Water System and Global Change (WSG) Group

Welcome to WSG

WSG is a solution-oriented multidisciplinary research group focusing on water systems and global change. We are one of the chair groups in the Environmental Sciences Group of Wageningen University & Research.

This report gives and impression of our teaching and research. It gives an overview of our courses, PhD candidates, and projects.

Our office is in the C wing of the Lumen Building. You are welcome to visit!

Our mission:
To create new knowledge to contribute to sustainable water systems in a changing global environment.

Our vision:
Sufficient, clean and climate-proof water for society and nature.

Too much, too little, too dirty:
opportunities and threats in water for society and nature
Education of the Water Systems and Global Change Group

Solution-oriented science for sustainable water system management, that is our approach. We analyse and assess the impacts of climate change and population growth on water systems and propose and test adaptation strategies. We use simulation models, earth system observations, scenario analysis and field studies and we invite students from different backgrounds, and skills and interests to take part in our courses and research.

The Water Systems and Global Change chair group offers several BSc and MSc courses and PhD Programmes. WSG master students can specialize on water systems and global change by following:

- the Adaptive Water Management in the Master International Land and Water Management and
- thesis track Water Systems and Global Change in the Environmental and Climate Change master programs.

Courses coordinated by WSG are:

- Disaster-Proof Planning and Preparedness in Water Management
- Integrated Water Management
- Climate Change Adaptation in Water Management
- Adaptation to Climate Change
- Design of Climate Change Mitigation and Adaptation Strategies
- Climate Smart Agriculture
- Modelling Future Water Stress
Research

The Water Systems and Global Change (WSG) group aims to improve the understanding of anthropogenically driven changes in water cycles in relation to interactions between climate-, water-, energy- and agricultural systems. We identify four main research lines and two cross-cutting researches (see illustration).

Main research lines:
1. Land-water-climate interactions
2. Water-food-energy nexus
3. Adaptive planning and design
4. Water pollution assessments

Cross-cutting research:
1. Future water stress
2. Climate-water services
We perform integrated assessments of water systems, in which we integrate knowledge on water systems and global change. To this end, we use a variety of models and observations. We combine modelling analyses with participatory approaches. Our water assessments focus on:

1. The effect of changing global drivers on water systems
2. Adaptation and
3. Mitigation strategies, comprising of novel approaches such as adaptive water management and ecosystem-based adaptation, and
4. Climate-water services.

We thus take an integrated approach across the water, food and energy systems at multiple spatial and temporal scales.
This theme focusses on dynamic feedbacks and interactions between water, carbon, and climate change, modelled and observed at mostly regional scales. We study the effects of climate change on natural vegetation and crops, but also the reverse i.e. the effects of large scale land use (change) on climate. Thus we aim to contribute to better exploit the potential of climate while respecting its constraints.

We use crop-, vegetation-, water models like WOFOST and LPJ to study the effects of climate change on the productivity of crops and the resilience of carbon stored in natural vegetation. We assess and improve the predictability of seasonal crop forecasts and long-term vegetation projections.

We use coupled land-atmosphere models like RAMS/WRF to study the effects of large scale irrigation and urbanization on rainfall recycling mechanisms.

Both require good knowledge on coupled evaporation – carbon exchange mechanisms in vegetation. Measurements at regional scales i.e. airborne flux measurements and remote sensing help us to improve parameterizations and scaling issues.
Water-Food-Energy Nexus

This theme focusses on analysis of how global change affects the links between the water, energy and agricultural sector. We especially address the question of how future water changes in climate and water demand affect trade-offs and synergies between water for energy, food and environment. To address these issues we develop integrated water modelling systems combined with large scale observational databases on water demand, availability and quality.

Currently we are working on how future changes in water systems affect the competition for water between the energy, agricultural and environmental sectors. In the agricultural sector, we focus mainly on irrigation water demands, and within the energy sector we focus on water for hydropower, biofuels, and cooling water needs of thermoelectric power plants. To improve trade-off analyses and assure that future water use is sustainable it is necessary to also quantify the water needs for the environment. To do this we developed an improved method for quantifying large environment flow requirements. The aim is to include this quantification in our modelling systems to improve water use analyses and to develop improved future water and land use scenarios.

The results of our modelling experiments are used to develop climate information services at different spatial scales and for a wide range of users. Our climate information services are developed in close collaboration with users and a wide range of other partners.
We analyse, assess and design strategies and plans to cope with impacts of global change. Our research covers dynamics in long term planning (adaptation turning points, adaptation pathways), innovations in coastal management (nature-based, multifunctional flood defences, building with nature), monitoring and analysis of real-life experiments (climate proofing of catchments) and development of hydro-meteorological information services.
The availability of clean water is at risk across the globe. Water pollution poses a threat to ecosystems and society. A multi-pollutant modelling approach can help to better understand and manage water quality issues.

We develop multi-pollutant models of causes, effects and solutions of future water stress, while accounting for water demand, water availability, and pollution in rivers, lakes, reservoirs and coastal seas. Many pollutants have common sources and multiple impacts. A new generation of models is needed to explicitly address the combined exposure of surface waters to multiple pollutants. Such models could serve as a basis for integrated water quantity and water quality assessments. In Wageningen, we co-develop such models, focusing on water quantity (the VIC model) and water quality (nutrients, pathogens, plastic, salinity, toxic chemicals, etcetera) (Figure 1). We develop global models, but apply them on multiple scales.

**Figure 1. Models co-developed and used for Water Pollution Assessments at WSG**

Please visit our website for details on the models ([http://www.wur.nl/en/Expertise-Services/Chair-groups/Environmental-Sciences/Water-Systems-and-Global-Change-Group/research/Water-pollution-assessments-1.htm](http://www.wur.nl/en/Expertise-Services/Chair-groups/Environmental-Sciences/Water-Systems-and-Global-Change-Group/research/Water-pollution-assessments-1.htm)).
Cross-cutting Research

Climate-water information services
We develop excellent science-based climate and water services, tailored to the needs and in interaction with users such as farmers, power companies and water managers. Several WSG PhD students contribute to this. Examples of WSG projects in which information services are key include SWICCA, EUPORIAS, WaterApps and EVOCA (see project descriptions on the last pages of this document).

