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A Snapshot of the World's Water Quality: Towards a global assessment

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Foreword: A Snapshot of the World's Water Quality "Towards a global assessment"

Flowing knowledge

The quality of surface water in many parts of the developed world has noticeably improved in recent decades, but is being challenged as economic growth, demographics and climate change lead to widespread and severe degradation. The need to reverse this damage is reflected in the 2030 Agenda for Sustainable Development, both as a dedicated goal and as an integral element of many others. By providing a snapshot of the current situation, this report offers a baseline to measure progress, a framework for global assessment and a pathway towards sustainable solutions that will deliver on that agenda.

With many rivers still in good condition, there are opportunities to prevent pollution and begin restoration. However, severe organic pollution is already affecting around one in seven rivers across Latin America, Africa and Asia. This poses a growing risk to public health, food security and the economy, while cultivating inequality by predominantly affecting the poor, women and children.

Freshwater systems in both developed and developing nations face growing pressure from the discharge of harmful chemicals, such as hormone disrupters. Unfortunately, municipal water treatment has become increasingly costly and developing countries in particular have problems matching expanding public water supplies and sewerage, with adequate treatment of the new wastewater flows. As a result, there is a significant risk to vital activities like inland fishing, which accounts for some 60 million jobs and almost a third of fish harvested for human consumption.

Sound knowledge is critical to understanding the underlying causes and developing the evidence based policies to improve it, including source control, waste treatment, ecosystem management and new forms of local and global governance. Yet, until now, insufficient collection and evaluation of data has made it difficult to grasp the intensity and scope of deteriorating water quality. While an overview of the situation in the Southern Hemisphere already feeds into UNEP's Global Environment Outlook, this report clarifies methodology and priorities for data collection, gaps and scale. Focussing on key hot spots, it applies advanced modelling to existing information, which will assist countries looking to establish their own planning, monitoring and guidelines.

Thanks to support from UN Water and the many contributing authors, this report will help bridge the gap between water quality, the inclusive green economy and wider development issues. I hope that by combining such a global issue with local understanding, it will provide public and private sector decision makers a practical tool to deliver on all of the water related commitments for the 2030 Agenda.

Achim Steiner, United Nations Under-Secretary-General and UNEP Executive Director

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Acronyms

Table of abbreviations

	Stands for	Notes
AMCOW	African Ministerial Council on Water	
BFG	(German) Federal Institute of Hydrology	
BOD	Biochemical oxygen demand	
CFU	Colony-forming unit	Used to estimate the number of viable bacteria, here faecal coliform bacteria.
DEWA	Division of Early Warning and Assessment	UNEP Division
DO	Dissolved oxygen	
DPSIR	Drivers, Pressures, States, Impacts, Responses	Causal framework, adopted by the EEA, for describing the interactions between society and the environment
ECOWAS	Economic Community Of West African States	
EEA	European Environment Agency	
FAO	Food and Agriculture Organization of the United Nations	
FC	Faecal coliform bacteria	
FD	(European) Floods Directive	
FishstatJ	Fishery and Aquaculture Global Statistics	FAO database
GDP	Gross domestic product	
GEMS/Water	(United Nations) Global Environment Monitoring System on Water	*http://www.unep.org/gemswater/Home/tabid/55762/Default.aspx*
GEMStat	Global Environment Monitoring Statistics	Global water quality database
HYDE	History Database of the Global Environment	*http://themasites.pbl.nl/tridion/en/themasites/hyde/*
JMP	Joint Monitoring Programme	WHO/UNICEF activity
MONERIS	**MO**delling **N**utrient **E**missions in **RI**ver **S**ystems	*http://www.moneris.igb-berlin.de/index.php/homepage.html*
N	Nitrogen	
NH_3-N	Ammonia nitrogen (un-ionised)	
NH_4^+-N	Ammonia nitrogen (ionised)	
NFP	National Focal Point	Facilitator of data flow between GEMS and national states
NGO	Non-governmental organisation	
NRS	National Reporting System	UNEP activity
P	Phosphorus	
PCB	Polychlorinated biphenyl	

	Stands for	Notes
SDG	Sustainable Development Goals	The SDGs were first formally discussed at the UN Conference on Sustainable Development held in Rio de Janeiro in June 2012 (Rio+20)
TC	Total coliform bacteria	
TN	Total nitrogen	
TP	Total phosphorus	
TDS	Total dissolved solids	
UN	United Nations	
UNEP	United Nations Environment Programme	
UNESCO	United Nations Educational, Scientific and Cultural Organization	
UN-Water		The United Nations inter-agency mechanism for all freshwater related issues, including sanitation
WaterGAP	Water – Global Assessment and Prognosis	Model used in the Assessment, see Appendix B
WFD	(European) Water Framework Directive	
WHO	World Health Organization	
WMO	World Meteorological Organization	
WorldQual		Water quality model embedded in WaterGAP modelling framework, and used in this report. See Appendix B
WWAP	World Water Assessment Programme	
WWQA	World Water Quality Assessment	
WQI	Water Quality Index	

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Executive Summaries

موجز تنفيذي

الرسائل الأساسية

- تعد نوعية مياه الجيدة مع توفر كمية كافية من الماء ضرورية جدا لتحقيق أهداف التنمية المستدامة من أجل الصحة والأمن الغذائي والأمن المائي. ولذلك فإن تفاقم تلوث الماء منذ التسعينيات في معظم أنهار أمريكا اللاتينية وأفريقيا وآسيا مثير جدا للقلق.
- ومن المهم أن ترتبط الإجراءات اللازمة لحماية نوعية المياه واستعادتها مع الجهود الرامية إلى تحقيق أهداف التنمية المستدامة ومع جدول أعمال التنمية لما بعد عام 2015.
- يؤثر التلوث الممرض الشديد بالفعل على ثلث مجمل مساحات أنهار أمريكا اللاتينية وأفريقيا وآسيا. بالإضافة إلى المخاطر الصحية الناجمة عن طريق شرب المياه الملوثة فإن كثير من الناس يعرضون أنفسهم لخطر المرض عن طريق ملامسة المياه السطحية الملوثة عند الاستحمام وتنظيف الملابس وممارسة الأنشطة المنزلية الأخرى. وقد يتراوح عدد سكان ريف هذه القارات المعرضون للخطر بهذه الطريقة إلى مئات الملايين.
- يؤثر التلوث العضوي الشديد حاليا على حوالي جزء من سبعة أجزاء لمجمل مساحات أنهار أمريكا اللاتينية وأفريقيا وآسيا ويشكل مصدر قلق لأنشطة صيد السمك في المياه العذبة وبالتالي لتوفير الأمن الغذائي وسبل كسب العيش أيضا.
- يؤثر التلوث بالأملاح الشديد والمعتدل على جزء من عشرة أجزاء لمجمل مساحات أنهار أمريكا اللاتينية وأفريقيا وآسيا ويثير القلق لأنه يعوق استخدام مياه الأنهار لأغراض الري والصناعة وغيرها من الاستخدامات.
- يكمن السبب المباشر في زيادة تلوث المياه في تزايد كميات المخلفات السائلة داخل الأنهار والبحيرات. أما الأسباب الأساسية فهي النمو السكاني وزيادة النشاط الاقتصادي وتكثيف الزراعة وتوسعها وتزايد شبكات الصرف الصحي ذات المستوى الضعيف أو المنعدم لمعالجة الفضلات السائلة.
- تشكل النساء إحدى الفئات الأكثر تأثرا بتدهور نوعية المياه في البلدان النامية بسبب استخدامهن المتكرر للمياه في التدبير المنزلي وأيضا الأطفال بسبب لعبهم في المياه السطحية المحلية ولأنهم كثيرا ما يتولون مهمة جمع المياه للأعمال المنزلية، وكذلك سكان الريف ذو الدخل المنخفض الذين يستهلكون الأسماك كمصدر هام للبروتين بالإضافة إلى الصيادين ذوي الدخل المحدود وعمال صيد السمك الذين يعتمدون على الصيد في المياه العذبة لكسب رزقهم.
- وعلى الرغم من خطورة وضع تلوث المياه والذي يزداد سوءا في أمريكا اللاتينية وأفريقيا وآسيا فإن غالبية أنهار هذه القارات الثلاث لا تزال في حالة جيدة، وهنالك فرص كبيرة للحد من التلوث بطرق قصيرة المدى ولإصلاح حالة الأنهار الملوثة. وستحتاج هذه المهام إلى جمع الإدارة الجيدة مع خيارات تقنية مدعومة من حكومة جديرة بهذه المسؤولية
- يتوفر للبلدان النامية نطاق واسع من الخيارات الإدارية والفنية لمكافحة تلوث المياه. ولم تكن الكثير من هذه الخيارات متوفرة أو مستخدمة من قبل الدول المتقدمة عندما واجهت تدهورا مماثلا لنوعية المياه قبل بضعة عقود.
- لا غنى عن مراقبة نوعية المياه وتقييمها لفهم شدة التحدي العالمي لنوعية المياه .ونطاقه. بيد أن تغطية البيانات في أجزاء كثيرة من العالم لا تكفي لهذا الغرض .على سبيل المثال فإن كثافة محطات قياس نوعية المياه في أفريقيا أقل مائة مرة من الكثافة المستعملة للمراقبة في أماكن أخرى من العالم. لذا فإنه من الضروري دعم جمع المعلومات حول نوعية المياه وتوزيعها وتحليلها من خلال برنامج النظام العالمي لرصد البيئة/ المياه المعروف باسم GEMS/Water وغيره من الأنشطة. ويمكن استخدام بؤر الإهتمام المُعَرّفة في هذا التقرير لتحديد الأولويات عند جمع البيانات.

يتطلب البشر والنظم البيئية على حد سواء *كمية* كافية من المياه بالإضافة إلى *نوعية* ملائمة منها. وبالتالي، هناك ضرورة ملحة لتحديد الأماكن التي تعاني من *نوعية مياه غير ملائمة أو مهددة* وكذلك لإدراج الحاجة إلى نوعية مياه جيدة في مفهوم الأمن المائي. ويركز هذا التقرير على نوعية المياه وعلاقتها بأهداف التنمية مثل الصحة والأمن الغذائي والأمن المائي. ولربط هذه العلاقة يستعرض التقرير المشاكل الأساسية لنوعية المياه السطحية بما في ذلك التلوث الممرض، والتلوث العضوي والتلوث بالأملاح والإثراء الغذائي . وينصب التركيز هنا على ثلاث قارات هم أمريكا اللاتينية وأفريقيا وآسيا.

كان لدعم الأمن المائي أولوية دولية على مدى السنوات الماضية فمن خلال الأهداف الإنمائية للألفية وغيرها من الأعمال أعطى المجتمع الدولي الأولوية للجانب الكمي للأمن المائي وذلك من خلال توسيع السبل لوصول الناس إلى إمدادات مأمونة للمياه. فعلا فإن توصيل *كمية* كافية من المياه للبشر وللنشاط الصناعي والزراعي يعد ولا بد أن يبقى ذو أولوية دولية عالية. ومع ذلك تزداد أهمية مقياس آخر للأمن المائي – ألا وهي التأكد من *النوعية* الكافية للمياه العذبة. ويعتبر هذا أمرا مهما لأن نوعية مياه الأنهار والبحيرات في العالم تمر بتغييرات بالغة. وتنعكس الأولوية المتزايدة لنوعية المياه في المقاصد المختلفة لأهداف التنمية المستدامة.

