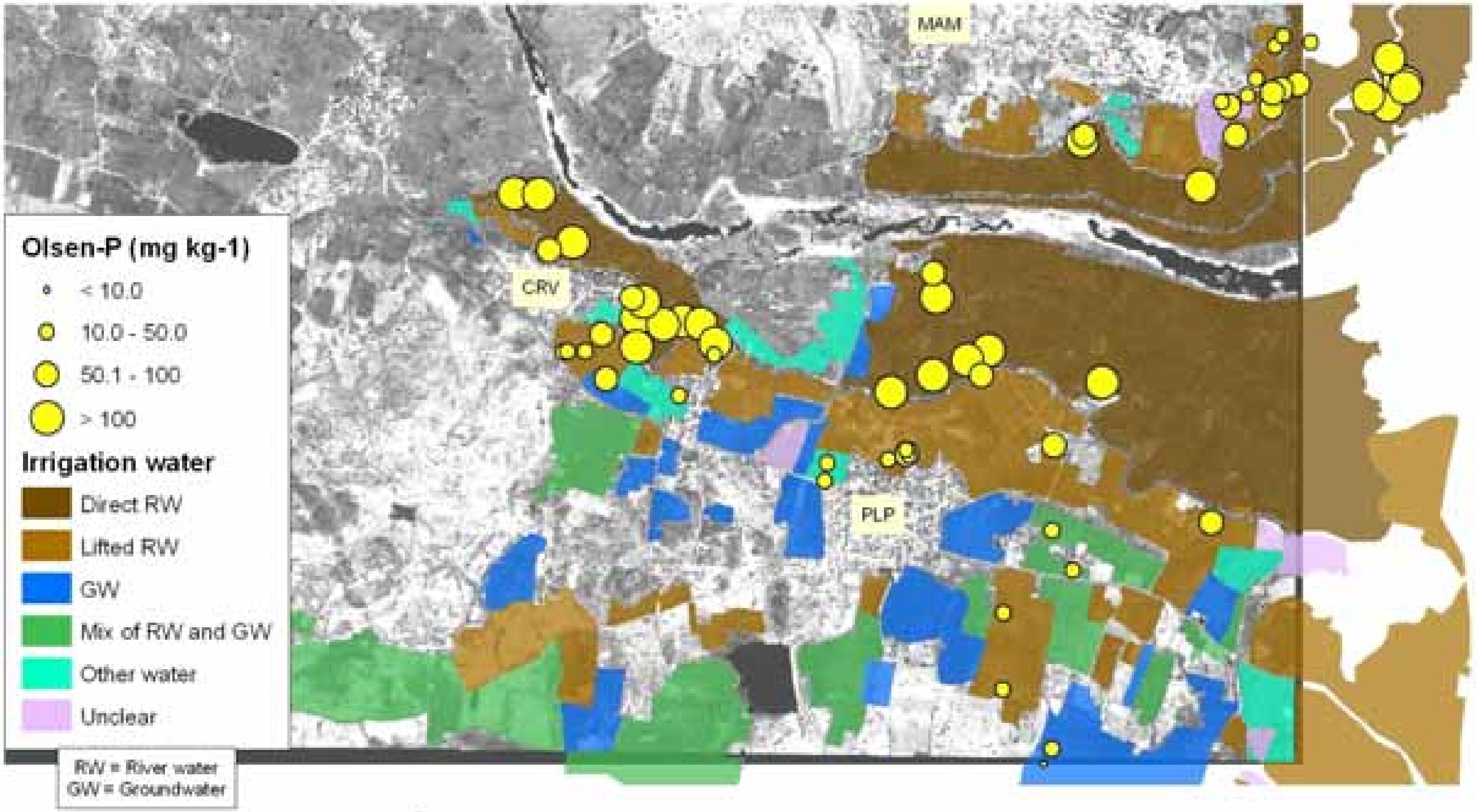
13. Irrigation with river water had both positive and negative effects on soil nutrient status and indicators of soil quality

In 2006, concurrent rice and soil samples were collected from 64 rice paddy plots from three rural villages. In each village, three *O. indica* rice varieties namely, 1010, 1001 and IR64 were sampled from four farmer plots (n = 36).

Key Findings:

- pH: Across all varieties and villages significant differences were observed in soil pH between river water and groundwater irrigated fields with values of 8.47, 8.36 and 8.00 respectively.
- ECe: Across all varieties and villages no significant differences were observed in soil ECe (dS m^{-1}) between 'lift', 'direct' or groundwater irrigated fields with mean values of 3.26, 3.81 and 4.01 dS m^{-1}, respectively. Tanji and Kielen, (2002) suggest a threshold ECe of 3.0 dS m^{-1} for rice above which a 12.0% yield reduction would be expected for each dS m^{-1}. The soil ECe values observed would suggest that salinity induced reductions in yields are to be expected (Tanji and Kielen, 2002).
- Nitrogen: Soil total-N concentrations in 'direct' and 'lift' irrigated plots are high and as expected were 1.5 and 2.1 times higher in 'direct' as compared with 'lift' and 'control' plots, respectively. In addition, in 'direct', 'lift' and 'control' irrigated plots, 79.0%, 64.3% and 44.5% of total-N consisted of Nitrate-N, respectively. Excess levels of soil-N are in large part responsible for the significantly lower rice grain yields observed in 'direct' irrigated as compared with 'lift' irrigated plots as high levels of Nitrate-N are known to reduce grain yields and reduce grain quality.
- Available-Phosphorous: Available-phosphorous (Olsen-P) concentrations in 'direct' and 'lift' irrigated plots are 2.4 and 12.9 times higher in 'direct' as compared with 'lift' and 'control' plots, respectively. In 'direct' and 'lift' irrigated plots Olsen-P levels significantly exceed crop requirements and it is recommended that farmers refrain from applying P-fertilizer subject to monitoring of soil-P.
- High levels of P may be exacerbating inherent Zn deficiencies reported in the study area and it is recommended that farmers apply supplemental-Zn to enhance rice grain yields. Available-P in control irrigated plots of <10 mg kg^{-1} would suggest probable yield responses to additional P-fertilizer addition.
- Exch-K: Exchangeable-K concentrations are significantly higher in 'direct' as compared with both 'lift' and 'control' plots, respectively. In 'direct' and 'lift' irrigated plots it is anticipated that Exch-K levels significantly exceed crop requirements.

Olsen-P in Soils of the Rural Villages



Village names:
MAM = Makta Anantharam
CRV = Chinnaraviralla
PLP = Pillaipalli

Data Source:
QuickBird satellite image May 2006,
Soil study Dr. R. Simmons

Map layout by: APT, philipp.weckenbrock@geographie.uni-freiburg.de, September 2008

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14. Cd and Pb levels in Musi River irrigated paragrass pose negligible risk to the fodder-milk-human food chain.