Future water stress
We develop novel tools to identify and evaluate solutions for future water stress. These tools account for the demand for water by society and nature, the availability of water, and the quality of water. We study at the basin, regional, continental and global scales, in spatially explicit models. Examples of such models include VIC (hydrology) and water quality models. Please visit the WSG website for details on these models.
PhD Research Projects
Effects of climate change on the growth of Zambezi teak forests in Zambia

Research Challenges

Southern Africa:
- Rainfall has reduced and is projected to reduce by more than 10% by 21st century above the 1986-2005 baseline.
- Temperature has increased and is projected to increase by more than 3.4°C by the end of the 21st century above the 1981-2000 baseline.

Aim: To determine the potential effects of climate change on the growth of the Zambezi teak forests in Zambia

Objectives
1. To develop above and below ground biomass models
2. To evaluate carbon stocks of the Zambezi teak forests.
3. To examine the sensitivity of the Zambezi teak forests to climate change

Results and conclusions

Correlations between temperature & tree ring chronologies

- *B. Plurijuga* correlates positively with rainfall and negatively with temperature and evaporation.
- Future temperature increase, which increases evaporation, and reduces rainfall adversely affects *B. Plurijuga*.

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Hydrological functioning of Tropical Montane Cloud Forests in the Orinoco river basin

Research Challenges

The Tropical Montane Cloud Forests (TMCF) in the Orinoco River basin are unique because they are located upwind from the seasonally flooded savannas in the basin’s lowlands, in contrast to the TMCF more south on the eastern Andes located upwind from the amazon forests. However, little is known about their hydrological functioning and the impacts land-use and climate change can have on their hydrology.

Methods

We setup a data collection system: meteorological stations, rainfall, fog, throughfall and streamflow gauges, and soil moisture sensors in three neighbouring TMCF catchments with contrasting forest cover (2013-2017). We collected organic and mineral soil samples.

All these data, coupled with modelling has allowed us to better understand the hydrological functioning of these forests.

Main results and conclusions

At higher elevations (2140 masl) conditions are wetter than at the lower elevations (1840 masl) even during the dry season. Fog/rainfall persistence is crucial for dry season stream flows.

The soil organic layers have a larger water storage than the canopy, and their absence due to deforestation define the higher peak flows in the deforested catchment.

Expected longer dry seasons can cause critical low levels of soil moisture affecting TMCF survival.

Fog inputs are relatively low in contrast to other TMCF, however it plays an important regulatory role as it reduces evapotranspiration and partially fills the canopy storage increasing the amount of precipitation that reaches the ground.

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Towards a probabilistic crop yield forecasts using dynamic seasonal climate forecasts and advanced Crop modelling over East Africa

Researcher

Supervisors
Dr Ronald Hutjes
Dr Philip Omondi (ICPAC)
Prof. Rik Leemans

Research Challenges

Problem definition:
• Use of dynamical seasonal climate forecasts for prediction of impacts on crop production;
• Lack of detailed information for users at different scales;
• Lack of detailed regional impact model.

The main objective:
• to improve model prediction of impacts of future seasonal climate conditions on agriculture at seasonal time scales.

Main results and conclusions

Different cropping seasons from climate and crop production forecasts (1981-2010):
• Prediction in meteorology: better for temperature than for rain and radiation;
• Fair prediction for maize yields a few months (at least 2-months) before start of season (e.g., Fig.1);
• Prediction varies with forecast lead time and region.

Percentage grid cells of good & significant prediction shown as a function of planting dates. METRIC: - Relative operating curve skill score (ROCSS). Dashed line show score obtainable by chance at 95% significance level.

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Climate effects of land restoration in Africa

Research Challenges

Land degradation leads to deterioration of ecosystem services provided by vegetation, soil and water in affected areas. Especially in semi-arid areas, land degradation interacts with climate change, each reinforcing the other. Livelihoods of people living in degraded areas, and downstream – hydrologically and meteorologically, are negatively affected.

Land restoration tries to remedy such adverse effects, sometimes explicitly aiming at climate restoration too. Potentially positive climate effects of re-greening, have been little quantified. It is not clear if negative climate effects following degradation are reversible upon restoration. Boundary conditions for climate restoration need identification.

Methods

- Make an inventory of existing re-greening projects around the world and in Africa in particular, with the aim to construct a chrono-sequence.
- Use satellite data to analyse observed hydro-climatic effects of re-greening as a function of project scale and – maturity, and physiography of the region.
- Use mesoscale atmospheric models to identify causal processes in the soil-vegetation-atmosphere continuum responsible for the observed effects or the lack thereof; analyse synergies and trade-offs between small and large hydrological cycle.

Expected results and conclusions

Quantify actual and potential climatic effects of re-greening in and downstream of restoration project areas as a function of modified (improved) land surface characteristics. Identify design rules for land restoration projects that maximize the chance of positive climatic effects.

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**Impacts of Climate Change on Coastal Ecosystems of Bangladesh**

**Research Challenges**

Challenge:
The methodology adopted is pioneering for climate change impact study on an ecosystem focussing the relationship and dependency of its components with one another.

Objectives:
Recent environmental changes in south-west coastal region of Bangladesh;
Impacts of salinity increase on Sundarbans mangrove and coastal people;
Develop adaptation pathway for salinity risk reduction in south-west of Bangladesh.

**Main results and conclusions**

Salinity increase is driven by a range of processes i.e., rising temperature, daily precipitation intensity index, reduced upstream flow and sea-level rise.

Further changes in salinity gradient will favour a shift in mangrove composition towards more salt tolerant species with reduced biodiversity.

Crop agriculture, Sundarbans mangrove and drinking water sources and health are the mostly affected coastal systems by salinity increase.