لقد تحسنت نوعية المياه بشكل ملحوظ في كثير من البلدان المتقدمة على الرغم من أن بعض المشاكل لا تزال قائمة. وفي غضون ذلك يميل الوضع في البلدان النامية إلى زيادة تلوث المياه نظرا للنمو السكاني في المناطق الحضرية وزيادة الاستهلاك المادي وانتشار كميات مياه الصرف الصحي غير المعالجة. لكن بسبب نقص المعلومات الأساسية لا يمكن إلا تخمين الوضع الحالي لنوعية المياه في كثير من النظم البيئية للمياه العذبة في هذا العالم. وعليه فإن هناك حاجة ملحة إلى إجراء تقييم لتحديد نطاق وحجم "التحدي العالمي لنوعية المياه ". وتهدف هذه الدراسة التمهيدية إلى توفير بعض العناصر الأساسية لتشكيل تقييم شامل النطاق لنوعية المياه العالمية والذي يمكن تطويره إلى تقييم مكتمل. كما تعرض هذه الدراسة التمهيدية أيضا تقديرا أوليا لوضع نوعية المياه في النظم البيئية العالمية للمياه العذبة مع التركيز على الأنهار والبحيرات في ثلاث قارات.

تفاقم تلوث المياه منذ تسعينيات القرن الماضي في معظم أنهار أمريكا اللاتينية وأفريقيا وآسيا[1].

لقد قدرت التغييرات في الفترة ما بين 1990 و 2010 باستخدام معالم الأنهار الرئيسية التي تعكس مدى التلوث الممرض (بكتريا قولونية غائطية) والتلوث العضوي (الطلب البيولوجي الكيميائي على الأكسجين؛ المعروف باسم BOD) والتلوث بالأملاح (مجموع المواد المذابة المعروف باسم TDS). لقد تدهور مستوى التلوث الممرض والتلوث العضوي في أكثر من 50 في المائة من مساحات الأنهار في جميع القارات الثلاث، في حين ساء التلوث بالأملاح في ما يقرب ثلث هذه المساحات[2]. إن الوضع السيء لبعض أجزاء هذه المساحات يثير القلق بشكل خاص حيث ازداد تلوث المياه هناك إلى مستوى شديد أو كان أصلا على مستو حاد في عام 1990 ثم تفاقم بحلول عام 2010.

يؤثر التلوث الممرض الحاد[3] حاليا على ما يقرب ثلث مجمل مساحات الأنهار في أمريكا اللاتينية وأفريقيا وآسيا. وقد يصل عدد سكان الريف الذين يواجهون أخطار صحية بسبب الإتصال بالمياه السطحية الملوثة إلى مئات الملايين في هذه القارات. النساء والأطفال هم من بين أكثر الفئات المهددة هناك.

يقدر أن التلوث الممرض الشديد حيث تزيد التركيزات الشهرية للبكتريا القولونية الغائطية في المياه على 1000 وحدة تشكيل مستعمرة لكل 100 مليلتر[4]) يؤثر على نحو ربع مساحات أنهار أمريكا اللاتينية وعلى نحو 10 إلى 25 في المائة من مساحات الأنهار الأفريقية وعلى حوالي ثلث إلى نصف مساحات الأنهار الآسيوية. وبالتالي يبدو أن الحد الأعلى للتلوث الممرض من بين هذه القارات الثلاث يقع في آسيا. وإذا أخذنا بعين الاعتبار نسبة السكان الريفيين الذين يتصلون على الأغلب بالمياه السطحية[5] فإن من المقدر أن قرابة 8 إلى 25 مليون شخص في أمريكا اللاتينية و32 إلى 164 مليون شخص في أفريقيا و31 إلى 134 مليون شخص في آسيا هم في خطر. هذا المدى الواسع لهذه التقديرات إنما يشير إلى أن العديد من عوامل الخطر

[1] يستخدم هذا التقرير المناطق الفرعية التالية المستخدمة في مشروع تو قعات البيئة العالمية لبرنامج الأمم المتحدة للبيئة (UNEP يونيب) لتحديد "أمريكا اللاتينية"، "أفريقيا"، و "آسيا":
أمريكا اللاتينية = أمريكا الوسطى ,أمريكا الجنوبية ,منطقة البحر الكاريبي؛
أفريقيا = وسط أفريقيا، شرق أفريقيا، شمال أفريقيا، جنوب أفريقيا، غرب أفريقيا، غرب المحيط الهندي؛
آسيا = آسيا الوسطى ,شمال شرق آسيا ,جنوب آسيا ,جنوب شرق آسيا ، منطقة غرب آسيا (شبه الجزيرة العربية، المشرق العربي)

[2] يستخدم هذا الملخص أعداد مقربة لوصف نتائج التحليلات. فإن من المناسب عرض نتائج مقربة لمراعاة أوجه عدم اليقين الموضوعية في التقديرات التي قامت عليها هذه النتائج. وتعرض هذه التقديرات الضمنية في النص الرئيسي

[3] يعرف مصطلح التلوث الممرض الحاد في الحاشية رقم 5 .إن المستوى العالي من البكتيريا القولونية الغائطة تشير في أغلب الظن إلى مستوى عال من مسببات الأمراض في أحواض المياه هذه والذي يسبب للناس الذين يتعاملون مع هذه المياه مخاطر صحية جسيمة.

[4] الوحدات المعيارية لتركيزات البكتريا القولونية الغائطية هي "وحدات تشكيل المستعمرة" لكل 100 مليلتر من عينة المياه.

[5] وهذا يشمل البشر الذين يتعرضون للأنهار التي تعاني من مستوى شديد للتلوث الممرض (س> 1000 وحدة تشكيل المستعمرة / 100مليلتر).

الحالية مازالت مجهولة حتى الآن وأيضا إلى أن احتمال أن تكون أعداد الأشخاص المعرضة للخطر كبيرة جدا. ولا تشمل هذه التقديرات المزارعين المعرضين لمياه الري الملوثة ولا سكان المدن.

إن النساء معرضات للخطر بشكل خاص بسبب استخدامهن المتكرر لمياه الأنهار والبحيرات لتنظيف الملابس وجمع المياه للأغراض المنزلية من طهي وشرب وكذلك الأطفال بسبب لعبهم في المياه السطحية المحلية وأيضا لأنهم يتولون غالبا مهمة جمع المياه للأعمال المنزلية.

من الجدير بالذكر أن تركيز البكتيريا القولونية الغائطية زاد بين عامي 1990 و 2010 في حوالي ثلثي مجمل الأنهار في أمريكا اللاتينية وأفريقيا وآسيا. وتعادل مساحات الأنهار التي "تميل إلى التدهور بشكل مقلق "[6] نحو ربع مجموع كيلومترات أنهار هذه القارات حيث ارتفعت مستويات البكتيريا القولونية الغائطية فيها إلى مستوى حاد أو كانت تعاني أصلا من مستو حاد في عام 1990 ثم تفاقم بحلول عام 2010. ويمكن اعتبار هذه المناطق بؤر إهتمام رئيسية في هذه القضية.

يرجع جزء كبير من هذا التزايد إلى توسع أنظمة الصرف الصحي التي تصرف المياه القذرة بغير معالجة إلى المياه السطحية. وبالنظر إلى جانب واحد، وهو إذا ما تم نقل مياه الصرف الصحي بعيدا عن المناطق المكتظة بالسكان، فبالتالي ستحد المصارف الصحية من المخاطر الصحية الناجمة عن الرعاية الصحية غير السليمة. ولكنها من ناحية أخرى نقلت المخاطر الصحية إلى المياه السطحية من خلال إلقاء مياه الصرف الصحي إلى المياه السطحية بلا معالجة. وأشارت التقديرات إلى أن تركيز القولونيات الغائطية المحملة في عام 2010 إلى الأنهار الأفريقية قد تكون أصغر بنسبة 23 في المائة إن لم يتم بناء المصارف الصحية. ولكن لا يكمن الحل في الحد من بناء المصارف الصحية بل في معالجة مياه الصرف الصحي المجمعة فيها.

يؤثر التلوث العضوي الشديد بالفعل على حوالي كيلومتر واحد من أصل كل سبعة كيلومترات من مجمل مساحات الأنهار في أمريكا اللاتينية وأفريقيا وآسيا. ويشكل ارتفاع مستوى التلوث العضوي وميوله نحو وضع أشد سوءا مصدر قلق بخصوص صيد أسماك المياه العذبة وبالتالي أيضا بخصوص توفير الأمن الغذائي وضمان سبل العيش. وتشمل الفئات المتضررة من التلوث العضوي سكان الريف الفقراء الذين يعتمدون على أسماك المياه العذبة كمصدر رئيسي للبروتين في غذائهم كما تشمل صيادي الأسماك والعمال ذوي الدخل المنخفض الذين يعتمدون في معيشتهم على صيد أسماك المياه العذبة.

ينشأ التلوث العضوي عن طريق تسرب كميات كبيرة من المركبات العضوية القابلة للتحلل في مجاري المياه السطحية. وكثيرا ما يؤدي انحلال هذه المركبات إلى انخفاض خطير في الأوكسجين المذاب في مصادر الأنهار والتي يعتمد عليها الأسماك والحيوانات المائية الأخرى.

تشكل أسماك المياه الداخلية جزءا هاما من البروتين في النظام الغذائي لسكان البلدان النامية. على الصعيد العالمي يعتبر صيد الأسماك الداخلية سادس أهم المصادر للبروتين الحيواني ولكن صيد أسماك المياه الداخلية يشكل في بعض البلدان النامية أكثر من 50 في المائة من البروتين الحيواني المنتج ضمن ذلك البلد.

كما أن صيد الأسماك المحلية يعتبر مصدرا هاما لكسب العيش في البلدان النامية فإنه يوفر فرص عمل لنحو21 مليون صياد وتوفير نحو38.5 مليون وظيفة ذات صلة بصيد الأسماك في البلدان النامية. وتتواجد أغلب هذه الوظائف في المصايد الصغيرة التي غالبا ما يتولاها أصحاب الدخل المنخفض والتي تشكل النساء فيها أكثر من نصف مجموع القوى العاملة. لذلك فإن من المقلق أن على الأقل 10٪ من جميع القياسات في أمريكا اللاتينية وأفريقيا وآسيا تبين مستويات مقلقة لثلاثة معايير على الأقل من أصل خمسة لنوعية المياه وذات الأهمية الخاصة لسلامة صيد الأسماك.

أن التلوث العضوي الشديد (حيث يزيد تركيز الطلب البيولوجي الكيميائي على الأكسجين شهريا على 8 ملغ / لتر في تيار المياه) قد أثر في عام 2010 على حوالي جزء من عشرة أجزاء مساحات أنهار أمريكا اللاتينية وعلى جزء من سبعة أجزاء مساحات الأنهار الأفريقية وعلى نحو سدس مساحات الأنهار الآسيوية.

ومما يثير القلق أيضا أن التلوث العضوي (المبين عن طريق ارتفاع تركيز الطلب البيولوجي الكيميائي على الأكسجين في الأنهار) قد تفاقم بين عامي 1990 و 2010 في قرابة ثلثي مجمل الأنهار في أمريكا اللاتينية وأفريقيا وآسيا. تشكل فئة مساحات هذه الأنهار التي "تميل إلى تفاقم الوضع بشكل مقلق" جزء من أصل عشرة أجزاء مجموع كيلومترات أنهار هذه القارات حيث

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[6] يقصد التقرير بالمناطق التي " تميل إلى التدهور بشكل مقلق " إلى مناطق تعاني من مستوى تلوث وصل إلى درجة التلوث الحاد بين عامي 2008 و2010 أو كان قد وصل أصلا إلى هذه المرحلة في الفترة بين عامي 1990 و1992 ثم ازدادت حدته في الفترة بين عامي 2008 و2010.