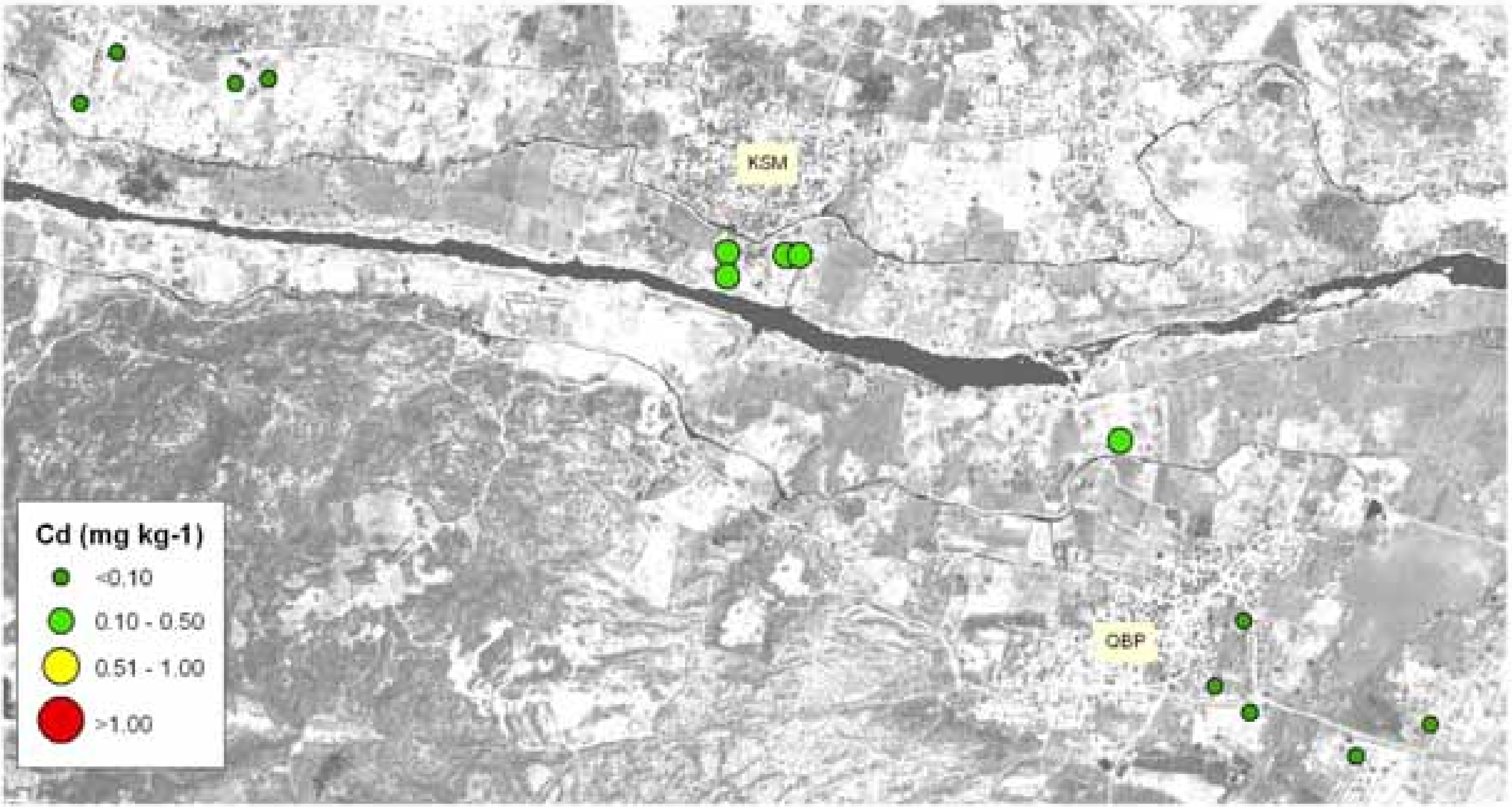
In 2006 concurrent soil and fodder samples were collected at time of harvest in three periurban villages from four farmer plots in each village (n = 12).

Key Findings:

- Cd concentrations were comparable to those of rice straw with mean (DW) values of 0.078 ±0.015 mg Cd kg^{-1}
- Pb concentrations were comparable to those of rice straw with mean (DW) values of 0.298 ±0.02 mg Pb kg^{-1}.
- All paragrass Cd and Pb levels were orders of magnitude below the EC Maximum permissible levels for Pb and Cd in feed materials of <1.0 and <10.0 mg kg^{-1}[*] (FW[†]) irrespective of irrigation method or duration of river water use.
- Cd and Pb levels in the paragrass samples evaluated pose negligible risk to the human food chain.

[*] EU Maximum Permissible (MP) level, directive 2002/32/EC
[†] Fresh weight

Cadmium Concentration in Paragrass in the Periurban Villages



Village names:
KSM = Kachivani Singaram
QBP =Outbullapur

N

0 250 500 1.000 Meters

Data Source:
QuickBird satellite image May 2006.
Soil study Dr. R. Simmons

Map layout by: APT, philipp.weckenbrock@geographie.uni-freiburg.de, September 2008

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15. Cd and Pb Levels in Musi River Irrigated Rice Straw poses Negligible Risk to the Fodder-Milk-Human Food Chain.

In 2006 concurrent soil and fodder samples were collected from 64 rice paddy plots from three rural villages to assess the impact of wastewater irrigation on levels of cadmium (Cd) and lead (Pb) in rice straw.

In each village three *O. indica* rice varieties namely, 1010, 1001 and IR64 were sampled from four farmer plots (n = 36). Rice straw samples were collected from both 'lift' and 'direct' irrigated plots. Direct irrigation is via in field irrigation canals and gravitational flow and 'lift' irrigation via electrical pump sets applied to fields upslope of the irrigation canals diverted from the Musi River. Three groundwater irrigated plots were also sampled to act as 'control' plots and represent 'background' soil and fodder Cd and Pb values.

Key Findings:

- Across all varieties sampled, rice straw (FW) Cd concentrations for 'direct', 'lift' and 'control' irrigated rice plots were 0.015, 0.024 and 0.029 mg Cd kg^{-1}, respectively
- Across all varieties sampled rice straw (FW) Pb concentrations for 'direct', 'lift' and 'control' irrigated rice plots were 0.249, 0.236 and 0.354 mg Pb kg^{-1}, respectively.
- All rice straw Cd and Pb levels were an order of magnitude below the EC Maximum permissible levels for Pb and Cd in feed materials of <1.0 and <10.0 mg kg^{-1}[*] irrespective of irrigation method or duration of river water use.
- Cd and Pb levels in rice straw poses negligible risk to the livestock-human food chain
- Over 95% of the rice straw samples contained Zn concentrations of <15 mg kg^{-1} (DW) which is considered as a reliable indicator of Zn deficiency.

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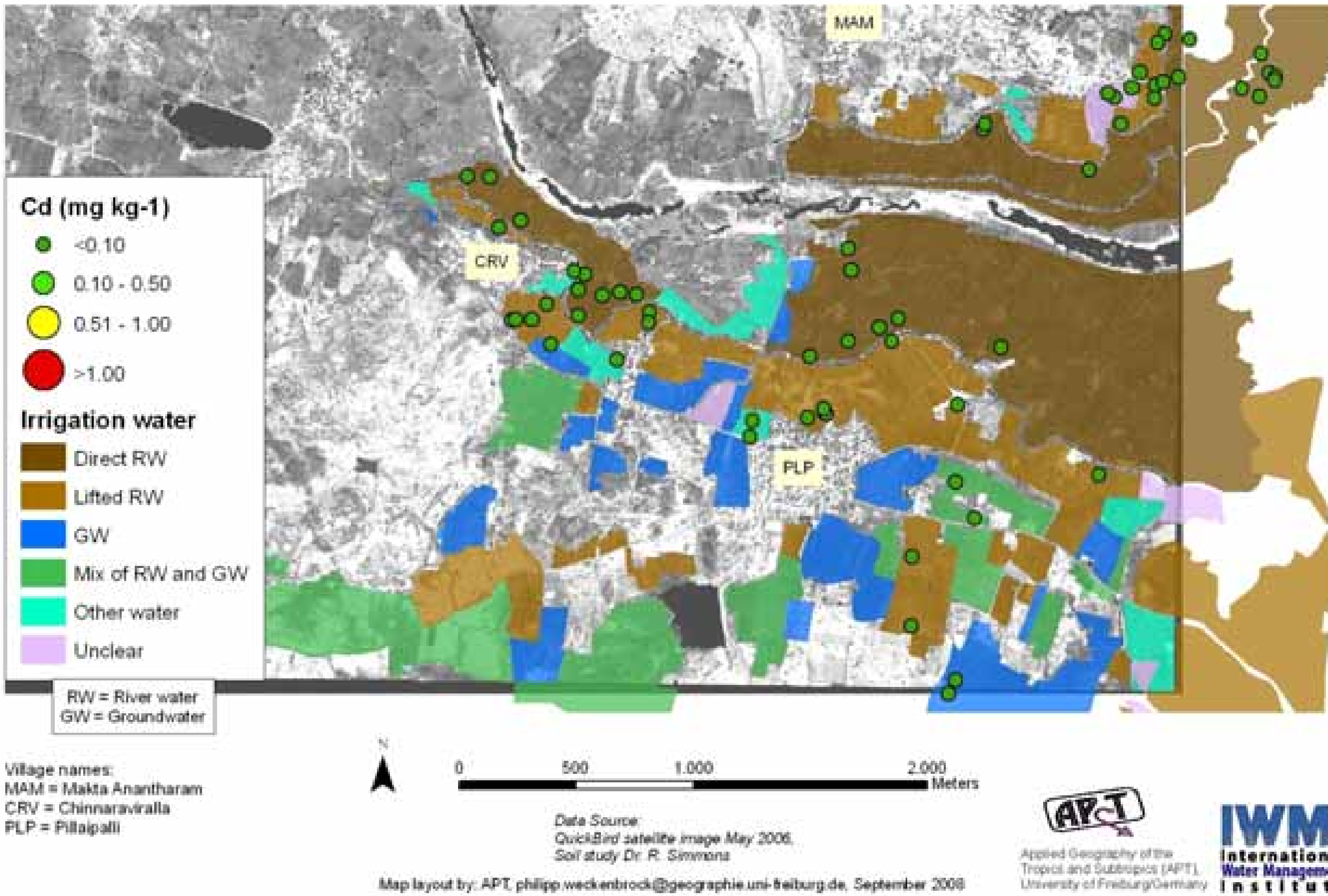
[*] EU Maximum Permissible (MP) level, directive 2002/32/EC