**Methods**

- Recent Environmental Changes
- Collection of observation data of five different hydro-climatic variables to analyse anomalies, trends, monthly, seasonal and decadal variation, Extreme climatic indices and cause-effect relationship among the variables.
- Quantitative vegetation survey using standard quadrat method along three major salinity transects by combining systematic and stratified sampling approach to develop importance value index and diversity indices of mangroves along the salinity gradients.
- Impacts on Sundarbans mangrove
- Households level survey to identify the observed causes of salinity increase, mostly affected coastal systems and communities, ways of being affected
- Impacts on coastal communities
- Questionnaire survey for both coastal community and resource persons to identify the potential measures, for multi-criteria analysis and to develop pathway map
- Adaptation Pathway

**Trends of different hydro-climatic**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Trend</th>
<th>Time Series</th>
<th>Years</th>
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<tbody>
<tr>
<td>Maximum temperature</td>
<td>+0.03°C/yr</td>
<td>1983-2050</td>
<td>30</td>
</tr>
<tr>
<td>Minimum temperature</td>
<td>+0.02°C/yr</td>
<td>1981-2050</td>
<td>30</td>
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<tr>
<td>Precipitation</td>
<td>6.555 mm/yr</td>
<td>1984-2050</td>
<td>30</td>
</tr>
<tr>
<td>Effective Sea level rise</td>
<td>+10.3 mm/yr</td>
<td>1983-2050</td>
<td>30</td>
</tr>
<tr>
<td>Salinity (high tide)</td>
<td>+0.4 ppt/yr</td>
<td>2000-2008</td>
<td>9</td>
</tr>
<tr>
<td>Salinity (low tide)</td>
<td>+0.5 ppt/yr</td>
<td>2000-2008</td>
<td>9</td>
</tr>
<tr>
<td>Fresh water discharge</td>
<td>4189.5 cubic yd</td>
<td>1976-2050</td>
<td>35</td>
</tr>
</tbody>
</table>

**Diversity Indices for three different salinity**

<table>
<thead>
<tr>
<th>Indices</th>
<th>Transect 1</th>
<th>Transect 2</th>
<th>Transect 3</th>
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<tbody>
<tr>
<td>Species richness (S)</td>
<td>12</td>
<td>10</td>
<td>7</td>
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<tr>
<td>Shannon-Wiener Diversity (H')</td>
<td>1.775</td>
<td>1.807</td>
<td>1.865</td>
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<tr>
<td>Simpson's Equability (E)</td>
<td>0.274</td>
<td>0.295</td>
<td>0.296</td>
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<tr>
<td>Simpson's Diversity (D)</td>
<td>4.333</td>
<td>5.333</td>
<td>3.230</td>
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<tr>
<td>Simpson's Equability (J)</td>
<td>0.363</td>
<td>0.395</td>
<td>0.324</td>
</tr>
</tbody>
</table>

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Living in Future: How much water do we really need?

Research Challenges

Objective:
Obtain better understanding of the sectorial water use development, and to identify the driving forces and associated uncertainties in water use under future changing climate and socio-economic development at the regional scale, with the Pearl River Basin (PRB) as a case study.

Main results and conclusions

The Pearl River Delta stabilized total water use, regardless its rapid socio-economic development. Salt-intrusion induced water shortage could be alleviated by water use management.

Downscale procedure is needed before using the globally developed scenarios for regional assessment. Water conflicts exist between different water users in the PRB under future climate change and socio-economic development.

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Multifunctional use of flood defences

**Research Challenges**

Flood defences have the potential to be integrated with many other function (e.g. nature, recreation, transport, housing etc.). Adding some functions can increase the risk of flooding of a primary flood defence whereas other functions (e.g. natural foreshores) can provide synergies to decrease flood risk. The objective is to gain more insight in the effects of the multifunctional use of flood defences on flood risk using the new probabilistic risk standards recently adopted in the Netherlands.

**Methods**

- Defining limit states for additional functions on dikes
- Calculating how multifunctional dike elements affect the probability of failure
- Calculating the probability a multifunctional dike cannot fulfil its secondary functions
- Apply these insights to case studies of multifunctional dikes in the north of the Netherlands

**Results and conclusions**

The means to objectively compare new dike concepts is lacking within the new risk standards. As a result, innovative multifunctional options are only occasionally implemented. This research will bridge this gap to allow for implementation of suitable multifunctional dike concepts by contributing to a comparative framework for multifunctional dikes.

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Research Challenges

Ecosystem-based Adaptation (EbA) is a novel approach that helps society adapt to climate change through conserving, restoring and creating ecosystem services. Uncertainty about the long-term effects of EbA measures, challenges both public and private actors. For adaptation to become successful we need to better understand entrepreneurial strategies to create and exploit opportunities and condition for success.

Methods

We conduct in-depth case studies using interviews and observations of entrepreneurs and document analysis. To overcome the limitation of having only qualitative analysis of a small set of case studies (making generalisation difficult) we apply Qualitative Comparative Analysis. This method uses formalised ranking rules to identify necessary and sufficient conditions for a certain outcome, in our research the opportunity creation process in EbA.

Results and conclusions

Entrepreneurial strategies for opportunity creation in EbA are analysed. Conditions for successful creation of new goods, services and new governance arrangements are ranked in terms of necessity.

Further, the process of shaping these conditions in a multi-party innovation project setting is analysed.

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Combined effects of climate change and human activities on water resources allocation of the Pearl River basin, China

Research Challenges

Problem definition:
1. How does climate change affect water resources in the Pearl River basin?
2. How to develop robust water allocation plans for the basin?

Main objective:
To identify and assess robust water allocation plans for the basin to reduce water scarcity and limit salt water intrusion in deltas.

Main results and conclusions

1. Climate change is likely to impact future flows of the Pearl River. Dry seasons are projected to become drier throughout the basin.
2. A Robust Assessment Model for Water Allocation was developed to support decision making about water release of different key reservoirs under future climate change.
3. Robust decision making using carefully selected MOEAs can help limit water shortages and salt intrusion in the Pearl River Delta.

Methods

Robustness assessment of water allocation plans under climate change uncertainties during the period of 2079-2084. Panel (a) and (b) show two different robust measures: regret (a) and satisficing (b). Panel (c) shows the selected robust water allocation plans.