ارتفعت مستويات تركيز الطلب البيولوجي الكيميائي على الأكسجين فيها إلى مستوى حاد أو كانت تعاني أصلا من مستو حاد في عام 1990 ثم ارتفع هذا المستوى بحلول عام 2010 ويمكن اعتبار هذه المناطق بؤر الإهتمام الرئيسية في هذه القضية.

يؤثر التلوث الشديد والمعتدل بالأملاح بالفعل على حوالي عُشر مجمل مساحات أنهار أمريكا اللاتينية وأفريقيا وآسيا. الأمر الذي يثير القلق لأن مستويات عالية من الملوحة يفسد استخدام مياه الأنهار للري والصناعة وغيرها من الاستخدامات. تشمل الفئات المتضررة من التلوث بالأملاح المزارعين الفقراء الذين يعتمدون على المياه السطحية كمصدر ري لأراضيهم البسيطة.

ينشأ "التلوث بالأملاح" عندما يرتفع تركيز الأملاح الذائبة والمواد الأخرى في الأنهار والبحيرات إلى درجة تعرقل استخدام هذه المياه على وجه حسن. وعلى الرغم من أن معظم الأنهار تقريبا تحتوي على بعض الأملاح بسبب تفتت الأتراب والصخور في مستجمعاتها المائية لكن المجتمع البشري سبب في ازدياد هذه المستويات إلى حد كبير بسبب تفريغ التدفق المرتد للري والمحمل بالأملاح وكذلك الفضلات السائلة المنزلية وتصريفات المناجم كلها في الأنهار.

إن التلوث بالأملاح أقل انتشارا من التلوث الممرض أو التلوث العضوي في القارات التي أجريت دراسة عنها. على الرغم من ذلك يؤثر التلوث بالأملاح المعتدل والشديد سويا (أي حيث يكون التركيز الشهري لإجمالي المواد المذابة أكثر من 450 ملغ / لتر) على واحد من كل عشرين كيلومترا من أنهار أمريكا اللاتينية وعلى حوالي عُشر مساحات أنهار أفريقيا وعلى حوالي سُبع مساحات أنهار آسيا. إن استخدام مياه الأنهار ذات التلوث المعتدل جزئيا محدود في مجال الري ولا يمكن استعماله في بعض المجالات الصناعية دون تنقية إضافية. وقد يكون المزارعون الفقراء الأكثر تأثرا لأنهم يعتمدون على المياه السطحية كمصدر لري أراضيهم البسيطة.

لقد تفاقم التلوث بالأملاح بين عامي 1990 و 2010 في ما يقرب ثلث إجمالي الأنهار في القارات الثلاث. جزء من مساحات الأنهار هذه (نسبة صغيرة من مجمل مجرى الأنهار) " يميل بشكل مقلق إلى تفاقم الوضع " حيث ارتفعت مستويات إجمالي المواد المذابة فيه إلى مستوى خطير أو كان يعاني أصلا من مستو حاد في عام 1990 ثم تفاقم هذا المستوى بحلول عام 2010.

تعد كمية المواد المغذية ذات المنشأ البشري والمحملة إلى البحيرات الكبرى كبيرة ويمكن أن تتسبب في الإثراء الغذائي لهذه البحيرات أو تزيد من شدتها. ويختلف المسار المستقبلي لحالة هذه الكميات مع اختلاف مناطق العالم.

الإثراء الغذائي هو التسميد المفرط للبحيرات والمسطحات المائية الأخرى مما يؤدي إلى اختلال عملياتها الطبيعية. وعادة ما تتسبب كمية الفوسفور ذات المنشأ البشري في الإثراء الغذائي للأنهار ولكن تستطيع كميات كبيرة من النيتروجين أن تلعب دورا في ذلك أيضا. تنشأ أكثر من نصف مجموع كميات الفوسفور المونوعية في 23 من أصل 25 بحيرة كبرى[7] عالميا من مصادر بشرية. وبالإضافة إلى ذلك فإن معظم البحيرات الكبرى في أمريكا اللاتينية وأفريقيا تعاني من كميات متزايدة فيها. وعلى سبيل المقارنة فإن هذه الكميات آخذة في التناقص في أمريكا الشمالية وأوروبا بفضل اللجوء إلى إجراءات فعالة لخفض الفوسفور.

يكمن السبب الرئيسي لتفاقم تلوث المياه في زيادة تحميل الأنهار والبحيرات بالفضلات السائلة. وتختلف أهم المصادر الحالية للتلوث حسب المواد الملوثة. لكن الأسباب الأساسية لتلوث المياه المتزايد تكمن في النمو السكاني وزيادة النشاط الاقتصادي وتكثيف الزراعة وتوسعها بالإضافة إلى نمو الصرف الصحي مع عدم معالجة المياه فيه أو معالجتها على مستو ضعيف فقط.

يقلل جمع المخلفات السائلة في المصارف من تعرض البشر المباشر للنفايات ومسببات الأمراض وتشكل المصارف بهذه الطريقة استراتيجية هامة لحماية الصحة العامة. ولكن مع ذلك فإن بناء شبكات الصرف الصحي أدى إلى تركيز رمي الملوثات في المياه السطحية وينقل بذلك موقع الخطر الصحي على الناس.

إن أكبر مصدر للتلوث الممرض (كميات محملة بالبكتيريا القولونية الغائطية) في أمريكا اللاتينية هو الفضلات السائلة المنزلية المجمعة في المجاري، أما في أفريقيا فهو النفايات المنزلية الغير مجمعة في مصارف، وبالنسبة لآسيا فهو الفضلات السائلة المنزلية المجمعة في المجاري تليها مباشرة النفايات الغير مجمعة في مصارف.

أكبر مصدر للتلوث العضوي (كميات الطلب البيولوجي الكيميائي على الأكسجين) في أمريكا اللاتينية هو الفضلات السائلة المنزلية المجمعة في المجاري، ، أما في أفريقيا فهو النفايات المنزلية الغير مجمعة في مصارف، وبالنسبة لآسيا فهو الفضلات السائلة الناتجة عن القطاع الصناعي.

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[7] يقصد هذا التقرير ب "البحيرات الكبرى العالمية" البحيرات الخمس الكبرى من ناحية مساحة سطحها في جميع المناطق الخمس المدروسة في مشروع تو قعات البيئة العالمية لبرنامج الأمم المتحدة للبيئة (UNEP يونيب)(أفريقيا وآسيا وأوروبا وأمريكا اللاتينية وأمريكا الشمالية).

ويعد أكبر مصدر بشري للتلوث بالأملاح (الكميات المحملة بإجمالي المواد المذابة) في أمريكا اللاتينية هو القطاع الصناعي أما في أفريقيا وآسيا فهو الزراعة المروية.

تعتبر النفايات الحيوانية والأسمدة غير العضوية من أهم مصادر الفوسفور البشري المنشأ المحمل إلى البحيرات الكبرى في أمريكا اللاتينية أما بالنسبة لأفريقيا فأهم المصادر هي النفايات الحيوانية وبالنسبة لآسيا وأوروبا هي الفضلات السائلة المنزلية والنفايات الحيوانية والأسمدة الغير عضوية وبالنسبة لأمريكا الشمالية هي الأسمدة الغير عضوية.

على الرغم من أن تلوث المياه يشكل وضعا خطيرا ويزداد سوءا في أمريكا اللاتينية وأفريقيا وآسيا فإن غالبية الأنهار في هذه القارات الثلاث إلا أنه لا يزال في حالة جيدة وهنالك فرص كبيرة للحد من التلوث بطرق قصيرة المدى ولإصلاح حالة الأنهار التي تحتاج حاليا لذلك.

لقد تمحور تركيز النقاط السابقة على مساحات الأنهار الواسعة التي تعاني من نوعية مياه سيئة ويزداد وضعها سوءا ولكن على الجانب الآخر مازال هناك العديد من روافد الأنهار *الغير ملوثة بعد*:

- ما يقرب من نصف إلى ثلثي إجمالي الروافد النهرية (في أمريكا اللاتينية وأفريقيا وآسيا) مستوى *منخفض* من التلوث الممرض
- أكثر من ثلاثة أرباع هذه الأنهار لديها مستوى *منخفض* من التلوث العضوي،
- لدى حوالي تسعة أعشار منها مستوى *منخفض* من التلوث بالأملاح.

ولا زالت حماية هذه الأنهار النظيفة من التلوث الشديد ممكنة. وكذلك يمكن أيضا استعادة نظافة الروافد النهرية الملوثة حاليا. ويمكن اتخاذ العديد من الإجراءات لتجنب زيادة التلوث ولاستعادة نظافة المياه العذبة الملوثة:

1. *الرقابة* – هناك حاجة ملحة إلى زيادة فهم شدة التحدي العالمي لنوعية المياه ونطاقه. ولإدراك هذا الفهم لا بد من توسيع الرقابة على نوعية المياه لا سيما في البلدان النامية وبخاصة على مستوى عالمي من خلال النظام العالمي لرصد البيئة/ المياه المعروف باسم GEMS/Water .
2. *التقديرات* – هناك حاجة ملحة إلى تقديرات محلية ودولية شاملة حول التحدي العالمي لنوعية المياه: تفيد هذه التقييمات في تحديد الطرق إلى المواقع ذات الأولوية الخاصة وتعيين الإجراءات اللازمة للتعامل مع تلوث المياه.
3. *خيارات تقنية وإدارية تقليدية وحديثة* – لا تتيح للدول النامية فرص لاستخدام أساليب تقليدية لمعالجة الفضلات السائلة فحسب، بل لديها أيضا فرص للإستفادة من الكثير من الخيارات الإدارية والتقنية الحديثة لإدارة نوعية المياه بما في ذلك الحلول المعتمدة على الطبيعة.
4. *إعداد مؤسسات فعالة* – يعد من أهم النقاط لإدارة نوعية المياه إنشاء مؤسسات تسير إجراءات السيطرة على تلوث المياه وتتغلب على العوائق التي تحول دون هذه السيطرة.

توضح هذه الأفكار في النقط التالية:

ما يمكن القيام به: أولا. الرقابة

لا يمكن وضع تقييمات شاملة لنوعية المياه العالمية بسبب ضعف تغطية بيانات نوعية المياه السطحية المسجلة في النظام العالمي لرصد البيئة/ GEMStat والتي تعتبر قاعدة البيانات العالمية الوحيدة المعنية بنوعية المياه.

يحتوي النظام العالمي لرصد البيئة/ GEMStat على كثافة منخفضة جدا مقارنة مع الكثافات الصغرى النمطية لمناطق الأحواض النهرية في الولايات المتحدة وأوروبا والتي تعادل حوالي 1.5 إلى4 محطات في كل 10000 كم^2. أما بالنسبة لقاعدة بيانات النظام العالمي لرصد البيئة/ GEMStat فإن من أصل 110 حوض من أحواض الانهار ذات البيانات يظهر 71 حوضا كثافة تعادل 0.5 محطة أو أقل لكل 10000 كم^2.

وصل معدل الكثافة في الفترة الزمنية بين عامي 1990 و 2010 في قارة أمريكا اللاتينية إلى حوالي 0.3 محطة لكل 10000 كم^2 وفي أفريقيا فكان 0.02 محطة[8] لكل 10000 كم^2 وأما في آسيا فكان 0.08 محطة لكل 10000 كم^2 .

[8] الأراضي الجافة غير محسوبة ضمن المنطقة القارية.