Cadmium Concentration in Rice Straw of the Rural Villages



16. Cd and Pb levels in Musi River Irrigated Leafy Vegetables pose Negligible Risk to the Human Food Chain.

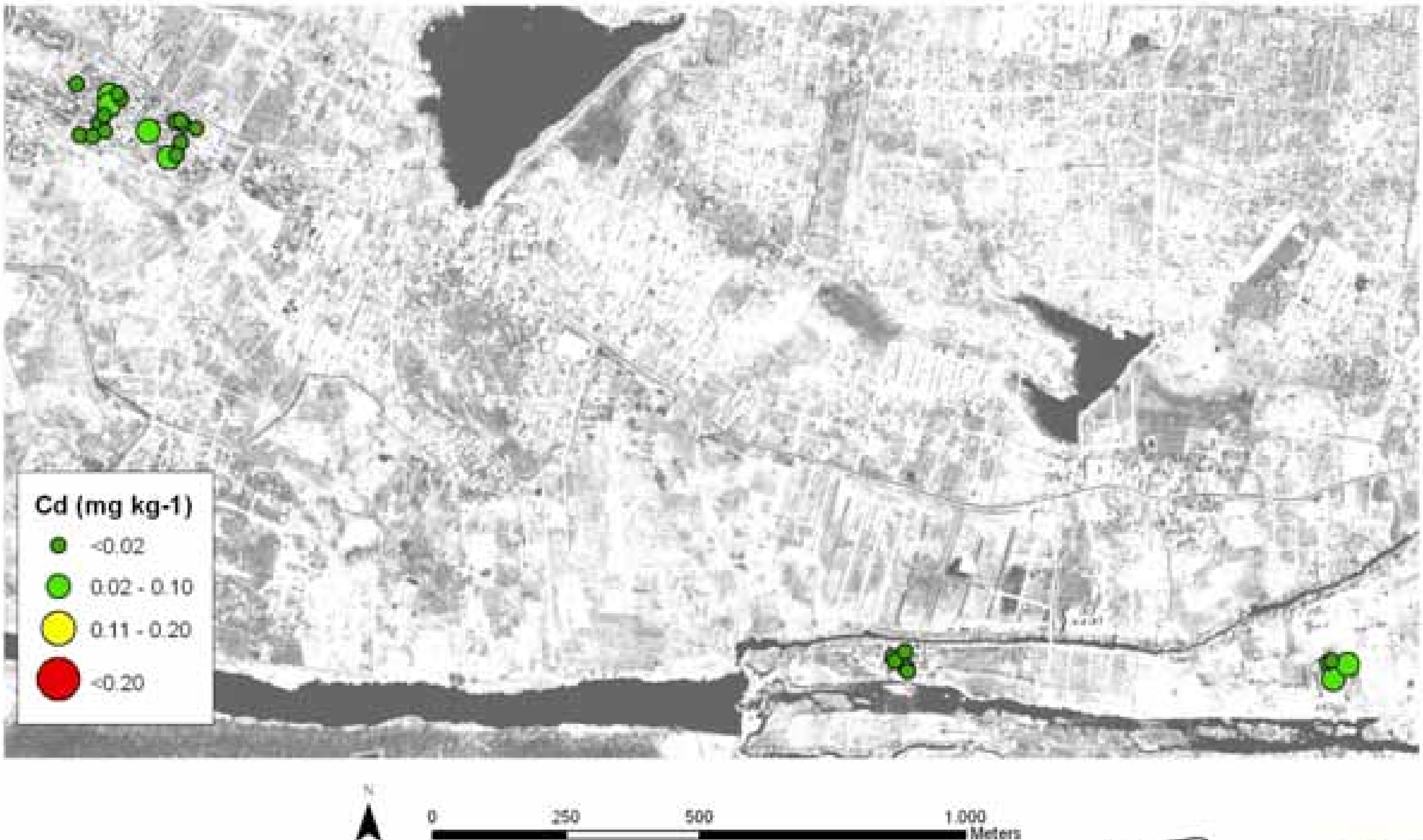
In January 2007, bulk composite vegetable samples were collected of the four main vegetable types irrigated with Musi River water namely, Coriander[*], Mint[†], Spinach[‡] and Amaranth[§].

Key Findings:

- Contrary to general perception, total concentrations (FW) of Cd and Pb in the vegetables sampled were orders of magnitude below the Maximum Permissible Levels established by CCFAC[**].
- Assuming a daily leafy vegetable intake of 0.011 kg (FAO, 1994) and a body weight (BW) of 60 kg for men (aged 20-50yrs) and 50 kg for women (aged 20-50yrs) the contribution to Weekly Intake of Cd and Pb derived from the consumption of Amaranthus or Spinach is for both men and women less than 0.5% of the JECFA Provisional Tolerable Weekly Intake[††].
- Consequently, the consumption of Musi River irrigated leafy vegetables poses negligible risk to the human food chain.

[*] *Coriandrum sativum* (Coriander, Kothimiri)
[†] *Mentha spicata* (Mint, Pudina)
[‡] *Spinacia oleracea* (Spinach, Palak)
[§] *Amaranthus gangeticus* (Amaranth, Thotekura)
[**] CCFAC Codex Commission on Food Additives and Contaminants http://www.codexalimentarius.net
[††] See section on International Standards for food additives and contaminants

Cadmium Concentration in Vegetables (Periurban Zone)



Data Source:
QuickBird satellite image May 2006,
Soil study Dr. R. Simmons

Map layout by: APT, philipp.weckenbrock@geographie.uni-freiburg.de, September 2008

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17. Lower Rice grain yields and increased N content in rice straw in Musi River irrigated areas