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Sustainability challenges and adaptation options in future drinking water extraction

Research Challenges

Drinking water companies need to decide on adaptation options to secure drinking water supply for the future. This requires balancing between the current drinking water extraction and future developments such as climate change. Before deciding on adaptation measures, all sustainability challenges for a local drinking water extraction facility need to be identified. This requires knowledge of the socio-economic, physical and technical subsystem as well of the future developments in these subsystems.

Results and conclusions

Sustainable drinking water extraction reaches further than just meeting the water demand. Adaptation options on extraction facilities therefore need to focus on a broader perspective. Future research includes elaboration of the integrated systems approach of the drinking water supply system into method to assess the sustainability of drinking water extraction facilities, that will help to identify sustainability challenges and adaptation options. A Veluwe case study clearly demonstrated the significant long-term impact of climate change on relocation of groundwater extractions.

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The role of climate research in Dutch Water Management

Research Challenges
The objective is to explore how scientific knowledge about climate change is used and how uncertainties are typified between scientists, policy makers and water users in Dutch Water management in the period 2000-2014.

This research question has been studied at national (Delta programme), regional (Southwest Netherlands) and at farm level (3 pilots) and can be qualified as a nested case study (Flyvbjerg, 2006) and within this PhD thesis presented as a temporal analogue (2000-2014).

Methods

Results and conclusions
The usability of climate research for Dutch water management could be further enhanced by working in interdisciplinary teams during policy formulation in which fact checkers, knowledge de-constructivists and knowledge constructors are equally represented. Many knowledge qualification methods and uncertainty assessment frameworks are all useful and valuable. We recommend defining relevant categories of uncertainty in a collaborative way between climate research and knowledge users in water management, before commissioning research, prioritizing research themes or starting a policy process.


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Assessing spatial and temporal impact and adaptation strategies of climate and land use changes on water supply and demand in the Mara River Basin, Kenya

Research Challenges

Problem definition;
- The Mara River Basin (MRB) is experiencing an increasing gap between water supply and demand.
- Limited knowledge exists on the combined spatial and temporal effect of climate and land use change on water supply and demand in MRB.

The main objective;
- to assess climate and land use change impacts and adaptation strategies to water supply and demand in MRB.

Methods

Integration of SWAT model and Multi criteria analysis to identify water management options.

Expected results and conclusions

- A review of current water supply and demand gaps in the Mara River Basin.
- Analysis of the impacts of climate change on water demand and supply in the Mara River Basin.

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Future Irrigation Water Requirements in the Northwest Zone of Bangladesh: Developing Scenarios and Analysing Adaptation Strategies

Research Challenges

Main objectives:
- To identify recent trends of water requirements of main dry season crop.
- To develop future scenarios of water requirements of main dry season crop.
- To identify and rank adaptation strategies for North-West Bangladesh.
- To develop possible adaptation pathways for North-West Bangladesh.

Expected results and conclusions

- Declined recent trends of crop water requirement (CWR) instead of an increase in temperature because of changes in humidity, wind-speed and sun-shine hours.
- Results indicate a reduction in future CWR also, mainly because of shortening growing days of Boro rice.
- Variable changes in future irrigation requirement because of variable rainfall in different models.
- Adaptation strategies for North-West Bangladesh will be identified and ranked.

Methods

Expected results and conclusions

- Declined recent trends of crop water requirement (CWR) instead of an increase in temperature because of changes in humidity, wind-speed and sun-shine hours.
- Results indicate a reduction in future CWR also, mainly because of shortening growing days of Boro rice.
- Variable changes in future irrigation requirement because of variable rainfall in different models.
- Adaptation strategies for North-West Bangladesh will be identified and ranked.

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Preserving the World Second Largest Hypersaline Lake under Future Irrigation and Climate Change

Research Challenges

- Urmia Lake desiccation is on the verge of triggering a socio-environmental disaster.
- The new official policy aims to increase inflow by cutting of irrigation water use substantially.
- It is still unclear if the water use reduction plan, which is about to start and has large socio-economic impacts, is able to restore and preserve the lake under future climate change.

Main results and conclusions

Methods

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The Mekong’s future flows: Quantifying hydrological changes and developing adaptation options

Research Challenges

- The international Mekong River faces critical challenges caused by climate change and rapid socioeconomic developments.
- Prevalent uncertainties exist in the future hydrological changes & associated risks.
- Anticipatory adaptation to hydro changes requires effective measures & strategies

Research objectives

1. To quantify future hydrological changes in the Mekong basin;
2. To develop measures and strategies to adapt to the projected hydrological changes.

Main results and conclusions

1. The future flow regime shows substantial changes, characterized by (1) altered annual & seasonal flow dynamics and (2) changes in extremes (i.e. increasing floods & higher dry season flows)
2. Hydrological changes are largely driven by impact interactions of climate change and human developments. This motivates active flow regime management through cross-sectoral water use optimisation.
3. Increasing flood risks in the Mekong Delta can be managed through combining (1) optimised & innovative flood control infrastructures with (2) improved governance and institutional capacities.

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Mobile No.: +31 62 246 2599
Tailor-made Water Information Services for Sustainable Food Production in Peri-Urban Delta in Bangladesh

Research Challenges

**Problem statement:** Water for agriculture is vital to safeguard sustainable food production. Due to urbanization and climate change, water availability (too much, too little and too early or late) is becoming erratic and farmers cannot rely on their existing knowledge to plan farming practices.

**Key objective:** This research aims to develop tailor made water information services with and for farmers in the peri-urban Ganges Delta in Khulna, Bangladesh.

Methods

An integrated socio-technical method will be applied for this research by 1) combining mobile information technology like apps; 2) integrating weather model results with observation of groundwater trends and river flows; and 3) adjusting knowledge about adaptive decision making and enabling governance structures to local situations.

Expected results and conclusions

Improved understanding of
1) Co-production of water information system with and for farmers.
2) Peri-urban farmers empowerment and livelihoods in Bangladesh Delta.
3) Capacity of small/medium farmers for sustainable food production in Bangladesh Delta.

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How to sustain water for food and ecosystems under global change?