ترجع الأولوية القصوى إلى التوسيع الزمني والمكاني لنطاق تغطية محطات المراقبة وذلك بدلا من زيادة عدد المعلمات التي يتم جمعها في المحطات المونوعية حاليا. ونظرا إلى التكاليف العالية للمراقبة ينبغي وضع أولويات تحدد الأنهار ذات البيانات الناقصة التي ينبغي رصدها أولا. ويمكن استخدام بؤر الإهتمام المُعرفة في هذا التقرير كمدخلات لتحديد المناطق التي ينبغي أن يُكثف فيها جهود الرصد.

يعود ضعف تغطية البيانات لأسباب سياسية ومؤسسية وتقنية ولكن يبقى هناك العديد من البدائل لتحسين تغطية البيانات حول نوعية المياه.

إحدى هذه البدائل لتحسين التغطية يمثل الاستفادة من بيانات الاستشعار عن بعد. وتغطي مجموعات البيانات الحالية المتغيرات الرئيسية لنوعية مياه البحيرات وفي المستقبل القريب سوف تصبح البيانات متاحة للأنهار أيضا. ويتمثل ميزة الاستشعار عن بعد في التغطية المكانية والزمانية الواسعة للبيانات؛ ويكمن عيوبها في العدد المحدود للمتغيرات التي يمكنه قياسها وفي معالجة المعلومات الأولوية المطلوبة.

تشمل الإمكانيات الأخرى لتحسين تغطية بيانات نوعية المياه ما يلي: (1) تشجيع الجهود الرامية إلى إدراج البيانات الوطنية والإقليمية في قواعد البيانات المونوعية حاليا (2) إنشاء فرق عمل وطنية لرصد المياه العذبة تعمل مع نظرائها في البلدان الأخرى على تقاسم واستخدام بيانات نوعية المياه (3) استرجاع البيانات من خلال مشاريع متعلقة بعلم المواطن. وتتمثل الميزة الإضافية لعلم المواطن في إشراك جمهور أوسع في تنظيف المياه الملوثة.

ينبغي أيضا أن تسعى جهود جمع البيانات لجعلها متاحة على نطاق واسع وقابلة للإسترجاع عن طريق منصة رقمية مثل المنبر التفاعلي لبرنامج الأمم المتحدة للبيئة. وينبغي أن تكون البيانات متاحة على نطاق واسع أيضا فيما يخص رصد أهداف التنمية المستدامة وتنفيذها.

<u>ما يمكن القيام به: ثانيا. التقييمات</u>

يحتاج تقدير الوضع المعرفي لجميع الجوانب الحساسة بخصوص نوعية المياه إلى تقييم شامل النطاق لنوعية المياه العالمية، وذلك لوضع روابط بين نوعية المياه وقضايا أخرى للتنمية تخص فترة ما بعد عام 2015 مثل الصحة والأمن الغذائي وكذلك لتحديد الجوانب ذات الأولوية القصوى لدراستها وتطبيقها.

يجب أن يكون التقييم:

- متعدد المستويات - مع تغطية عالمية مرتبطا بتقييمات وطنية متعلقة بالموضوع.
- شفاف وتشاركي - يشمل مجموعة واسعة من أصحاب المصلحة والعلماء.

وينبغي أن يحتوي التقييم على ما يلي:

- الأهداف والمواضيع التي تم تحديدها بشكل مشترك من قبل المجتمعات السياساتية والعلمية.
- تحليل للخيارات السياساتية الهادفة لحماية نوعية المياه واستعادتها.
- تيسير النتائج على شكل واسع عن طريق إتاحتها على المنصات الرقمية الجديدة (مثل: المنبر التفاعلي لبرنامج الأمم المتحدة للبيئة).

ينبغي أيضا الإستفادة من التقييم كفرصة لزيادة القدرات التقنية للبلدان النامية وتشجيع وصولها إلى أحدث النتائج العلمية.

<u>ما يمكن القيام به :ثالثا. الإدارة والخيارات الفنية</u>

يتوفر العديد من الخيارات للبلدان النامية لتجنب تدهور نوعية مياه الأنهار والبحيرات. قبل عقود مضت كان الكثير من هذه الخيارات غير متوفرا أو مستخدما في الدول المتقدمة عندما واجهت بدورها تدهورا مماثلا لنوعية المياه.

تتمثل الخيارات الفنية الرئيسية في:

(1) *منع التلوث* عن طريق تجنب مصدر تلوث المياه قبل أن يتحول إلى مشكلة.

(2) *معالجة المياه الملوثة* وهو النهج التقليدي لتقليل كميات الملوثات قبل تفريغها في المياه السطحية.

(3) *الاستخدام الآمن لمياه المجاري* وإعادة تدويرها لاستخدامها في الري وغيره من الاستخدامات.

(4) *"الحلول التي تعتمد على الطبيعة" والتي تضمن إصلاح النظم البيئية وحمايتها* مثل إعادة إنشاء الغابات في مناطق المستجمعات بهدف الحد من انجراف التربة ومن تحميل الرواسب إلى الأنهار أو استعادة المناطق الرطبة لإزالة الملوثات من تدفقات المياه في المناطق الحضرية أو الزراعية.

ونجد في إطار هذه البنود العديد من الأفكار الجديدة التي لم تكن متاحة للبلدان المتقدمة عندما واجهت لأول مرة تدهورا مماثلا لنوعية المياه منذ ثلاثة عقود أو أكثر. ومن بين هذه الأفكار الجديدة: *الإنتاج الأنظف في الصناعة، الأراضي الرطبة التي تم إنشائها، والتخلص كليا من تصريف الفضلات السائلة، والمدفوعات مقابل خدمات النظم البيئية لمنابع الأنهار المشجرة.*

هناك حاجة لاستراتيجيات تقنية مختلفة للسيطرة على الأنواع المختلفة من تلوث المياه ومصادرها. ومن المفيد اختبار هذه الاستراتيجيات وتجميعها إلى حزم يمكن تطبيقها على العديد من أحواض الأنهار المختلفة.

ومن ناحية أخرى، وحسبما أشرنا أعلاه ، فأن المصادر الرئيسية للتلوث تختلف مع اختلاف أنواع تلوث المياه. وهذا يعني أن فكرة "حل واحد يناسب الجميع" لن تنجح في حل مشكلة التحدي العالمي لنوعية المياه. ولكن من ناحية أخرى فإن تحديات مماثلة لنوعية المياه تقع في جميع أنحاء العالم وذلك رغم الاختلاف الشديد للمواقع والأوضاع فيها. لذلك فقد يكون من الممكن تطوير حزم تشمل إمكانيات تقنية مختلفة لاستخدامها في العديد من أحواض الأنهار المتنوعة للتعامل مع مشاكل مماثلة.

ما يمكن القيام به :رابعا. الإدارة والمؤسسات

أشارت دراسات حالات عن أحواض أنهار مختلفة إلى أهمية الإدارة الرشيدة وفعالية المؤسسات لإدارة نوعية المياه.

لقد تبين أن أهم العوائق التي تحول دون التغلب على مشاكل تلوث المياه تشمل ما يلي:

- انقسام السلطة ضمن منطقة حوض نهر معين،
- نقص في القدرات التقنية، و
- قلة وعي الرأي العام حول أسباب تلوث المياه.

وللتغلب على هذه العوائق وغيرها أظهرت الخبرة من دراسات الحالات أن حملة التوعية العامة هي مقياس أول جيد لكسب الدعم في مكافحة تلوث المياه. كما بينت هذه الخبرة أن *خطة العمل* المتفق عليها من قِبل جميع الجهات الفاعلة الرئيسية لحوض النهر هي خطوة رئيسية لإصلاح الأنهار والبحيرات. وكذلك يشكل إنشاء *هيئات تعاونية* خطوة تأسيسة رئيسية أخرى للأنهار الدولية كما هو الحال للجان الدولية على نهري الإلبه وفولتا التي تهدف إلى وضع خطة عمل وتنفيذها. وبالنسبة إلى نهر الإلبه فقد تبين أيضا أن مؤسسة وطنية واسعة النطاق (منظومة حوض نهر الإلبه) تستطيع أن توفر منبرا قيما لكسب تعاون جميع الجهات الفاعلة الوطنية الأساسية لمنطقة حوض النهر.

يرتبط مواجهة التحدي العالمي لنوعية المياه ارتباطا وثيقا بعدة أولويات اجتماعية أخرى مثل الأمن الغذائي والصحة. ولهذا يجب أن تنضم الإجراءات اللازمة لحماية نوعية المياه في مشروع الاستدامة الأوسع وكذلك يجب أن تكون جزءا من الجهود الرامية إلى تحقيق أهداف التنمية المستدامة الجديدة.

أظهرت دراسات الحالات أن التحدي المتمثل في حماية نوعية المياه يتشابك مع العديد من المهام الاجتماعية الأخرى - توفير الغذاء وتنمية الاقتصاد وتوفير خدمات الصرف الصحي الآمنة. ولذلك سيكون من المهم جدا على مدى السنوات القادمة ربط أهداف نوعية المياه مع الأهداف الأخرى لجدول أعمال ما بعد عام 2015 وكذلك ربطه مع أهداف التنمية المستدامة الجديدة.

执行摘要

主要内容

- 良好的水质与充沛的水源，对于实现卫生、食品安全与水安全等可持续发展目标而言不可或缺。自上世纪九十年代以来，拉美、非洲和亚洲的大部分河流受污染的现象不断加剧，成为人们关注的问题。
- 保护与恢复水质的各种行动与为实现可持续发展目标以及 2015 年后发展议程而付出的各种努力紧密相关，了解这一点十分重要。
- 拉美、非洲和亚洲所有河流中约有三分之一已受到病原菌的严重污染。除面临受污染的饮用水带来的健康风险外，许多人还因沐浴、洗衣和其他家务接触受污染的地表水，而面临感染疾病的风险。在这三大洲中面临这种风险的农村人口数量可能达到数个亿。
- 拉美、非洲和亚洲所有河流中约有七分之一已出现严重的有机污染，引发人们对淡水渔业现状以及食品安全和民生的担忧。
- 拉美、非洲和亚洲所有河流中约有十分之一已出现中度至重度的盐度污染，污染使得将河流水用于灌溉、工业和其他用途受到限制，令人担忧。
- 造成日益严重的水污染问题的直接原因，是排放到河流与湖泊中的废水不断增多。而人口增长、经济活动增加、农业密集化与扩大化、未经处理或处理程度极有限的污水量日益增多，是导致水污染的根本原因。
- 在发展中国家，易受到水质恶化问题影响的群体包括：妇女，因为她们需要经常使用地表水做家务；儿童，因为他们经常在当地地表水中玩耍，且还经常要完成为家里取水的任务；将鱼类作为重要的蛋白质来源的低收入农村人口；依靠淡水渔业维持生计的低收入渔民和渔业人员。
- 虽然水污染在拉美、非洲和亚洲变得日益严重，不过这三大洲大部分河流情况仍然良好，在防止河流进一步受到污染和恢复受污染的河流方面有较大的可能性。要完成这些任务，需要将管理、技术和良好治理相结合。
- 现在有很多种管理和技术方案可供发展中国家使用，来控制水污染。在这些方案中，有许多方案是数十年前发达国家在面临类似的水质恶化问题时尚未提出或未被利用的。
- 监督和评估水质是了解全球水质问题严重性和范围不可或缺的重要方面。但是在全球许多地方数据覆盖不足，未能满足这一要求。例如，在非洲，水质测量站的密集度仅是全球其他水质监测点的百分之一。因此，当前一项紧急任务是通过国际 GEMS/水计划和其他活动来扩大水质数据的收集、分发和分析。本报告中提及的水污染热点区域可用于设置数据收集优先顺序。