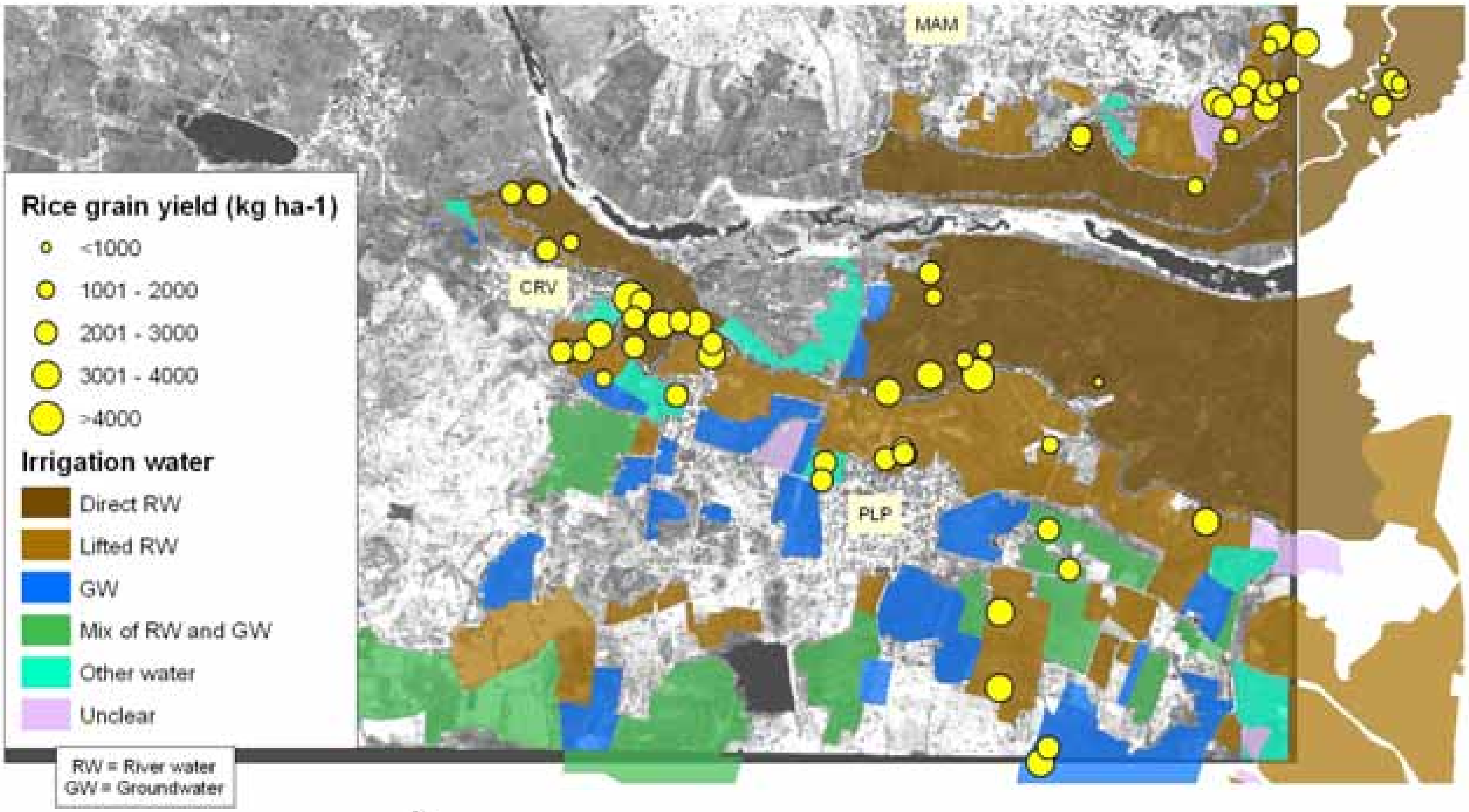
In 2006 concurrent soil and fodder samples were collected from 64 rice paddy plots from three rural villages. In each village, three *O. indica* rice varieties namely, 1010, 1001 and IR64 were sampled from four farmer plots (n = 36).

Rice straw samples were collected from both 'lift' and 'direct' irrigated plots. 'Direct' irrigation is via in-field irrigation canals and gravitational flow and 'lift' irrigation via electrical pump sets applied to fields upslope of the irrigation canals diverted from the Musi River. In general, 'direct' and 'lift' irrigated plots have been irrigated for >25yrs and <5yrs respectively.

Key Findings:

- Across all varieties, no significant differences were found in straw yields between 'lift' and 'direct' irrigated fields with values of 3,328 and 3,124 kg ha^{-1}, respectively.
- However, across all varieties, mean rice grain yields were 29.3% lower in 'direct' irrigated fields compared to 'lift' irrigated (1914 versus 2,708 kg ha^{-1}).
- Nitrogen (N) content was significantly lower in straw from 'lift' irrigated fields as compared with straw from 'direct' irrigated fields with mean values of 1.08% and 1.38%, respectively.
- In contrast in vitro digestibility was slightly but significantly higher in straws 'lift' irrigated (43.3%) as compared to straws harvested from 'direct' irrigated fields (42.1%).
- Rice straw N content (%) may be considered as very high under both irrigation conditions as compared with the control value of 0.721%. Further, this may in large part reflect the high N content attributed to river water.
- In long-term ('direct') Musi River irrigated plots significantly higher straw and grain yields were associated with rice variety 1001 as compared with 1010 and IR64. In contrast, no significant varietal differences in straw biomass or grain yield were observed in short-term ('lift') irrigated plots.

Rice Grain Yields in the Rural Villages



Village names:
MAM = Makta Anantharam
CRV = Chinnaraviralla
PLP = Pillaipalli

Data Source:
QuickBird satellite image May 2006,
Soil study Dr. R. Simmons

Map layout by: APT, philipp.weckenbrock@geographie.uni-freiburg.de, September 2008

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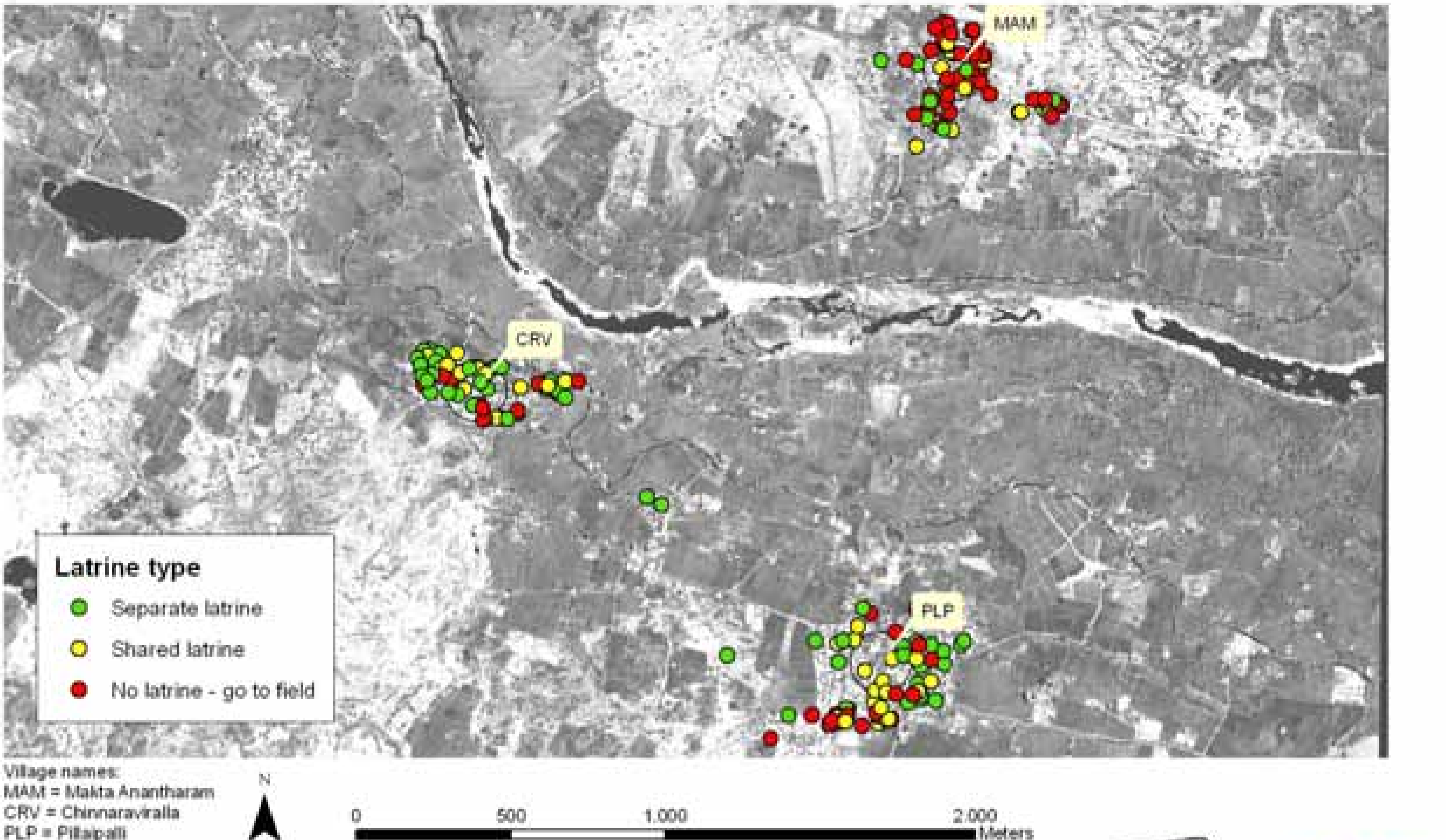
International Water Management Institute

18. Majority of the households in the periurban zone had latrine facilities

Overall, 164 farming households participated in the health survey. Of these, 80% of the households had latrine facilities of which 39% were shared. The rest did not have latrines, and defecated outside.