Research Challenges

1. Design a global method for calculating water requirement for ecosystems known as: “Environmental Flow Requirements (EFRs)” at global scale
2. Estimate Environmental flow deficit
3. Estimate impact of implementation of EFRs on food security
4. Calculate trade-offs between land use, water use and trade to satisfy both ecosystems and food

Main results and conclusions

1. We identified hot-spots with high water stress for freshwater ecosystems and potential high risk of food insecurity in Asia and Mediterranean areas.
2. By 2050, under global change, we need to increase by 15% international trade, reduce water use by 50% and expand agricultural cropland by 20% to safeguard water for food and ecosystems.

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Hydro-climatic Services for Improving Rice Farm Management Decisions in Ghana Using Seasonal Climate Forecast

Research Challenges

- Over reliance on unpredictable rainfall affects rice farm management decisions of farmers and irrigation water managers in Ghana.
- Seasonal climate forecasts (SCF) have potential to insulate African farmers from climate shocks.
- SCF have no inherent value, unless it influences decision and impact on systems under consideration.
- To avoid one directional approach of science, to produce end-users access, we use citizen science to co-produce the hydroclimatic-EVOCA with farmers.

Main Objective
To assess the potential of making seasonal climate forecast information actionable for rice farmers in northern Ghana

Expected results and conclusions
1. Hydroclimatic informational needs of rice farmers and the skills of ECMWF-S4 in meeting them.
2. The indigenous knowledge and mechanisms used by farmers in making local rainfall and yield predictions.
3. Predictability of seasonal water availability using seasonal climate forecast (ECMWF-S4)

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Hydrological Response of the High-Altitude Indus Basin to Climate Change

Research Challenges

Problem definition:
- Largely an underexplored basin due to:
  - inadequate climate monitoring network
  - measurement errors in observed data
  - Substantial errors in global/regional scale gridded climate datasets, particularly in precipitation products
  - Large uncertainty of hydro-climatic predictability

Main objective:
- Analyse climate change and its hydrological implications

Results and conclusions:
- Gridded precipitation products often underestimate precipitation in the study area, but reanalysis products are relatively better.
- The corrections significantly improved the quantitative and spatiotemporal distribution of precipitation
- The contribution of net glacier mass balance to river flows is only marginal.
- The corrected Pr and T climatologies are used to develop a reference dataset which will be used to analyse climate change and its hydrological implications for the future.

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Supervisors
Prof. Pavel Kabat
Prof. Eddy Moors
Prof. Fulco Ludwig

Researcher
Zakir Hussain Dahri
(2012 – 2017)
Impact Assessment of future climate change on the streamflow of the lower Ganges basin

Research Challenges

Problem Statement:
- Vulnerable to climate change and upstream water diversion.
- Wide seasonal variations in precipitation.
- Reduced flow in the dry season.

The main Objective:
Assessment of future water availability based on combined impact of climate change and anthropogenic interventions through hydrological model development and scenario analysis.

Methods

Expected results and conclusions

- Calibrated and validated hydrological model for Ganges basin.
- Future estimate of hydrological components – streamflow, water yield, ET, GW recharge.
- A robust hydrological scenario using four-quadrant matrix approach.
- Strategical revision to cope with future water diversion issues.

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Research Challenges
Changes in climate, demography and lifestyles increase imbalances between water availability and water needs for agriculture, energy, manufacturing, livestock, households and ecosystems. Resulting water scarcity increases competition for water resources between different sectors and nations.

Assessing future water-scarcity impacts worldwide requires quantifying the consequences of such trends.

Methods
An integrated water-assessment framework will be developed. This framework consists of models for hydrology, crop cultivation, electricity production, sectoral water demands and allocation.

Results and conclusions
The integrated water-assessment framework will produce water-scarcity maps and identify trade-offs and synergies within the water-food-energy nexus for different scenarios up to 2050, which help to develop better water management strategies.

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**Research Challenges**

**Problems**
- Freshwater ecosystem degradation
- Water shortage
- Lack of insight into the dynamics of seasonal nutrients output to freshwater systems

**Methods**

An integrated and quantitative assessment tool for management options to reduce nutrients loadings in surface water will be developed based on three complementary models: NUFER, MARINA and PC Lake.

**Research objectives**

The main objectives of this research are to improve our understanding (1) effect of nutrient pollution on water quality and water availability in the Hai He basin, and (2) of possibilities to reduce this pollution.

**Expected results**

Assessment of:
1. Nutrient inputs by season and by source to the Guan Ting reservoir
2. Nutrient inputs to the large lakes and reservoirs and the effects of nutrient pollution on water availability in the Hai He Basin
3. How nutrient inputs affect the large lakes and reservoirs of the Hai He Basin
4. Combinations of technical measures and structural changes in agriculture in the Hai He basin to reduce the impact of nutrient inputs to rivers, lakes and reservoirs

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Nutrient Use Efficiencies of Food Production and Water Pollution in China

**Researcher**
Mengru Wang
(2014-2018)

**Supervisors**
Prof. Carolien Kroeze
Prof. Lin Ma

**Motivation**

Nutrient use efficiencies of nitrogen (N) and phosphorus (P) are low in China. This has led to large N and P losses to aquatic systems, causing eutrophication in Chinese rivers and seas.

The **objective** is to explore nutrient management options to improve N and P use efficiencies of food production, and to reduce water pollution in China.

**Research Challenges**

- Model inputs
- Spatial scales
- Calibration and validation
- Region specific scenarios

**Methods**

Integrated modelling

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Reducing point source inputs of nutrients to rivers and their impact on ecosystems and society in China

Problem definition

- Point sources are major sources of water pollution in China; few studies explicitly consider manure as point source inputs to rivers.
- The linkages between water pollution and water scarcity are not well understood.
- Interpreting model results at biophysical scales at administrative scales is a challenge.

Methods

(A) Model development (B) Theoretical framework of multi-scale modelling.

Expected results

(1) An updated database for point sources inputs to waters in China
(2) An integrated model to assess the impacts on both water quality and water quantity in China
(3) Indicators for water quality and clean water availability
(4) Effectiveness of management options for point sources in related to local characteristics
(5) Scenario analysis based on latest climate and socio-economic scenarios.