无论是人们，还是生态系统，都需要*足量*且*质量*达标的水。因此，对*水质不达标或水处理不充分*的地方进行评估并将对优质水的需求纳入水安全的理念，是迫在眉睫的要务。本报告重点阐述了水质及其与卫生、食品安全和水安全等发展目标的关系。为体现这一关联性，本报告回顾了关于地表水的重要水质问题，包括病原菌污染、有机污染、盐度污染和富营养化问题。重点关注三大洲：拉美、非洲和亚洲。

在过去几年，增强水安全一直是全球优先要务。通过千年发展目标和其他积极努力，国际社会优先考虑了水安全的*数量*方面，增加人们使用安全水源的机会。的确，为人们、工业和农业提供*足量*的水一直是国际社会优先考虑的要务。

不过，水安全的另一方面现在变得日益重要——确保淡水的水质足够*优质*。由于全球的河流湖泊的水质正出现重要变化，这个方面成为人们的关注焦点。现在水质日益成为人们优先考虑的方面，这在可持续发展目标的各种具体目标中都有体现。

许多发达国家的水质都有了明显的提高，不过仍存在一些问题。而在发展中国家，由于城市人口增长，物质消耗增加，未经处理的废水量增加，出现了水污染日益严重的趋向。不过，全球大部分地区的淡水生态系统的实际状况由于缺乏基本信息，只能进行推测。因此，现在迫切需要进行相关评估以确定“全球水质问题”的范围与规模。这种*预研究*的目的在于为全球全面的水质评估提供某些基础，这种评估可升级为全面评估。而且这种预研究也针对全球淡水生态系统的水质状况提供了初步评估，重点关注拉美、非洲和亚洲这三大洲的河流湖泊。

自上世纪九十年代以来，拉美、非洲和亚洲的大部分河流受污染的现象不断加剧。[1]

本报告对 1990 年至 2010 年河流重要参数的变化进行了评估，这些参数反映了病原菌污染（粪大肠菌）、有机污染（生化需氧量 (BOD)）和盐度污染（总溶解固体 (TDS)）情况。在这三大洲超过 50% 的河流出现病原菌污染和有机污染加剧的现象，而有近三分之一的河流出现盐度污染加剧的现象[2]。在这些河流的某些分支中，水污染已达到严重程度，或在 1990 年已处于严重程度，到 2010 年污染加剧，这种情况令人格外担忧。

拉美、非洲和亚洲所有河流中约有三分之一已受到病原菌的严重污染[3]。在这三大洲中因接触受污染的地表水而面临健康风险的农村人口数量可能达到几亿。最易面临风险的人群为妇女与儿童。

根据预估，约有 1/4 的拉美河流、约有 10-25% 的非洲河流以及约有 1/3-1/2 的亚洲河流存在严重的病原菌污染（每月河流中粪大肠菌浓度为 > 1000 cfu/100ml[4]）。由此可见，在这三大洲中，亚洲河流的病原菌污染情况最为严重。就可能与地表水接触的农村人口[5]数量而言，预计在拉美约有 800 万至 2500 万、在非洲约有 3200 万至 1.64 亿、在亚洲约有 3100 万至 1.34 亿人面临健康风险。这些预估值的宽泛范围说明关于实际风险仍有许多未知因素，处于风险的人口数量可能十分庞大。这些预估值并不包含与受污染的灌溉水接触的务农者，也不包含城市住民。

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[1] 本报告采用了以下联合国环境规划署的“全球环境展望”子区域来界定“拉美”、“非洲”和“亚洲”：

拉美 = 中美、南美、加勒比海区；

非洲 = 中非、东非、北非、南非、西非、西印度洋；

亚洲 = 中亚、东北亚、南亚、东南亚、西亚地区（阿拉伯半岛，马什里克 ）

[2] 在本摘要中，分析结果采用了取整的数字。鉴于基础评估数据的不确定性，因此采用取整的结果较为合适。正文提及了这些基础评估数据。

[3] 脚注 5 对病原菌污染的严重程度进行了定义。受到这种污染的水体可能含有一定程度的病原菌，高含量的粪大肠菌说明了这点，意味着与这些水体接触的人面临较高的健康风险。

[4] 粪大肠菌浓度的标准单位为每 100 毫升的水样中的“菌落形成单位”(cfu)。

[5] 这包括与存在病原菌严重污染的河流接触的人群 (x > 1000 cfu/100ml)

特别遭受这种健康风险的人群为妇女与儿童，这是因为妇女们需要经常取用来自河流湖泊的水洗衣、做饭并将其作为家庭饮用水来源；儿童经常在当地地表水中玩耍且还经常要完成为家里取水的任务。

值得一提的是 1990 年至 2010 年在拉美、非洲和亚洲的所有河流中近三分之二的河流的粪大肠菌浓度增加。具有“令人特别担忧的粪大肠菌浓度增加趋势”[6]的河流相当于这三大洲河流总公里数四分之一左右，这些河流的粪大肠菌污染在 1990 年已上升到或处于严重程度，截止 2010 年情况更加恶化。这些河流可被视为污染重区。

粪大肠菌浓度增加的很大一部分原因是由于排污系统将未经处理的废水排入地表水。一方面，排污系统将废水从人口密集的地区排走，降低了陆地因不安全的卫生惯例造成的健康风险。而另一方面，排污系统将未经处理的污水排泄到地表水，从而将健康风险转移到地表水。有人预估，如未建立排污系统，在 2010 年非洲河流中的粪大肠菌数量可能减少 23%。不过，要解决这个问题，不是减少修建排污系统，而是要对排污系统收集的废水进行处理。

拉美、非洲和亚洲所有河流中每七公里就有一公里受到严重的有机污染。有机污染的严重程度与其加剧的趋势给淡水渔业以及相关的食品安全和民生都带来了困扰。受有机污染影响的群体，包括依靠淡水鱼作为饮食中蛋白质主要来源的贫穷农村人口和依靠淡水渔业维持生计的低收入渔民和渔业人员。

有机污染由大量的可分解有机复合物释放至地表水体造成。这些复合物的分解经常导致河流的溶解氧来源锐减，溶解氧是鱼类和其他水生动物生存所不可或缺的。

来自内陆水体的鱼类是发展中国家人群的饮食中蛋白质的重要来源之一。从全球角度而言，内陆渔业是动物蛋白质的第六大重要来源，不过在某些发展中国家，内陆鱼类的捕集数量占据这些国家的动物蛋白质供应数量的 50% 以上。

内陆捕集渔业也是发展中国家的一个重要生计来源。在发展中国家，内陆渔业为 2100 万渔民提供谋生机会并提供 3850 万个相关就业机会。 这些谋生机会几乎都是在小规模渔业中，从事这些工作的大部分人都属于低收入人群，其中妇女占了总劳动力的一半以上。来自拉美、非洲和亚洲的所有测量数据中至少有 10% 显示对渔业健康发展特别重要的五个水质参数中至少有三个存在不同程度的问题，这种现象令人堪忧。

根据预估报告，在 2010 年，严重的有机污染（指每月河流中生化需氧量的浓度 ＞ 8 mg/l）对多达十分之一左右的拉美河流、七分之一左右的非洲河流以及六分之一左右的亚洲河流造成了影响。

1990 年至 2010 年,在拉美、非洲和亚洲的所有河流中近三分之二的河流出现有机污染（由河流生化需氧量浓度增加显示）加剧，这同样令人堪忧。具有“粪大肠菌浓度增加趋势引发特别担忧”的河流分支相当于这三大洲河流总公里数十分之一左右，这些河流的生化需氧量在 1990 年上升到或处于严重程度，截止 2010 年情况更加恶化。这些河流可被视为污染重区。

拉美、非洲和亚洲所有河流中约有十分之一受到中度至重度的盐度污染，水中的高盐度使得将河流水用于灌溉、工业和其他用途受到限制，令人担忧。受盐度污染影响的人群包括贫穷的务农者，他们依靠地表水作为灌溉其小块农田的水源。

当河流湖泊中溶解的盐分和其他物质达到足够高的浓度，阻碍人们对这些水体的利用时，即出现了“盐度污染”。由于河流流域中的土壤和岩石风化作用，几乎所有河流都含有某些盐分，而人们将含盐的灌溉回流水、生活废水和来自矿场的径流排泄至河流，也导致河流的含盐量大幅提高。

比起病原菌污染或有机污染，盐度污染在本报告中研究的三大洲的影响范围相对较小。但是，中度至严重的盐度污染（即，每月河流的总溶解固体浓度 ＞ 450 mg/l）对三大洲的河流都造成了不同程度的影响，在拉美每二十公里的河流就有一公里河流受到盐

[6] 本报告中的“令人特别担忧的粪大肠菌浓度增加趋势”表示污染在 2008-2010 年达到严重级别，或在 1990-1992 年已处于严重污染级别，之后在 2008-2010 年粪大肠菌浓度进一步增加。

度污染影响，而在非洲、亚洲受到影响的河流分别多达十分之一左右和七分之一左右。处于中度污染级别的河水在灌溉用途上受到部分限制，而且如未经进一步净化，就无法用于某些工业应用。受盐度污染严重影响的人群可能为贫穷的务农者，他们依靠地表水作为灌溉其小块农田的水源。

1990 年至 2010 年，在拉美、非洲和亚洲三大洲的所有河流中近三分之一的河流出现盐度污染加剧现象。这些河流的某些分支（所有河流河段的一小部分）具有“令人特别担忧的盐度污染增加趋势”，在这些河流中，总溶解固体等级在 1990 年上升到或处于严重级别，截止 2010 年情况更加恶化。

人类活动产生的养分排放到大型湖泊中的现象十分严重，会造成或进一步恶化这些湖泊的富营养化现象。水体富营养化趋势在全球不同地方有所不同。

富营养化指湖泊与其他水体养分过足，导致其自然进程受到破坏。湖泊的富营养化通常由人为因素产生的大量磷导致，不过大量的氮也可能会促成这种现象。在全球 25 个大型湖泊中有 23 个其总磷量的一半以上源自人为因素[7]。此外，拉美和非洲的大部分大型湖泊存在养分负荷增加的情况。相比之下，由于采取了有效的减少磷的措施，在北美和欧洲湖泊承受的养分负荷正在减少。

造成日益严重的水污染问题的直接原因是排泄到河流与湖泊中的废水不断增多。当前最重要的污染源因污染物而有所不同。而人口增长、经济活动增加、农业密集化与扩大化、未经处理或处理程度极有限的污水量日益增多，是导致水污染的根本原因。

利用排污系统收集废水减少了人们与废水和病原菌的直接接触，这种方式对保护公众健康十分重要。但是，修建排污系统同时也导致将污染物集中排放到地表水，给人们健康带来风险。

在拉美病原菌污染（粪大肠菌污染）的最大来源是来自排污系统的生活用水，在非洲则是未经排污系统直接排放的生活用水，在亚洲则是来自排污系统的生活用水（紧接着便是未经排污系统直接排放的生活用水）。

在拉美有机污染（生化需氧量污染）的最大来源是来自排污系统的生活用水，在非洲则是未经排污系统直接排放的生活用水，在亚洲则是来自工业领域的废水。

在拉美盐度污染（总溶解固体污染）的最大人为因素来源是工业，在非洲和亚洲则是灌溉型农业。

在拉美与人为因素相关、向大型湖泊排放磷的重要污染源为家畜粪便和无机化肥，在非洲则是家畜粪便，而在亚洲和欧洲则是生活废水、家畜粪便和无机化肥，在北美则是无机化肥。

虽然水污染在拉美、非洲和亚洲变得日益严重，不过这三大洲大部分河流的情况仍然良好,在防止进一步污染和恢复具有恢复必要性的河流上有较大的可能性。

在前面几点中，重点阐述了水质差且在进一步恶化的河流的广阔河段。不过，另一方面，不少河流的许多河段*尚未遭到污染:*

- 在（拉美、非洲和亚洲的）所有河流中，约有一半至三分之二的河段出现*轻度*病原菌污染，
- 超过四分之三的河段出现*轻度*有机污染，
- 约有十分之九的河段出现*轻度*盐度污染。