With rapid urbanization of the city of Hyderabad, and high land values in this zone, a high level of construction of new houses, colleges and residential housing blocks is transforming the landscape. The housing infrastructure of the poor communities is also being is also influenced by rapid development and many changes have been noted. Many of the poorer households have taken advantage of the development activities around their surroundings and conformed to the special government programs on latrine construction, hence the high percentage of households with latrines.

Latrine Facilities in the Rural Villages



Spatial Reference System: WGS 1984 UTM Zone 44N
Data Source: QuickBird satellite image May 2006,
Health study by Dr. P. Amerasinghe

Map layout by: APT, philipp.weckenbrock@geographie.uni-freiburg.de, September 2008

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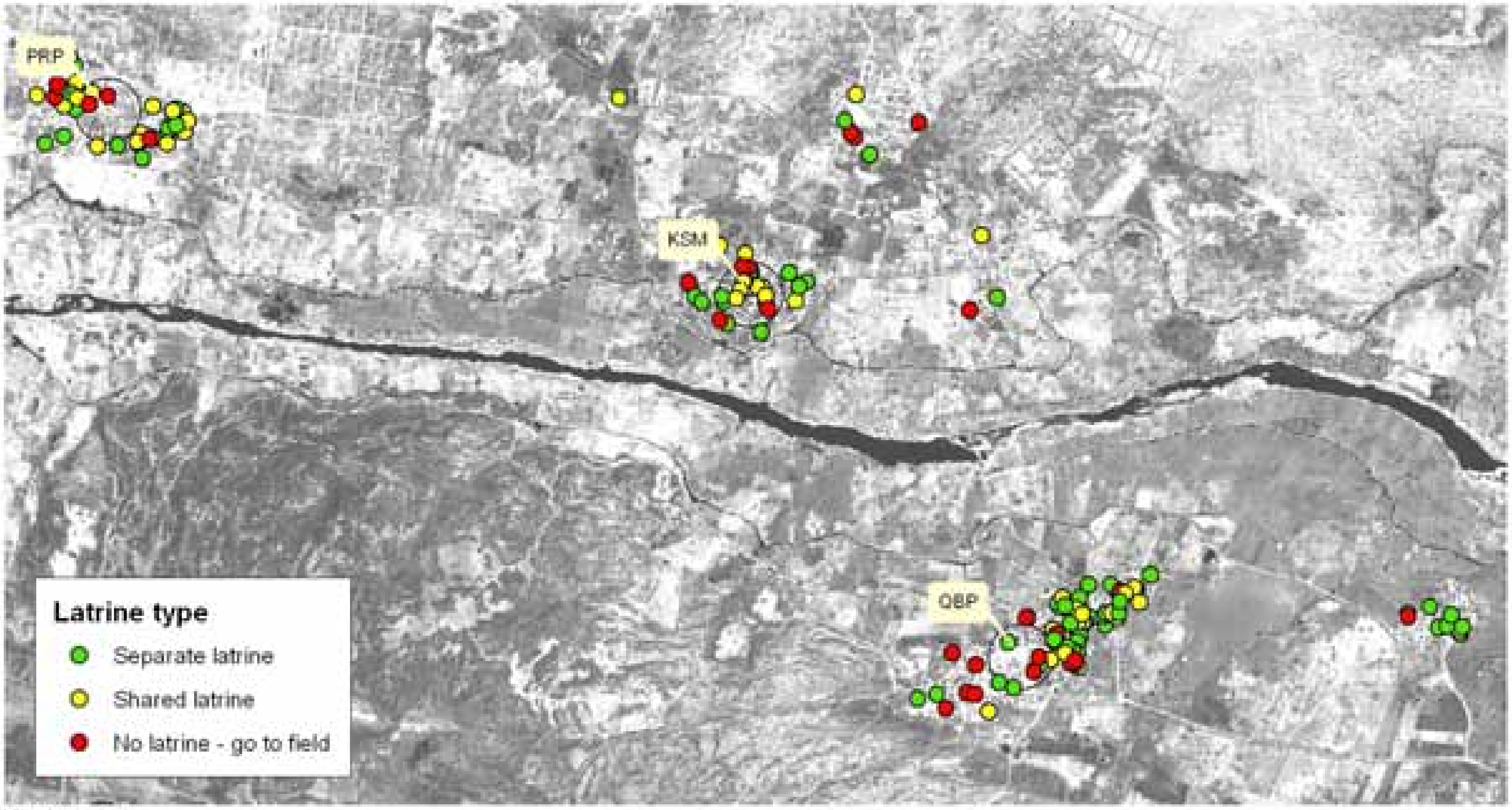
19. More open defecation in the rural zone, due to lack of latrine facilities

Overall, 187 farming households participated in the health study.

Only 60% of the sampled households had latrine facilities, of which 25% were shared. A large percentage (40%) was defecating in the areas surrounding the settlements, and had no latrines despite the support extended by the government.

This contributed to the overall poor hygiene and sanitation conditions in the villages and increased exposure to parasitic infections

Latrine Facilities in the Periurban Villages



Village names:
PRP = Parvatapuram
KSM = Kachivani Singaram
QBP = Qutbullapur

N

0 500 1,000 2,000 Meters

Spatial Reference System: WGS 1984 UTM Zone 44N
Data Source: QuickBird satellite image May 2006,
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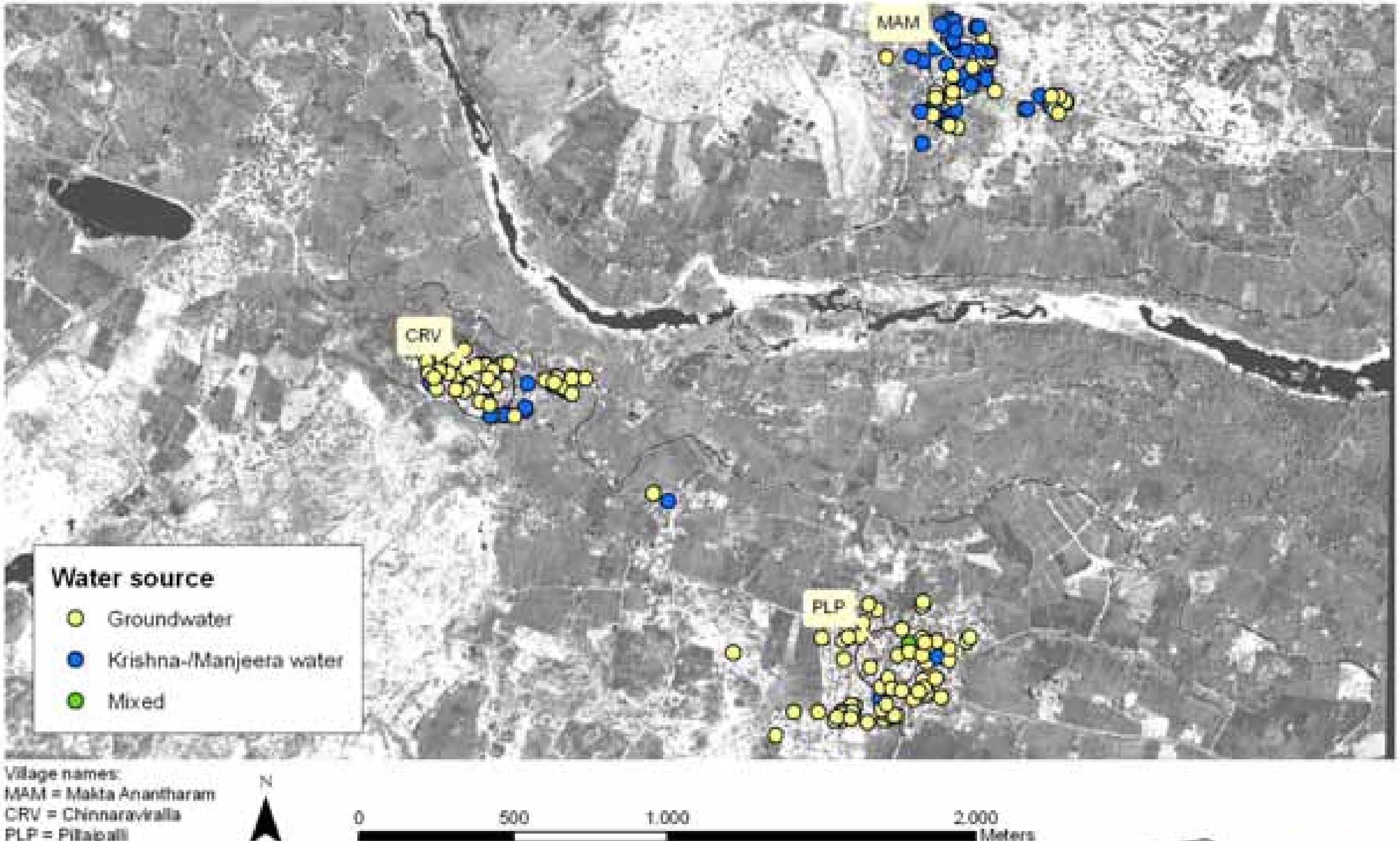
20. Growing demand for city water in the periurban villages