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Supervisors
Prof. Carolien Kroeze
Prof. Lin Ma
Dr Michelle van Vliet
Dr Maryna Strokal

Researcher
Chen Xi (Coco)
(2016-2020)
Sustainable Pathways in Food Production Chain in North China Plain

Research Challenges

We will explore sustainable pathways for food production in the North China Plain by applying linked models to assess the water quality in terms of eutrophication and nutrient use efficiencies in food production chains.

Methods

I will use a back-casting method and the linked MARINA-NUFER model.

Research Framework

Expected results

First step: Critical levels of N and P for coastal eutrophication. (eg. Fig. 2)
Second step: Assessment of technologies and strategies to reduce river export of nutrients.
Third step: Sustainable pathways.

Critical levels of P for coastal eutrophication for Yellow, Huai and Hai rivers in 2050

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Modelling the environmental impact of nutrients on lakes in Yunnan

Research Challenges

1) The eutrophication problem of the lakes in Yunnan province has become one of the major environmental issue that restrict local economic and social development.

2) Lakes in Yunnan province have smaller environmental capacity than coastal seas, so it is easier to suffer from eutrophication.

3) Detailed spatial information and long-term data for the lakes in Yunnan province is absent.

Methods

1. Apply MARINA model and PCLake model
2. Upscale the model for lake DIanchi to the other 8 large lakes
3. Scenario analysis to explore alternative future trends

Expected results and conclusions

Assessment of:

1. N and P inputs to lake Dianchi, and the impact of nutrients on water quality in lake Dianci
2. past and future N and P inputs to all nine large lakes in Yunnan
3. past and future water quality in other large lakes in Yunnan
4. sources and possible solutions for future eutrophication in the lakes of Yunnan

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Seasonal nitrogen flows in agriculture and their effects on water quality in the Yangtze River basin, China

Research Challenges

1. Maintaining food security with low environmental impacts on water quality in the Yangtze River basin is challenging in the coming years;

2. The contribution of different crop systems to water pollution is not well studied for the Yangtze River basin;

3. The effect of seasonality on nutrient export by the Yangtze River is still not well understood.

Expected results and conclusions

1. Diffuse sources will be improved for the Yangtze River basin in the MARINA model (Model to Assess River Inputs of Nutrients to seAs in China);

2. The critical nitrogen inputs to the Yangtze River will be quantified with back-casting methods and the improved version of the MARINA model;

3. Sustainable pathways for water management will be explored.

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Other Research Projects
EUPORIAS
Seasonal forecasts of agricultural and hydrological impacts

Researchers
Dr Iwan Supit
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Dr Ronald Hutjes

Research Challenges
Develop climate services based on seasonal forecasts for agriculture and water management. Successful climate services are salient, credible and legitimate. We assessed the potential credibility, i.e. predictability of crop yields and river discharge, as well as the sources and propagation of skill through the dynamic modelling chain.

Methods
Seasonal climate hindcasts were analysed for (sources of ) skill in Europe and East Africa. Then these were used to force a suite of hydrology and crop models of varying complexity (VIC, LPJmL and WOFOST). EPS type of experiments were performed to identify sources of skill.

Here we focus on hydrological skill in Europe. (For agricultural skill in East Africa, see page by Geoffrey Ogutu)

Main results and conclusions
Hydrological forecasts are skillful in large parts of Europe at least 3 months ahead. Skill is derived more from initial conditions than from meteorological forecast quality.

Publications:
Greuell et al., 2016. Seasonal streamflow forecasts for Europe – I. Hindcast verification with pseudo- and real observations. HESS-D
Greuell et al., 2016. Seasonal streamflow forecasts for Europe – II. Explanation of the skill. HESS-D
Ogutu et al., 2016. Probabilistic maize yield prediction over East Africa using dynamic ensemble seasonal climate forecasts. AFM
Ogutu et al., 2016. Skill of ECMWF System-4 ensemble seasonal climate forecasts for East Africa. IJC

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GHG-Manage
Managing and reporting of greenhouse gas emissions and carbon sequestration in different landscape mosaics

Research Challenges
The Paris agreement to significantly reduce GHG emissions emphasised the urgency of accurately quantifying GHG sources and sinks, as well as identifying new mitigation options. Management and land conversion in forests, croplands and grazing lands affect sources and sinks of carbon dioxide, methane and nitrous oxide. Current knowledge on the impact of land-use on GHG exchange refers largely to homogeneous landscapes. The challenge is to quantify the GHG balance of typical farmed landscapes, comprising a mosaic of different elements, and to provide optimal combinations of land use that have a minimum impact on the GHG budget.

Methods
We will work along the following approaches:
- Develop and use relatively simple measurement devices to monitor C-balance of landscape and farm elements.
- Use airborne observations to assess carbon dioxide exchange in complex, heterogeneous landscapes.
- Develop simple ‘discounting rules’ allowing the compensate farm emissions by C-sequestration within the same landscape.

Expected results and conclusions
Agricultural landscapes sustain food systems and any GHG mitigation benefits need to be targeted by the food production sector. Many farmers working for a range of multinational companies and organizations use the Cool Farm Tool (CFT), an on-farm GHG emission and mitigation activity calculator. We will improve the CFT, particularly its ability to assess the GHG mitigation of heterogeneous landscapes, in view of currently adopted commitments to combat climate change.

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AMAZON-FACE - impact of future elevated CO2 on the forests of Amazonia

Consortium lead: Prof. David Lapola, Universidade de Campinas, SP, Brazil
Wageningen contact: Dr Bart Kruijt
Start 2015; end undefined

Research Challenges

Amazon-FACE is a large and long-term initiative to study the direct impact of future elevated CO2 concentrations on the forests of Amazonia. The overarching question is whether increasing CO2 concentrations will stimulate biomass growth and water use efficiency, or at least increase forest resilience against other detrimental effects of climate change, as a result of its stimulating effects on photosynthesis and water use efficiency.

Methods

The experiment, located in an undisturbed forest reserve north of the city of Manaus (Amazonas state, Brazil), consists of a total of four replicate planned plot pairs of 30 m diameter where CO2 will be artificially elevated by 200 ppm above ambient. The forest, trees, and soils, and their dynamic physiology will be monitored and modelled in detail during the experiment. After installation, fumigation and the experiment is planned to last for about 10 years.