现在仍有可能防止这些干净的河段遭受严重污染。而且也有可能将已被污染的河流河段恢复原貌。我们可以采取各种行动来防止污染加剧，恢复被污染的淡水水体。

1. *监控* – 对全球水质问题的严重性和范围我们应该做更多的了解。为了了解这些情况，当务之急应扩大对水质的监控，

[7] 在本报告中，“全球大型湖泊”指联合国环境规划署“全球环境展望”中提及的五个地区（非洲、亚洲、欧洲、拉美和北美）中的每个地区以湖泊表面积衡量最大的五个湖泊。

特别是在发展国家中，以及通过 GEMS/水计划加强国际社会对水质的监控。

2. *评估* – 现在需要从国家层面和国际层面对全球水质问题进行综合评估。在应对水污染问题上，要确定优先考虑的地理位置和行动必须进行此类评估。

3. *管理和技术上的新旧方案* – 发展中国家不仅可以采用传统的废水处理系统，也可以采用许多新的管理和技术方案（包括基于自然的解决方案）来控制水质。

4. *设立高效机构 – 控制水质的一个重要方面是建立可推动水污染控制行动与克服水污染控制障碍的高效机构。*

以下方面对这些观点进行详细说明：

可采取的行动：I.监控

由于在全球唯一的水质数据库 GEMStat 中地表水的水质数据缺乏，因此无法进行全球水质的综合评估。

在美国和欧洲每 10,000 km^2 河流流域约有 1.5-4 个监控站，这是常见的最低监控站密度，相比之下，GEMStat 所具有的监控站密度很低。在 GEMStat 中，有数据可循的 110 个河流流域中有 71 个流域的站点密度为每 10,000 km^2 有 0.5 个站点或更少。

在 1990 年至 2010 年期间，拉美监控站点平均密度为每 10,000 km^2 有 0.3 个站点，非洲则为[8]每 10,000 km^2 有 0.02 个站点，亚洲则为每 10,000 km^2 有0.08 个站点。

现在，当务之急是要从时间和空间角度扩大监控站点的覆盖面，而不是增加现有站点收集到的参数数量。鉴于水质监控成本高昂，务必确定应首先监控哪些数据缺乏的河流，将此作为优先考虑事项。本报告中确定的重点区域在决定应在何处加强监控力度时作为参考资料。

水质数据涵盖面小有政治、机构和技术方面的原因。不过要扩大水质数据涵盖面有多种可选方案。

一种方案是利用远程感应数据。当前的数据集涵盖湖泊的重要水质变量，在不久的将来，也将可以提供河流相关数据。远程感应的一个优势在于可从时间和空间角度实现宽泛的数据涵盖面；弊端则包括可测量的变量数量有限，要对原始数据进行处理。

扩大水质数据的涵盖面的其他方案有：(i) 通过更积极的努力，将国家范围和区域范围的数据纳入现有数据库；(ii) 建立国家淡水监控工作组，与其他国家的同行人员共享和一起使用水质数据；(iii) 通过公民科学项目检索数据。公民科学具有动员公众消除水污染的额外优势。

还应在收集数据方面做出积极努力，让这些数据得到广泛利用，并且通过“联合国环境规划署在线”数字平台实现数据检索。还应让与可持续发展目标的实施和监督相关的数据得到广泛利用。

可采取的行动：II.评估

需要进行全面的全球水质评估，以对有关水质所有重要方面的信息情况进行评估，将水质和其他 2015 年后发展问题（如卫生和食品安全）相关联，并确定在开展研究和采取行动方面优先考虑的区域。

这种评估应具有：

- 多层面——具有全球覆盖性，与国家评估和专题评估相关联。
- 透明性和参与性——参加人员包括各种利益相关者和科学家。

这种评估应包括/实现：

- 由政策制定团体和科学人员团体共同选定的对象和主题。

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[8] 旱地区域未包括在这些陆地区域中。

- 对保护和恢复水质的政策方案的分析。
- 评估结果可被广泛利用（通过“联合国环境规划署在线”等新的数字平台实现）。

还应通过评估提高发展中国家的技术能力，增加他们接触最新科学成果的机会。

<u>可采取的行动：3.管理与技术方案</u>

发展中国家可利用许多方案来避免其河流湖泊水质恶化。在这些方案中有许多方案是数十年前发达国家在面临类似的水质恶化问题时尚未提出或未被利用的。

主要的技术方案有：

(i) *污染防止型方案*，这种方案在水污染成为问题前遏制污染源。

(ii) *污水处理型方案*，这种方案是在污染物排放至地表水之前减少污染物数量的传统方法。

(iii) *废水安全利用型方案*，这种方案对废水进行回收，用于灌溉和其他用途。

(iv) *“基于自然的解决方案”，这种方案涉及生态系统的恢复和保护*，例如在集水区重建林地以减少对河流的侵蚀和对其施加的沉积物负荷，或恢复湿地以消除来自城市或农业径流的污染物。

这些标题下的许多新理念是发达国家在三十年前或更多年前首次面对类似的水质恶化问题时未曾出现的。这些新理念有：*工业实现更清洁的生产*、*建设湿地*、*污水零排放*、以及*林区水源生态系统服务有偿使用*。

需要采用不同的技术策略来控制各种不同的水污染和污染源。尝试这些不同的策略并将其整合和应用于各种不同的河流流域，这是有意义的行动。

一方面，如上所述，不同类型的水污染主要的污染源不同。这意味着“通用型”方案不能解决全球水质问题。另一方面，即使地理位置和具体情况可能差别很大，但类似的水质问题在全球范围内均存在。因此，可以针对各种河流流域开发不同的技术方案包以解决类似问题。

<u>可采取的行动：IV.管理与机构</u>

不同的河流流域个案研究表明良好的治理与高效的机构对控制水质具有重要作用。

人们发现应对水污染问题的重要障碍包括：

- 在某一河流流域管辖部门职权分散、
- 缺乏技术能力、
- 缺乏从公众利益出发了解水污染的原因的意识。

个案研究的经验表明，要克服这些障碍和其他障碍，需要首先发起公众教育活动以获得控制水污染的支持。另外一个经验是针对某一河流流域，所有主要行动参与者一致同意实施的*行动方案*是恢复河流湖泊的关键一步。对于跨国河流的另一个重要的机构步骤则是设立*协作机构*，例如针对易北河流和沃尔特河流设立的国际委员会，在制定和实施行动方案方面发挥作用。易北河事例也说明了影响范围宽泛的国际机构（易北河流域社区）可对实现某一河流流域的所有重要*国家*参与者之间的合作提供宝贵的平台。

应对全球水质问题与社会的其他许多要务（例如食品安全和卫生）紧密相关。因此，保护水质的各项行动应融于更广泛的可持续性发展理念中，成为实现新的可持续性发展目标举措的内在组成部分。

事例研究表明保护水质这一挑战与社会许多其他任务——提供粮食、发展经济、以安全方式确保卫生——紧密关联。因此，在今后多年内将水质目标与 2015 年后发展议程的其他目标以及新的可持续发展目标紧密联系变得十分重要。

Executive Summary

Main messages

- Good water quality, together with an adequate quantity of water, are necessary for achieving the Sustainable Development Goals for health, food security and water security. Therefore it is of concern that water pollution has worsened since the 1990s in the majority of rivers in Latin America, Africa and Asia.
- It is important that actions to protect and restore water quality are linked to efforts to achieve the Sustainable Development Goals and the Post 2015 Development Agenda.
- Severe pathogen pollution already affects around one-third of all river stretches in Latin America, Africa and Asia. In addition to the health risk of drinking contaminated water, many people are also at risk of disease by coming into contact with polluted surface waters for bathing, clothes cleaning and other household activities. The number of rural people at risk in this way may range into the hundreds of millions on these continents.
- Severe organic pollution already affects around one-seventh of all river stretches in Latin America, Africa and Asia and is of concern to the state of the freshwater fishery and therefore to food security and livelihoods.
- Severe and moderate salinity pollution affects around one-tenth of all river stretches in Latin America, Africa and Asia and is of concern because it impairs the use of river water for irrigation, industry and other uses.
- The immediate cause of increasing water pollution is the growth in wastewater loadings to rivers and lakes. Ultimate causes are population growth, increased economic activity, intensification and expansion of agriculture, and increased sewerage hook-ups with no or a low level of treatment.
- Among the groups most vulnerable to water quality deterioration in developing countries are women because of their frequent usage of surface water for household activities, children because of their play activities in local surface waters and because they often have the task of collecting water for the household, low income rural people who consume fish as an important source of protein, and low income fishers and fishery workers who rely on the freshwater fishery for their livelihood.
- Although water pollution is serious and getting worse in Latin America, Africa, and Asia, the majority of rivers on these three continents are still in good condition, and there are great opportunities for short-cutting further pollution and restoring the rivers that are polluted. A mix of management and technical options supported by good governance will be needed for these tasks.
- A wide range of management and technical options are available to developing countries for water pollution control. Many of these options were not available or used by developed countries when confronted with similarly deteriorating water quality decades ago.
- Monitoring and assessment of water quality are essential for understanding the intensity and scope of the global water quality challenge. Yet the coverage of data in many parts of the world is inadequate for this purpose. For example, the density of water quality measuring stations in Africa is one hundred times lower than the density used elsewhere in the world for monitoring. An urgent task is therefore to expand the collection, distribution, and analysis of water quality data through the international GEMS/Water Programme and other activities. Hot spot areas of water pollution identified in this report can be used to set priorities for data collection.

People and ecosystems require both an adequate *quantity* of water as well as an adequate *quality* of water. Therefore, it is urgent to assess where *water quality is inadequate or under threat* and to incorporate the need for good water quality into the concept of water security. This report focuses on water quality and its relation to development objectives such as health, food security and water security. To make this connection, the report reviews important water quality problems in surface waters including pathogen pollution, organic pollution, salinity pollution and eutrophication. The focus is on three continents: Latin America, Africa, and Asia.

Enhancing water security has been an international priority for the last several years. Through Millennium Development Goals and other efforts, the international community has given priority to the quantity side of water security by expanding the access of people to a safe water supply. Indeed, delivering an adequate amount of water to people, to industry, and to agriculture is, and should remain, a high international priority.

But another dimension of water security is becoming increasingly important – ensuring that freshwaters have an adequate quality of water. This is of concern because the water quality of the world's rivers and lakes is going through important changes. The growing priority being given to water quality is reflected in various targets in the Sustainable Development Goals.

Water quality has markedly improved in many developed countries, although some problems persist. Meanwhile, in developing countries the tendency is towards increasing water pollution as urban populations grow, material consumption increases and untreated wastewater volumes expand. But the actual situation of water quality in freshwater ecosystems in much of the world can only be conjectured because of the lack of basic information. Therefore, an assessment is urgently needed to identify the scope and scale of the "global water quality challenge". This pre-study aims to provide some of the building blocks for a full-scale world water quality assessment that can be scaled up to a full assessment. It also presents a preliminary estimate of the water quality situation of freshwater ecosystems in the world, with an accent on rivers and lakes on three continents.