Overall, 164 farming households participated in the survey. At the time of the survey, 80% were dependent on ground water which was pipe-borne and from deep bore wells. More recently, city water (from the Krishna and Manjira rivers) has been supplied through separate pipelines which were confined to a few taps along the road-side. The water supply in these taps was not regular, and was distributed only two or three times a week for a few hours per day. Not all households had adequate containers to store water between supply periods and had to depend on bore well water to supplement their drinking water supplies. In general, groundwater was of inferior quality with high levels of total dissolved solids (tds) and EC.

We understand the current trend is changing and more and more people are using city water for drinking purposes. However, villagers continue to use the bore well water for drinking and other domestic purposes when the need arises.

The demand for city water is in part due to the heightened awareness on water quality and health following government promotional and awareness programmes. Another reason for the growing demand for city water is that it has a better taste compared to groundwater.

Source of Drinking Water for Households in the Rural Villages



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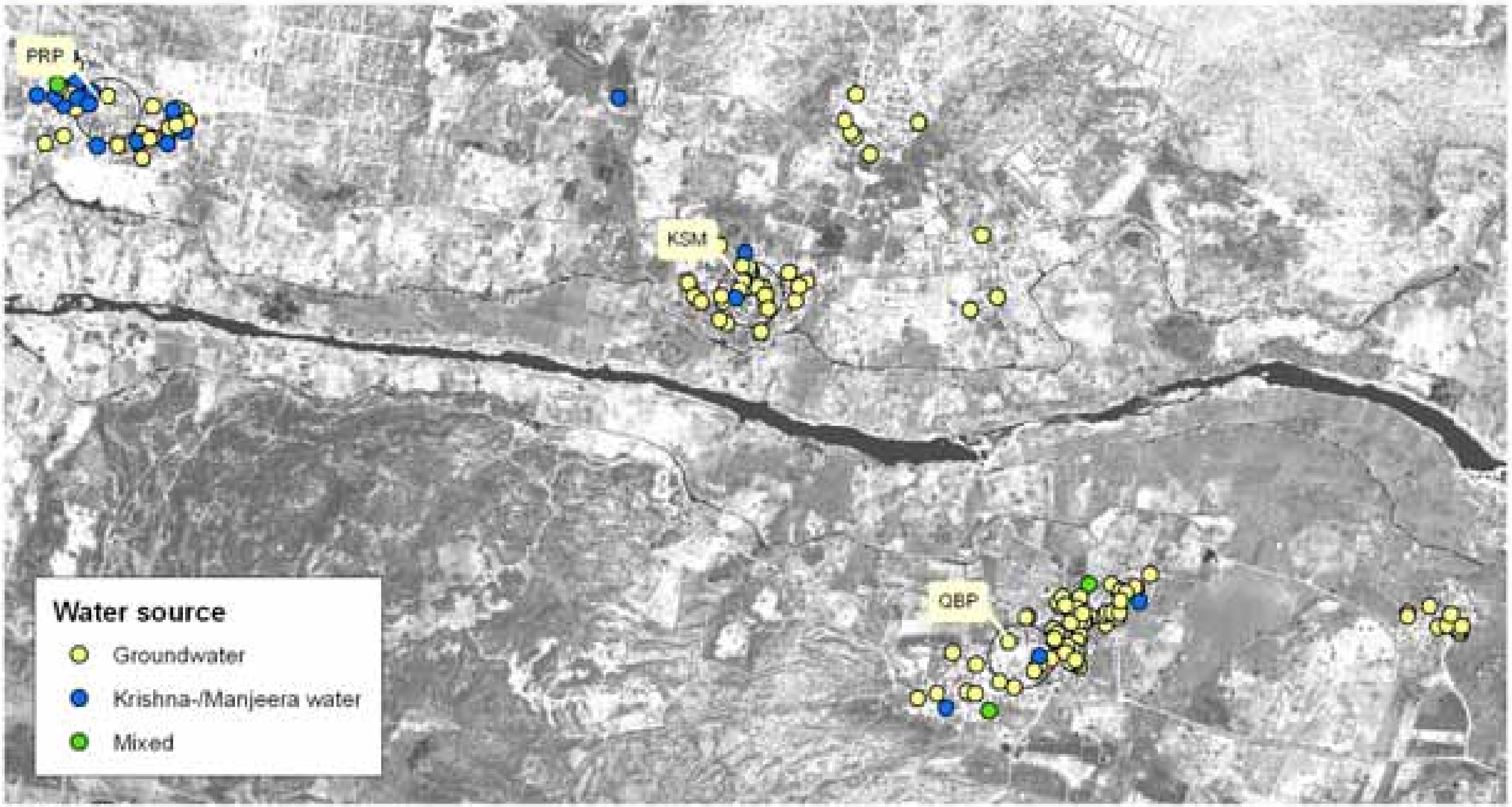
21. High demand for city water for drinking purposes in the rural villages

Overall, 187 rural farming households participated in the survey. A large majority (71%) used ground water, with the exception of the village Makta Anantharam, where a good number of households purchased city water (from the Krishna and Manjira rivers), owing to the high fluoride content in the ground water. While the city water supply has reached the rural village of Chinnaraviralla, the two villages of Makta Anantharam and Pillaipalli have still to get a connection. Both villages, Makta Anantharam and Pillaipalli, belong to the Nalgonda District, which is identified as a high risk district for fluorosis. However, fluoride in bore wells was not high in the village of Pillaipalli. In these two villages, private vendors have taken up the business of selling drinking water, transported from the city.

Source of Drinking Water for Households in the Periurban Villages



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N

0 500 1,000 2,000 Meters

Spatial Reference System: WGS 1984 UTM Zone 44N
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22. Overall, low parasite prevalence in the periurban villages