Results and conclusions

The most important scientific challenge is to determine the degree to which the poor soils, particularly extremely low phosphorus, will limit such stimulating effects. Whether or not the forests of Amazonia will suffer under climate change is crucial for the future of Amazonian society, South-American rainfall regimes and global climate.

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**CLIMAX**
Climate Services through knowledge co-production: a Euro - South American initiative for strengthening societal adaptation response to extreme events

**Research Challenges**
Climate variability patterns linking Amazonia, with south-eastern South America, influence climate extremes that impact a.o. agricultural production and hydropower. We need to better understand regional climate variability:
1) the combined role of remote and local drivers on South America climate variability
2) the predictability of regional climate patterns
3) extent prediction beyond climate to impacts on agriculture and hydrology
4) how climate data are used by various stakeholders in their socio-cultural contexts;
5) to analyse communication conditions of knowledge co-production

**Methods**
We will use (combined) hydrology crop models like VIC, LPJmL and WOFOST to assess the predictability of anomalous crop production and hydropower generation, as well as the causes of absence or presence of predictive skill in various parts of the modelling chain.

We will engage in stakeholder interactions in order to tailor forecast products to the needs of potential users, in order to maximise the uptake of climate services in the decision making process.

**Expected results and conclusions**
Innovative technologies will be co-developed to produce products and tools for the SSA-RCC, agriculture and hydropower sectors. The project will be implemented in the context of the southern South America Regional Climate Centre, and will include actors from the national meteorological services, agriculture and energy stakeholders organizations.

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Glorious-
Copernicus Climate Change Service –
Global impacts

Research Challenges

Future climate change will have a major impact on different sectors around the globe. Currently lots of information, data and model output is available on future climate change and potential impacts. This information however is difficult to access for organisations who are planning or implementing adaptation plans. The aim of the Glorious project is to improve user uptake of relevant and high-impact climate information world-wide, addressing sectors such as water, health, transport, biodiversity and agriculture.

Methods

The Glorious project will develop key indicators on climate change drivers and impacts at the global scale. The aim of these indicators will be to support climate adaptation world-wide. Together with 8 champion users operating globally and 12 regional or local users from across the globe the project will develop showcases on all continents for inspiration and provide data with guidance in best practices for climate-change adaptation.

Expected results and conclusions

- Easy access and user guidance on scientific data and climate-change impacts.
- Tailoring of information based on user requests and co-design with climate experts.
- Maps, graphs and downloads of readily available climate impact indicators world-wide.
- Showcases from site-specific indicator production, merging global data with local data/tools.

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Waterapps: Water information services for sustainable food production in peri-urban delta areas in Ghana & Bangladesh.

Waterapps team: A multidisciplinary team with researchers from WSG and PAP groups, 3 PhD students, in collaboration with various partners from the Dutch private sectors, universities and organisations in Ghana and Bangladesh.

Research Challenges

Due to urbanisation and climate change in deltas, water availability is becoming erratic, affecting farming practices. Despite increasingly available forecast data and rapid IT developments, farmers do not have access to timely & reliable forecast information.

Objective: To develop tailor made water information services with and for farmers in peri-urban areas in Accra, Ghana and Khulna, Bangladesh to improve water and food security.

Methods

This interdisciplinary research will implement three interlinked steps during 2016-2020.

1) Combine mobile information technology (e.g. apps) and insights on knowledge sharing;

2) Integrate weather model results with observations of relevant hydro-climatic parameters;

3) Attune knowledge about adaptive decision making and enabling governance structures to local situations. These insights will be used to co-create and test water information services.

Expected results and conclusions

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Responsible life-science innovations for development in the digital age: EVOCA

EVOCA (Environmental Virtual Observatories For Connective Action) focuses on knowledge sharing platforms and their potential to transform development in five case study areas in rural Africa. Timely information on relevant environmental dynamics holds promise to overcome rural development challenges, for example in agriculture. Central research question: How can life-science knowledge, digital technologies and responsible innovation concepts be leveraged to address the pressing development challenges in crop, water, health and wildlife management?

WSG and PAP lead a case on climate, water and food; harmonising scientific and indigenous local knowledge systems to provide actionable hydro-climatic information that helps farmers adapt.

Expected results and conclusions

- Participatory virtual platforms & digital applications for resource management in African rural communities; Lessons on how digital applications depend on and/or change innovation and research for development (R4D) systems.
- A participatory developed hydro-climatic information service and platform for adaptive decision making in rice farming systems in Ghana.
- 11 PhDs, of which 2 co-supervised by WSG.

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The introduction of new flood risk standards in the Netherlands leads to a complex task to assess all flood defence and to reinforce dike sections that do not meet these new standards. There are still many uncertainties (a.o. related to the impact of climate change), which results in a need for more knowledge and innovation. Furthermore, the involvement of a broad range of stakeholders forms a challenge. All-Risk is expected to result in major savings in public expenditures, as future dike reinforcements can be more cost-effective than in the traditional, often conservative, approach.

This project will focus on different representative cases (e.g. the Dutch Wadden Sea coast, and in particular on the innovative Parallel defence concept in Delfzijl and on the Wide green dike along the Dollard – eastern Wadden Sea). Attention will be paid to all different functions in the foreshore, the dike zone, as well as at the landward side of the dike zone.

All-Risk participants:
- Delft University of Technology (program leader)
- Wageningen University
- NIOZ & RU Groningen
- UNESCO-IHE Delft
- University of Twente
- Utrecht University
- Radboud University Nijmegen:

Users:
- Companies
- Knowledge Institutes and International academic partners
- Water boards, RWS, NGO’s, Provinces

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In this Copernicus Climate Change Service (C3S) project we co-design climate services together with especially consultant companies active in the water sector.

In contrast current services we aim to provide hydrological indicators directly, instead of climate indicators only. We provide changes in management relevant flow characteristics for various climate scenarios and in the near future also for seasonal forecast.

We derived changes in future, user requested flow characteristics based on a set of multiple hydrological models driven by multiple (bias corrected) climate models for multiple emission scenarios. Both ensemble average changes, as well as changes predicted by single model combinations are produced, providing clear indication on the robustness of the projections.