Water pollution has worsened since the 1990s in the majority of rivers in Latin America, Africa, and Asia.[1]

Changes between 1990 and 2010 in key parameters in rivers reflecting pathogen pollution (faecal coliform bacteria), organic pollution (biochemical oxygen demand; BOD), and salinity pollution (total dissolved solids; TDS) have been estimated. The level of pathogen pollution and organic pollution worsened in more than 50 per cent of river stretches on all three continents, while salinity pollution worsened in nearly a third[2]. The worsening is of particular concern in a subset of these river stretches where water pollution has increased to a severe level, or was already at a severe level in 1990 and had worsened by 2010.

Severe pathogen pollution[3] already affects around one-third of all river stretches in Latin America, Africa and Asia. The number of rural people at risk to health by coming into contact with polluted surface waters may range into the hundreds of millions on these continents. Among the most vulnerable groups are women and children.

Severe pathogen pollution (where monthly in-stream concentrations of faecal coliform bacteria are > 1000 cfu/100ml[4]) is estimated to affect around a quarter of Latin American river stretches, around 10 to 25 per cent of African river stretches and about a third to one-half of Asian river stretches. Hence, of the three continents, the extent of pathogen pollution appears to be greatest in Asia. Taking into account the fraction of rural population that is likely to come into contact with surface waters[5] it is estimated that approximately 8 to 25 million people are at risk in Latin America, 32 to 164 million in Africa and 31 to 134 million in Asia. The wide range of these estimates shows that there are still many unknowns about the actual risk, but also that the numbers of people at risk are likely to be very large. These estimates do not include farmers exposed to contaminated irrigation water, nor people living in cities.

[1]In this report the following UNEP "Global Environmental Outlook" sub-regions are used to define "Latin America", "Africa", and "Asia":
Latin America = Central America, South America, Caribbean;
Africa = Central Africa, Eastern Africa, Northern Africa, Southern Africa, Western Africa, Western Indian Ocean;
Asia = Central Asia, North East Asia, South Asia, South East Asia, West Asia region (Arabian Peninsula, Mashriq)
[2]In this summary, rounded figures are used for the results of analyses. It is appropriate to present rounded results considering the uncertainties of the underlying estimates. The main text presents these underlying estimates.
This includes people coming into contact with rivers that have a severe level of pathogen pollution (x > 1000 cfu/100ml)
[3]A severe level of pathogen pollution is defined in Footnote 5. Such water bodies are likely to have a level of pathogens as indicated by a high level of faecal coliform bacteria, implying that people coming into contact with these waters are exposed to a high health risk.
[4]The standard units of fecal coliform concentrations are "colony-forming units" (cfu) per 100 ml of water sample.
[5]This includes people coming into contact with rivers that have a severe level of pathogen pollution (x > 1000 cfu/100ml)

At particular risk are women because of their frequent usage of water from rivers and lakes for cleaning clothes and collecting water for cooking and drinking in the household, and children because of their play activities in local surface waters and also because they often have the task of collecting water for the household.

It is worth noting that concentrations of faecal coliform bacteria have increased between 1990 and 2010 in almost two-thirds of all rivers in Latin America, Africa and Asia. The river stretches with an "increasing trend of particular concern"[6] amount to about one-quarter of the total kilometres of rivers in these continents where faecal coliform bacteria levels increased to a severe level, or were at a severe level in 1990 and worsened by 2010. These can be considered hot spot areas.

A large fraction of the increase is due to the expansion of sewer systems that discharge wastewater untreated into surface waters. On one hand, by taking the wastewater away from populated areas, the sewers have reduced the health risk posed by unsafe sanitation practices on land. On the other hand, by dumping sewage untreated into surface waters, they have transferred the health risk from the land to surface waters. It was estimated that if sewers had not been built, fecal coliform loadings into African rivers in 2010 might have been 23 per cent smaller. The solution, however, is not to build fewer sewers, but to treat the wastewater they collect.

Severe organic pollution already affects around one out of every seven kilometres of all river stretches in Latin America, Africa and Asia. The high level of organic pollution and its increasing trend is of concern to the state of the freshwater fishery and therefore to food security and livelihoods. Groups affected by organic pollution include poor rural people that rely on freshwater fish as a main source of protein in their diet and low income fishers and workers who rely on the freshwater fishery for their livelihood.

Organic pollution is caused by the release of large quantities of decomposable organic compounds into surface water bodies. The breakdown of these compounds often leads to a serious reduction in the dissolved oxygen resources of a river relied upon by fish and other aquatic fauna.

Fish from inland waters make up an important part of the protein in the diet of people in developing countries. Globally, the inland fishery is the sixth most important source of animal protein, but in some developing countries the catch of inland fish accounts for more than 50 per cent of the animal protein produced within that country.

Inland capture fisheries are also an important source of livelihood in developing countries. Inland fisheries in developing countries provide employment for 21 million fishers and 38.5 million related jobs. Almost all of these were in small scale fisheries, occupied by mostly low income people, with over half of the total workforce being women. It is therefore disquieting that at least 10% of all measurements from Latin America, Africa, and Asia show levels of concern for at least three out of five water quality parameters of particular importance to the health of fisheries.

In 2010, severe organic pollution (where monthly in-stream concentrations of BOD are > 8 mg/l) is estimated to affect up to around one-tenth of Latin American river stretches, up to about one-seventh of African river stretches, and up to about one-sixth of Asian river stretches.

It is also of concern that organic pollution (as indicated by increasing river concentrations of BOD) has increased between 1990 and 2010 in almost two-thirds of all rivers in Latin America, Africa and Asia. A subset of these river stretches with an "increasing trend of particular concern" amount to about one-tenth of the total kilometres of rivers in these continents where BOD levels increased to a severe level, or were at a severe level in 1990 and worsened by 2010. These can be considered hot spot areas.

Severe and moderate salinity pollution already affects around one-tenth of all river stretches in Latin America, Africa and Asia and is of concern because high salinity levels impair the use of river water for irrigation, industry and other uses. Groups affected by salinity pollution include poor farmers that rely on surface waters as a source of irrigation water for their small holdings.

"Salinity pollution" occurs when the concentration of dissolved salts and other substances in rivers and lakes is high enough to interfere with the use of these waters. Although almost all rivers have some salt content because of weathering of soils and rock in their drainage basin, society has greatly increased these levels by discharging salt-laden irrigation return flows, domestic wastewater and runoff from mines into rivers.

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[6]"Increasing trend of particular concern" in this report means a pollution level that increased into the severe pollution category in 2008–2010, or was already in the severe pollution category in 1990-1992 and further increased in concentration by 2008–2010.

Saline pollution is less widespread than pathogen or organic pollution on the continents studied. Nevertheless, moderate and severe salinity pollution together (i.e., where monthly in-stream concentrations of TDS are > 450 mg/l) affect one out of every twenty kilometres of rivers in Latin America, up to about one-tenth of river stretches in Africa, and up to about one-seventh of river stretches in Asia. River water in the moderate pollution category is partly restricted for use in irrigation, and cannot be used for some industrial applications without further purification. Particularly affected may be poor farmers who rely on surface waters as a supply of irrigation water for their small holdings.

Salinity pollution has increased between 1990 and 2010 in almost one-third of all rivers on the three continents. A subset of these river stretches (a few percent of all river reaches) have an "increasing trend of particular concern" in which TDS levels increased to a severe level, or were at a severe level in 1990 and worsened by 2010.

Anthropogenic loads of nutrients to major lakes are significant and may cause or further advance eutrophication of these lakes. The trends of these loads are different in different parts of the world.

Eutrophication is the over-fertilisation of lakes and other water bodies which leads to a disruption of their natural processes. Lake eutrophication is usually caused by anthropogenic loads of phosphorus, but loads of nitrogen can also play a role. More than half of the total phosphorus loads in 23 out of 25 major lakes[7] worldwide are from anthropogenic sources. In addition, most of the major lakes in Latin America and Africa have increasing loads. By comparison, loads are decreasing in North America and Europe because of effective phosphorus-reducing measures.

The immediate cause of increasing water pollution is the growth in wastewater loadings to rivers and lakes. The most important current sources of pollution vary from pollutant to pollutant. Ultimate causes of growing water pollution are population growth, increased economic activity, intensification and expansion of agriculture, and increased sewerage with no or low level of treatment.

Collecting wastewater in sewers reduces the direct contact of people with wastes and pathogens and in this way is an important strategy for protecting public health. However, building sewers has also concentrated the discharge of pollutants into surface waters and shifted the location of health risk to people.

The largest source of pathogen pollution (loadings of faecal coliform bacteria) in Latin America is domestic wastewater from sewers, for Africa it is non-sewered domestic waste, and for Asia it is domestic wastewater from sewers followed closely by non-sewered domestic waste.

The largest source of organic pollution (BOD loadings) in Latin America is domestic wastewater from sewers, for Africa it is non-sewered domestic waste, and for Asia it is wastewater from the industrial sector.

The largest anthropogenic source of salinity pollution (loadings of TDS) in Latin America is industry, and in Africa and Asia it is irrigated agriculture.

Important sources of anthropogenic phosphorus to major lakes in Latin America are livestock wastes and inorganic fertiliser, in Africa livestock wastes, in Asia and Europe domestic wastewater, livestock wastes and inorganic fertiliser, and in North America inorganic fertiliser.

Although water pollution is serious and getting worse in Latin America, Africa, and Asia, the majority of rivers on these three continents are still in good condition, and there are great opportunities for short-cutting further pollution and restoring the rivers that need to be restored.

In previous points the focus was on the extensive reaches of rivers where water quality is poor and further deteriorating. But the other side of the coin is that many stretches of rivers *are not yet polluted:*

- About one half to two-thirds of all river reaches (in Latin America, Africa and Asia) have a *low* level of pathogen pollution
- More than three-quarters have a *low* level of organic pollution, and
- About nine-tenths have *low* salinity pollution.

It is still possible to prevent these clean river reaches from becoming heavily polluted. It is also possible to begin restoring the river reaches that are already polluted. Many actions can be taken to avoid the increase in pollution and restore polluted freshwaters:

[7] In this report "major world lakes" means the five largest lakes in terms of lake surface area in each of five UNEP "Global Environmental Outlook" regions (Africa, Asia, Europe, Latin America, and North America).

1. *Monitoring* – More understanding is needed about the intensity and scope of the global water quality challenge. For this understanding, it is urgent to expand the monitoring of water quality, especially in developing countries, and especially at the international level through GEMS/Water.
2. *Assessments* – Comprehensive national and international assessments of the global water quality challenge are needed. These assessments are needed for pointing the way to priority locations and actions for dealing with water pollution.
3. *New and old management and technical options* – Developing countries have an opportunity to not only employ traditional wastewater treatment, but also to draw on many more new management and technical options for managing water quality including nature-based solutions.
4. *Setting up effective institutions* – An essential part of managing water quality is setting up institutions that promote action and overcome barriers to controlling water pollution.

These ideas are elaborated in the following points:

What can be done: I. Monitoring

Comprehensive assessments of global water quality are not possible because of the poor coverage of water quality data of surface waters in GEMStat, the only global water quality data base.

GEMStat has a very low density of stations as compared to typical minimum densities of around 1.5 to 4 stations per 10,000 km^2 of river basin area in the USA and Europe. In GEMStat, 71 out of the 110 river basins with data have a density of 0.5 stations per 10,000 km^2 or less.

The average density for the Latin American continent is 0.3 stations per 10,000 km^2, for Africa 0.02 stations[8] per 10,000 km^2, and for Asia 0.08 stations per 10,000 km^2 for the time period between 1990 and 2010.