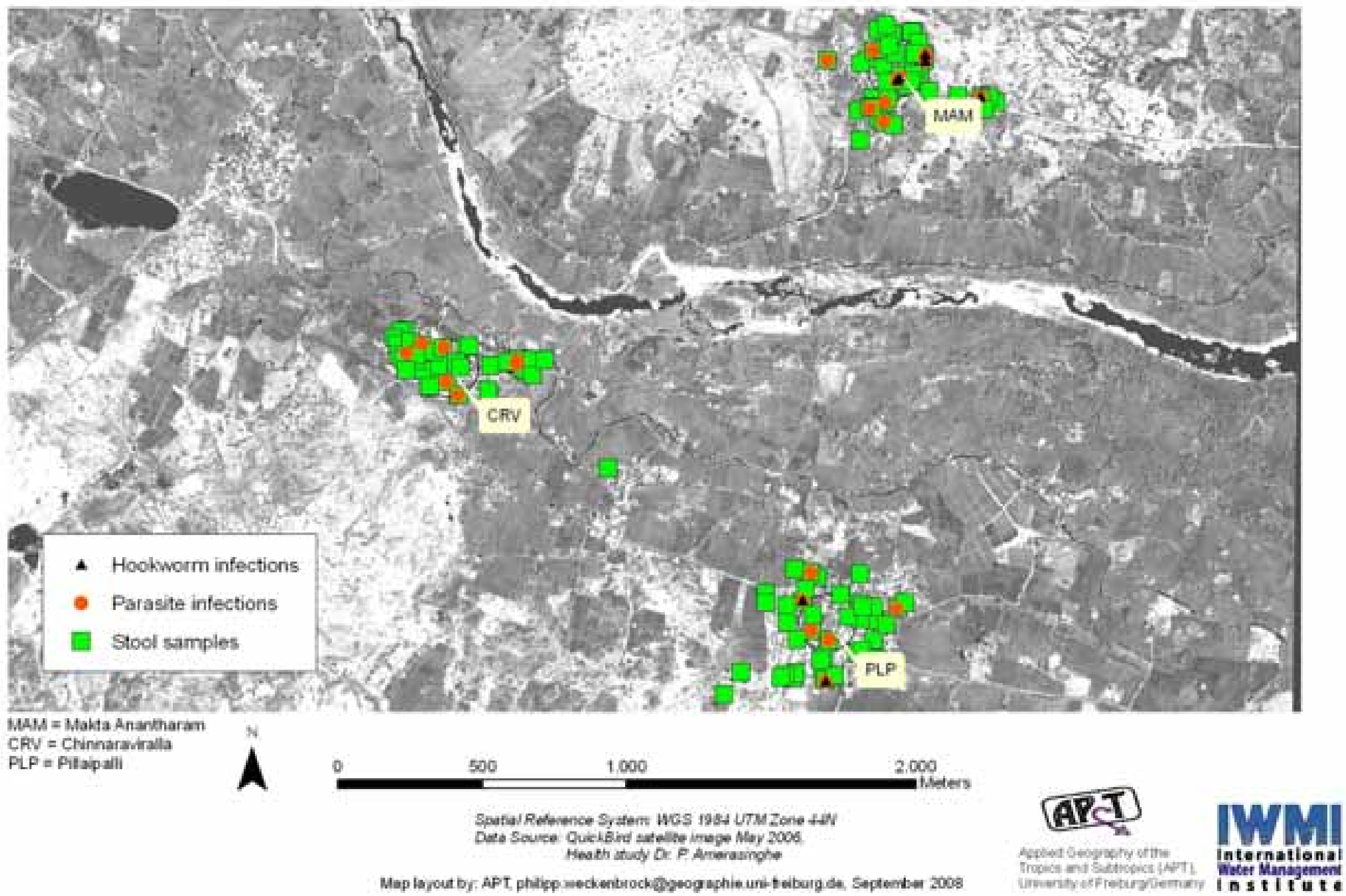
In general, the parasite prevalence was low (cross sectional study) in the three periurban villages studied. Overall, parasite prevalence was 8% (n=225), with a combination of different parasitic infections (protozoa, nematodes and cestodes). Parasite species prevalence was as follows.

Entamoeba histolytica (0%)
Giardia lamblia (0%)
Enterobius vermicularis (1.3%)
Ascaris lumbricoides (1.3%)
Trichuris trichura (0%)
Hook worms (0%)
Hymenolepis nana (4.1%)
Taenia saginata (1.3%)

A separate cross-sectional study (n=295) on diarrhoea carried out in 2007, showed that 37.5% of the periurban population engaging in Musi River related activities (n=152) complained of having suffered from an episode of diarrhoea, during a two week to three month period prior to the date of interview. Nearly 35.1% perceived that this was associated with water. Only a few (1.8%) stated that the episode was related to food consumption. Around 47.4% were not aware of the cause of the diarrhoeal episode.

In the non-farming category (n=143), 39% reported a diarrheal episode for the same time period, and 76% felt that water was the cause of the episode. Around 4.1% perceived that it was food borne. 12.2% said that they were not aware of the causative agents.

Parasite Infections in the Rural Villages



23. Overall, low parasite prevalence in rural communities.

In general, the parasite infections were low (cross sectional study). Overall, the parasite prevalence was 9% (n=225), with a combination of different parasitic infections (protozoa, nematodes and cestodes). Parasite species were *Entamoeba histolytica*, *Giardia lamblia*, *Ascaris lumbricoides, Trichuris trichura,* Hook worms and *Hymenolepis nana* (Fig-1).

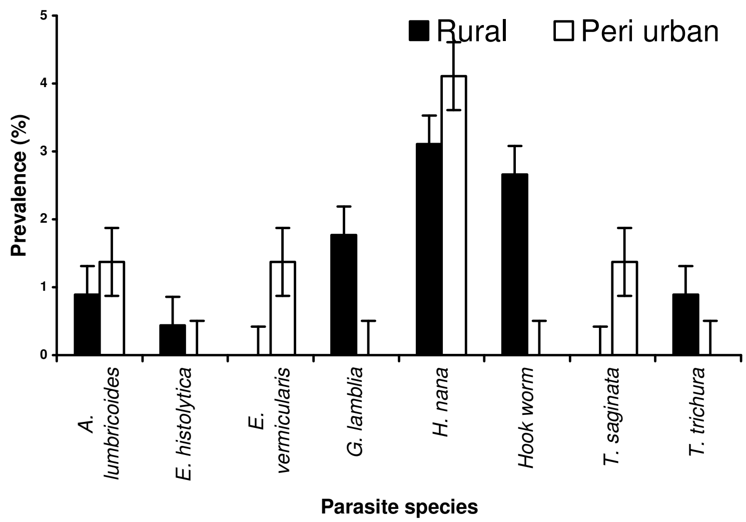


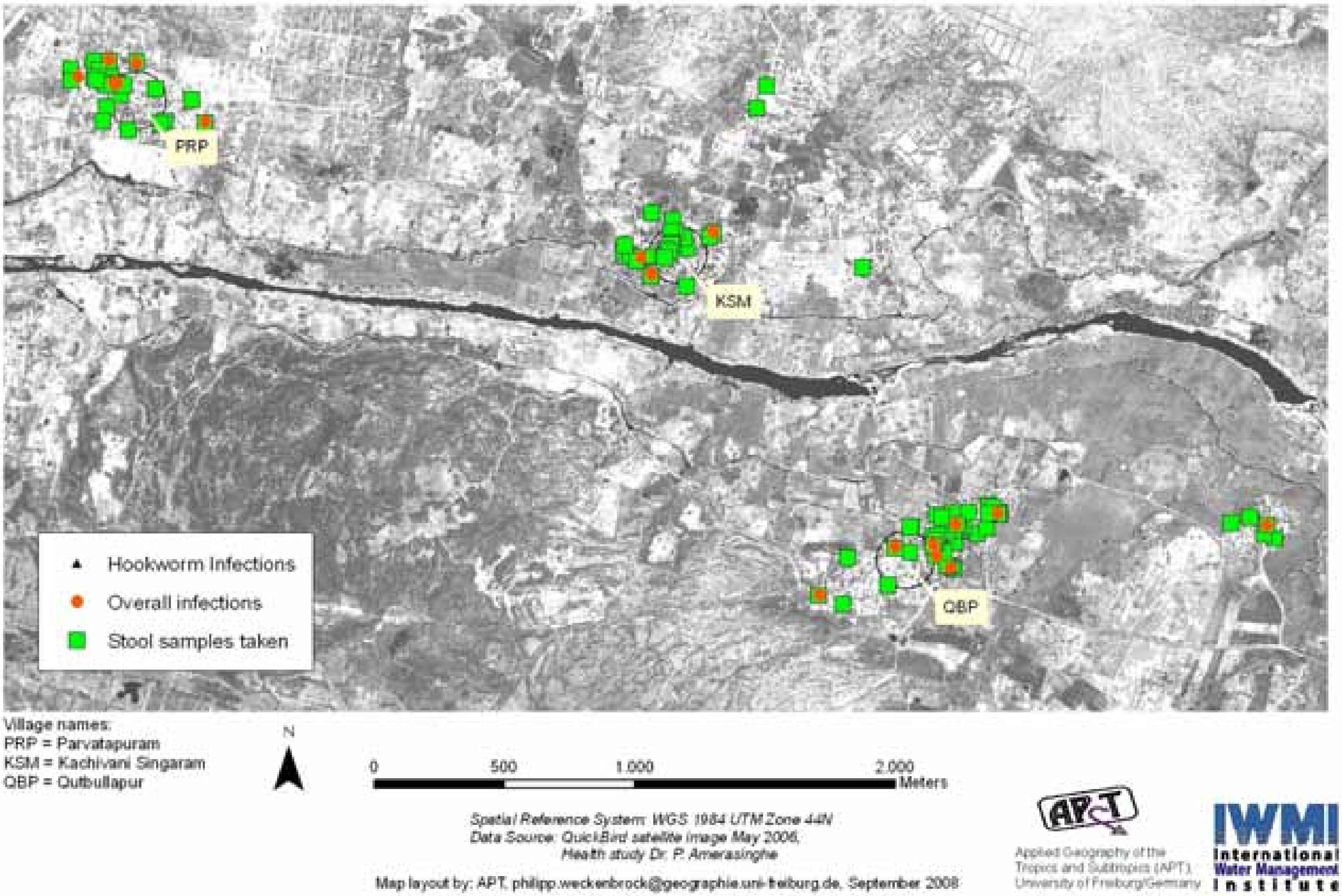
Figure 1: Parasite species prevalence

Hook worm infections were present only in the rural communities. Despite the fact that the irrigation water did not contain any worm eggs, the population was harboring infections, probably associated with poor sanitation. Potential sources of infection can be the migrant labour coming for work and practice of open defecation.