Maps, graphs and data downloads, are accompanied by extensive guidance on interpretations on do’s and don’ts.

Thus we significantly ease the burden on hydro-climatic knowledge purveyors, for complicated modelling and data processing workflows, enabling them to focus more on the facilitation of decision making and local climate adaptation for their clients.

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See: http://swicca.climate.copernicus.eu/
Evidence-Based Guiding Principles for Developing Adaptation Pathways to Inform Adaptation Policy and Practice in Africa and Asia

CARIAA Adaptation Pathways team: this project brings together a dedicated team of researchers and strategic partners from four consortia supported by the Collaborative Adaptation Research Initiative in Africa and Asia (CARIAA) Programme (cariaa.net).

Research Challenges

In the context of climate change adaptation, adaptation pathways are proposed as a promising decision-focused approach.

Adaptation pathways sequence measures over time and allow for progressive implementation depending on how the future unfolds. Potentials are the ability to account for uncertainty, to identify ‘no or low regrets’ interventions, and to avoid lock-in, threshold effects and mal-adaptation.

The CARIAA consortia, as well as other research groups, are experimenting with pathway development. As yet, there has been no systematic analysis of different approaches to adaptation pathway development.

Expected results and outcomes

This project will deliver:

- Lessons on the strength and weaknesses of different ways to develop adaptation pathways
- Evidence-based Guiding Principles for adaptation pathway development to inform decision-making for adaptation policy and practice
- Community of Practice
- Pocket guide and publication with guiding principles to make use of the strength of adaptation pathways development for the needs of policy and practice

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Methods

The project will first design a framework for structured synthesis and learning about adaptation pathway development.

Second, the project will develop adaptation pathways in selected cases in Africa and Asia.

Third, a Community of Practice will be initiated by project partners and strategic partners.

Third, synthesis will yield lessons across consortia and guiding principles.
Dutch water authorities are aware that water catchments currently are not sufficiently resilient to cope with expected changes in extreme weather events. Water systems are characterized by dense networks of hard water infrastructure. These infrastructures are not flexible and cause vulnerabilities. Additionally authorities have to invest in ecological restoration of water systems. Flexible and nature based approaches like building with Nature are needed.

Expected results and conclusions

Monitoring of building with nature projects in the Netherlands together with theory building will lead to a robust knowledge basis of nature based designs for small rivers. Including methods to assess risks and costs and benefits.

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Quality matters: Including water quality in global water stress projections

Research Challenges

- A growing global population and climate change will strongly impact the gap between the supply and demands for clean water, increasing water stress (scarcity).

This NWO Veni project aims to assess:
- present and future water stress including a water quality dimension.

Identify in which regions and to what extent waste water treatment, desalination and water reuse could be further developed to reduce water quality-driven water stress.

Methods

A new global water stress indicator and model framework has been developed including a new global water quality model and sector water use modules linked to the VIC hydrological.

Preliminary results

- Water quality matters for seasonal water stress (scarcity).
- We need deeper insights into the causes, impacts, solutions to reduce the gap between supply and demand of water of a suitable quality and to better contribute to achieving the SDGs

Example for the Pearl river in China. Summer water scarcity levels for the energy sector are higher when water temperature is included. When we include salinity as a critical parameter for irrigation, water scarcity levels increase during other parts of the year. Similar results are obtained when we focus on ammonia concentrations as a critical water quality requirement for drinking water use (van Vliet et al., nature geoscience 2017).

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Ven, Vidi, Vici
SURE+: Sustainable Resource Management for Adequate and Safe Food Provision in China

Subproject 2 and B: 2017-2021
Subproject leader: Prof. Carolien Kroeze
PhD students: Ang Li and Jing Yang
Postdocs: Dr Maryna Strokal and Dr Annette Janssen

Research Challenges
- Inadequate food production with environmental impacts;
- The SURE+ project aims at interdisciplinary research on the land, water and food nexus in China (Fig. 1).

Methods
- Innovative methodologies (e.g., Fig. 2) that can be applied for examining similar problems in other parts of the world

Expected results
Recommendations for adequate and safe food provision based on sustainable resource management.

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Fig. 1 Relationships between the sub-projects of SURE+. Red indicates the WSG subprojects.

Fig. 2 Integration of existing models and development of new models
Research Challenges

Nutrient pollution is a problem in many Chinese rivers. As in many other world regions, the most important causes include agriculture, urban waste, and industries. In China, animal production is a relatively large source of nutrients in rivers. This is a result of the fast industrialization of the animal production sector, and low nutrient use efficiency of food production.

Methods

MARINA is a Model to Assess River Inputs of Nutrients to seAs. It is a downscaled version of the Global NEWS (Nutrient Export from WaterSheds) model for China, but with better modelling of animal manure and human waste as well as with updated information for reservoirs. The model runs at the sub-basin scale for six main rivers in China that drain into the Bohai Gulf, Yellow Sea and South China Sea (see figure below).

Example of model output

Total river export of phosphorus by sub-basin (kton)

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Many rivers are polluted with nutrients. This is a worldwide problem. Excessive nutrient loads may result in eutrophication. The associated environmental problems include ground water pollution with nitrate, eutrophication and harmful algal blooms.

The most important causes of nutrient pollution are human activities on land: agriculture, urban waste, and industries are important sources of nutrients in rivers.

Global NEWS is a Nutrient Export from WaterSheds model. The model quantifies annual river export of nitrogen, phosphorus, carbon and silica in dissolved inorganic, organic and particulate forms. The model quantifies the source attribution and the Indicator for Coastal Eutrophication Potential (ICEP). The model distinguishes between point and diffuse sources of nutrients in rivers. Point sources include sewage effluents from wastewater treatment plants. Diffuse sources include typically leaching/runoff of nutrients to rivers from fertilized and non-fertilized soils.

Example of model output

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Multi-pollutant modelling of water quality

Research Challenges

- More than one pollutant in rivers
- Common sources
- Multiple impacts

Simplified illustration of multi-pollutant problems in river systems.

Example of model output

Preliminary results for inputs of selected multiple pollutants to rivers from sewage systems in 2010

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