A separate cross-sectional study (n=298) on diarrhoea carried out in 2007, showed that 57.14% of the rural population engaging in Musi River related activities (n=196) complained of having suffered from an episode of diarrhoea during a two week to three month period prior to the date of interview. Nearly 33% perceived that it was associated with water. Only a few (7.1%) stated that the episode was related to food consumption. 54.5% said that they did not know the cause of the diarrhoeal episode.

In the non-farming category (n=102), 48.16% reported a diarrheal episode, and 81% felt that water was the cause of the episode. Around 4.1% perceived that it was food borne. 12% said that they were not aware of the causative agents.

Parasite infections in the Periurban Villages



24. Spinach, in contrast to Amaranthus, mint and coriander, contained microbiological contaminants above permissible levels

Based on a permissible level of <20 *E. coli* for market produce (UK standards), the *E. coli* contamination in the vegetables tested could be regarded as varied. Spinach had a higher level of contamination than others (ANOVA statistic at 95% CI, p=0.000) (Fig 1). This could be related to the type of irrigation practice, and the height of the plants. Most often, flood type of irrigation was used and in short plants like spinach, leaves can become submerged during watering.

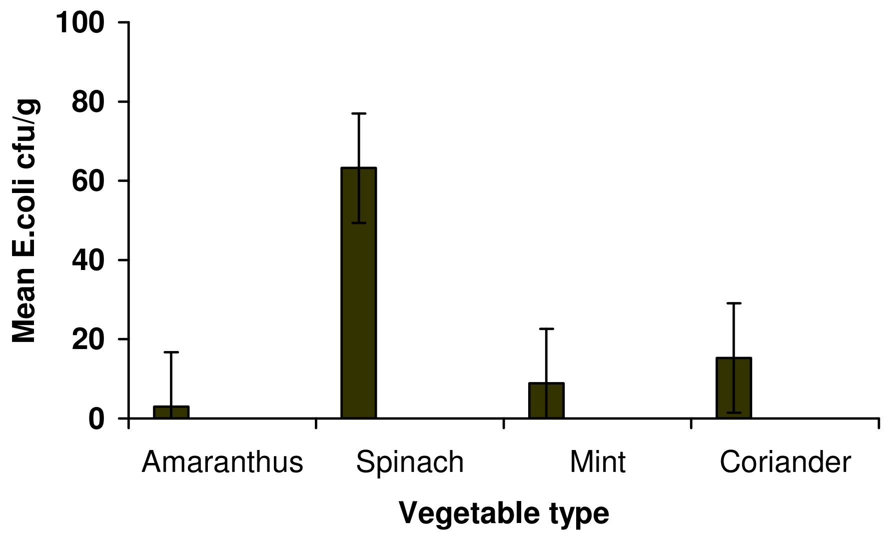
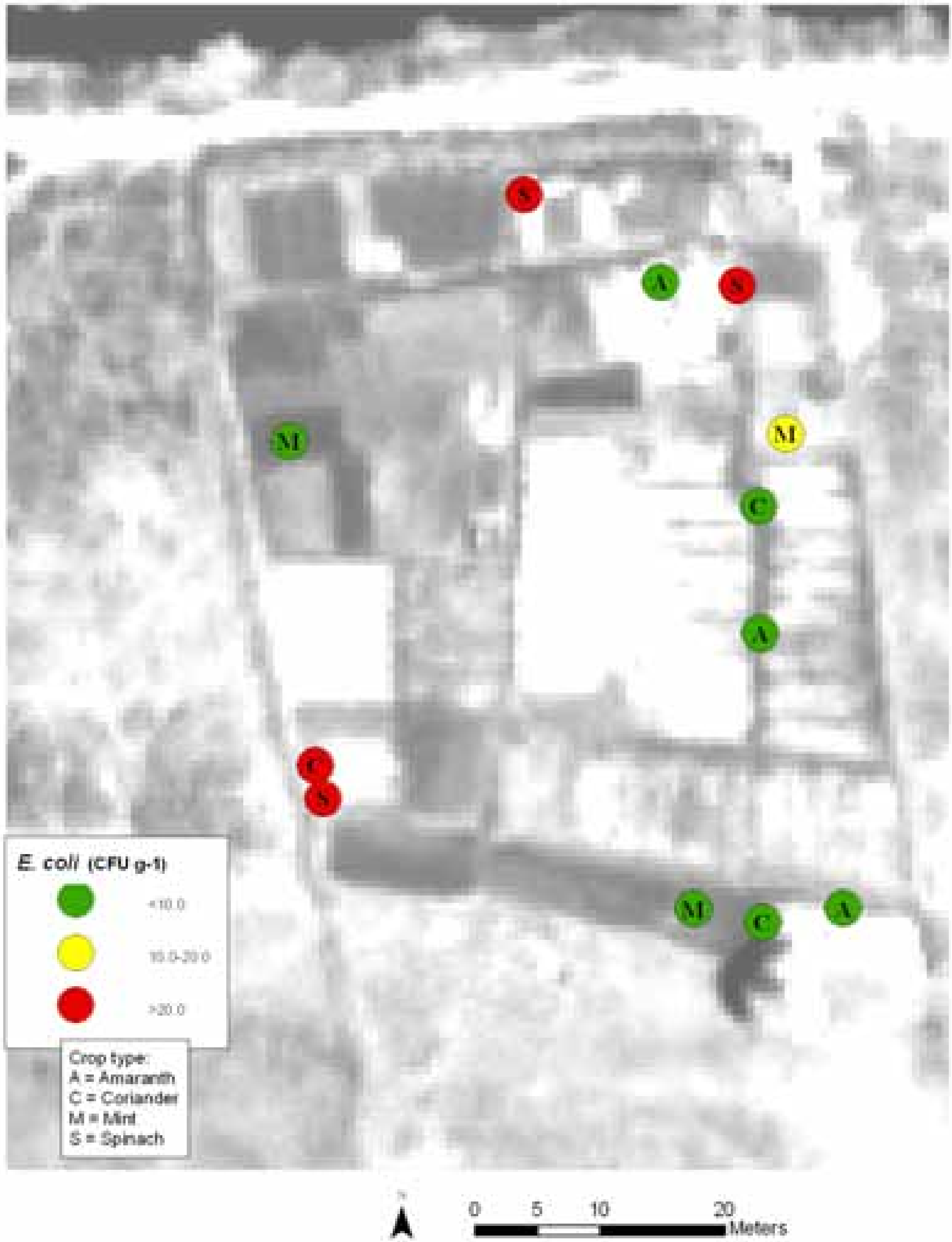


Figure 1: Mean E. coli levels in vegetables tested

Helminth ova were found at less than ≤1 ova g^{-1} posing negligible risk. Many of the leafy vegetables used for consumption are cooked which can reduce the risks associated with microbiological contaminants. Moreover, thorough washing of vegetables that are eaten raw can bring contaminants down to safe levels, as evidenced by studies carried out elsewhere. Good washing practices can thus make the vegetables safe for consumption.

Microbiological Contamination of Leafy Vegetables



Data Source:
QuickBird satellite image May 2006,
vegetable analysis by
Dr. P. Amerasinghe

Map layout by:
philipp.weckenbrock@geographie.uni-freiburg.de,
September 2008

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