The highest priority is to expand the temporal and spatial coverage of monitoring stations rather than increase the number of parameters collected at existing stations. Considering the high costs of monitoring it is important to set priorities on which data-deficient rivers should be monitored first. The hot spot areas identified in this report can be used as input in deciding where to expand monitoring efforts.

The reasons for poor data coverage are political, institutional, and technical. But there are many alternatives for improving coverage of water quality data.

One alternative for improving coverage is to make use of remote sensing data. Current data sets cover key water quality variables for lakes, and in the near future data will become available for rivers. An advantage of remote sensing is the extensive spatial and temporal coverage of the data; disadvantages include the limited number of variables that can be measured and the processing of raw data that is required.

Other options for improving coverage of water quality data are: (i) increasing efforts to incorporate national and regional data into existing databases, (ii) establishing national freshwater monitoring working groups to work with their counterparts in other countries on sharing and using water quality data, (iii) retrieving data through citizen science projects. Citizen science has the added advantage of engaging a wider public in cleaning up water pollution.

Data collection efforts should also strive to make these data widely available and retrievable through a digital platform such as "UNEP Live". Data should also be made widely available in connection with the monitoring and implementation of the Sustainable Development Goals.

What can be done: II. Assessment

A full scale World Water Quality Assessment is needed to assess the state of knowledge about all critical aspects of water quality, to make linkages between water quality and other Post 2015 Development issues such as health and food security, and to identify priority areas for study and actions.

The assessment should be:

- Multi-level – with global coverage linked to national assessments and thematic assessments.
- Transparent and participatory – involving a wide range of stakeholders and scientists.

[8]Dryland areas are not included in the continental area.

The assessment should include:

- Objectives and themes that are jointly selected by the policy and science communities.
- An analysis of policy options for protecting and restoring water quality.
- Wide access to results by making them available on new digital platforms (e.g. "UNEP Live").
- The assessment should also be used as an opportunity to increase the technical capacity of developing countries and their access to the latest scientific results.

What can be done: III. Management and Technical Options

There are many options available to developing countries for avoiding the water quality deterioration of their rivers and lakes. Many of these options were not available or used by developed countries when confronted with similarly deteriorating water quality decades ago.

The main technical options are:

(i) *Pollution prevention* in which the source of water pollution is avoided before it becomes a problem.

(ii) *Treatment of polluted water* which is the traditional approach to reducing the loading of pollutants before they are discharged into surface waters.

(iii) *The safe use of wastewater* recycling it for irrigation and other uses.

(iv) *"Nature-based solutions" involving the restoration and protection of ecosystems*, such as re-establishing woodlands in catchments in order to reduce erosion and sediment loadings to rivers or restoring wetlands to remove pollutants from urban or agricultural runoff.

Under these headings there are many new ideas that were not available to developed countries when they first confronted similarly deteriorating water quality three or more decades ago. Among these new ideas are: *cleaner production in industry*, *constructed wetlands*, *zero effluent discharges*, and *payment for ecosystem services of forested headwaters.*

Different technical strategies will be needed to control the diverse types of water pollution and sources of pollution. It is worthwhile to try and cluster these strategies into packages that can be applied to many different river basins.

On one hand, it was noted above that the main sources of pollution differ between the different kinds of water pollution. This means that a "one size fits all" option will not work to solve the global water quality challenge. On the other hand, similar water quality challenges are occurring around the world even if the locations and situations are very different. Therefore, it may be possible to develop different packages of technical options that can be used in many different river basins to deal with similar problems.

What can be done: IV. Governance and Institutions

Case studies of different river basins pointed out the importance of good governance and effective institutions for managing water quality.

It was found that important barriers to coping with water pollution problems include:

- Fragmentation of authority within a river basin,
- Lack of technical capacity, and
- Lack of awareness on behalf of the public about the causes of water pollution.

To overcome these and other barriers, experience from the case studies showed that a public education campaign is a good first measure for gaining support for water pollution control. Another lesson is that an *Action Plan*, agreed upon by all the main actors in a river basin, is a key step in restoring rivers and lakes. Yet another key institutional step for international rivers is to set up a *collaborative body* such as the international commissions on the Elbe and Volta rivers for developing and carrying out an action plan. In the case of the Elbe, it was also shown that a wide-reaching national institution (the Elbe River Basin Community) can provide a valuable platform for gaining the cooperation of all critical *national* actors within a river basin.

Coping with the global water quality challenge is closely connected to many other priorities of society such as food security and health. Therefore, actions to protect water quality should be embedded in the larger concept of sustainability, and be part of efforts to achieve the new Sustainable Development Goals.

The case studies showed that the challenge of protecting water quality is intertwined with many other tasks of society – providing food, developing the economy, and providing safe sanitation. Therefore, over the coming years it will be very important to link goals for water quality with other goals of the Post 2015 Agenda and the new Sustainable Development Goals.

Résumé analytique

Messages clefs

- La bonne qualité de l'eau, en quantité suffisante, est nécessaires afin de réaliser les objectifs de développement durable incluent des objectifs de santé, de sécurité alimentaire et hydrique. Il est en conséquence préoccupant que la pollution de l'eau se soit aggravée depuis les années 1990 dans la majorité des fleuves d'Amérique Latine, d'Afrique et d'Asie.
- Il est d'importance que des mesures pour protéger et restaurer la qualité de l'eau soient liées aux efforts pour réaliser les objectifs de développement durable et le programme de développement durable de l'après 2015.
- Plusieurs pollutions pathologiques affectent d'ores et déjà environ un tiers de toutes les étendues fluviales en Amérique Latine, Afrique et Asie. En plus du risque sanitaire que constitue le fait de boire de l'eau contaminée, de nombreuses populations encourent des risques de maladies en entrant en contact avec des eaux de surface polluées pour se baigner, nettoyer leurs vêtements et d'autres activités ménagères. Le nombre de populations rurales exposées à des risques de cet ordre peut atteindre plusieurs centaines de millions sur ces continents.
- Une pollution organique grave affecte d'ores et déjà environ un septième de toutes les étendues fluviales en Amérique Latine, Afrique et Asie et constitue un sujet de préoccupation pour l'état des ressources de pêche en eau douce et en conséquence pour la sécurité alimentaire et les moyens de subsistance.
- Des pollutions salines graves et modérées affectent environ un dixième de toutes les étendues fluviales en Amérique Latine, Afrique et Asie et constituent un sujet de préoccupation car faisant obstacle à l'utilisation de l'eau des fleuves pour l'irrigation, l'industrie et d'autres usages.
- La cause immédiate d'augmentation de la pollution des eaux est la croissance des charges d'eaux usées dans les fleuves et les lacs. Les causes premières sont constituées de la croissance démographique, l'activité économique accrue, l'intensification et l'expansion de l'agriculture et les branchements de systèmes d'égouts sans aucun ou avec un faible niveau de traitement.
- Les femmes font partie des groupes les plus vulnérables à la détérioration de la qualité des eaux dans les pays en développement du fait de leur usage fréquent des eaux de surface pour les activités ménagères, les enfants du fait de leurs activités de jeux dans les eaux de surface locales et parce qu'ils ont souvent la tâche de collecter l'eau pour le foyer, les populations rurales à faible revenu qui consomment du poisson comme source importante de protéine, et les pêcheurs et travailleurs de la pêche à faible revenu qui dépendent de la pêche en eau douce pour leur subsistance.
- Bien que la pollution de l'eau soit importante et s'aggrave en Amérique Latine, Afrique et Asie, la majorité des fleuves sur ces trois continents est encore en bon état et il existe des possibilités de limiter rapidement une pollution supplémentaire et de restaurer les fleuves pollués. Une combinaison de gestion et d'options techniques soutenue par une bonne gouvernance sera nécessaire pour réaliser ces tâches.
- Un large éventail d'options de gestion et d'options techniques est à disposition des pays en développement pour le contrôle de la pollution des eaux. Nombre de ces options n'étaient pas disponibles ou utilisées par les pays développés lorsqu'ils ont été confrontés il y a plusieurs décennies à une détérioration similaire de la qualité des eaux.
- La surveillance et l'évaluation de la qualité des eaux sont indispensables à la compréhension de l'intensité et de l'étendue du défi mondial de la qualité des eaux. Pourtant, la couverture des

données dans de nombreuses parties du monde n'est pas adéquate. Par exemple, la densité des stations de mesure de la qualité de l'eau en Afrique est cent fois plus faible que la densité des stations de surveillance ailleurs dans le monde. Une tâche urgente est en conséquence d'accroître la collection, distribution et l'analyse de données relative à la qualité des eaux via le programme international de surveillance GEMS/Water et d'autres activités. Les zones sensibles de pollution des eaux identifiées dans ce rapport peuvent être utilisées pour fixer les priorités de la collection des données.

Les populations, tout comme les écosystèmes ont besoin d'une *quantité* suffisante ainsi que d'une *qualité* optimale de l'eau. En conséquence, il est urgent d'évaluer les endroits où la *qualité de l'eau* est *insuffisante* ou menacée et d'incorporer le besoin d'une bonne qualité des eaux dans le concept général de sécurité hydrique. Ce rapport se concentre sur la qualité des eaux et sur son lien avec les objectifs de développement tels que la santé, la sécurité alimentaire et la sécurité hydrique. Afin d'établir ce lien, le rapport passe en revue des problèmes significatifs de la qualité de l'eau dans les eaux de surface telle que la pollution pathogène, la pollution organique, la pollution saline et l'eutrophisation. Le rapport se concentre sur trois continents: l'Amérique latine, l'Afrique et l'Asie.

Améliorer la sécurité hydrique a constitué une priorité internationale au cours des dernières années. Avec les Objectifs du Millénaire et d'autres efforts, la communauté internationale a donné la priorité à l'aspect *quantitatif* de la sécurité hydrique en augmentant l'accès des populations à une source d'eau sûre. En effet, faire en sorte que les populations, l'industrie et l'agriculture aient accès à une *quantité* adéquate d'eau est et devrait demeurer une priorité internationale élevée.

Mais une autre dimension de la sécurité hydrique est en train de gagner en signification – garantir que les eaux douces possèdent une *qualité* suffisante d'eau. Ce point est préoccupant car la qualité des eaux des fleuves et lacs du monde subit d'importants changements. La priorité donnée à la qualité de l'eau se reflète dans différentes cibles des objectifs du développement durable.

La qualité de l'eau s'est améliorée sensiblement dans plusieurs pays développés, malgré la persistance de plusieurs problèmes. En même temps, dans les pays en développement, la tendance est à l'augmentation de la pollution des eaux tandis que les populations urbaines croissent, que la consommation matérielle augmente et que les volumes d'eaux usées non-traitées augmentent. Mais la situation réelle de la qualité des eaux dans des écosystèmes d'eau douce dans la majorité des régions du monde peut seulement faire l'objet d'hypothèses du fait du manque d'informations de base. En conséquence, une évaluation est nécessaire de manière urgente afin d'identifier l'étendue et la portée du « défi mondial de la qualité de l'eau ». Cette *pré-étude* vise à fournir quelques-uns des éléments nécessaires à une évaluation mondiale à grande échelle de la qualité de l'eau qui puisse être transformée en une évaluation complète. Elle présente également une estimation préliminaire de la situation de la qualité de l'eau des écosystèmes d'eau douce, en mettant l'accent sur les fleuves et lacs de trois continents.

La pollution de l'eau s'est aggravée depuis les années 1990 dans la majorité des fleuves d'Amérique latine, d'Afrique et d'Asie[1].

Les changements survenus entre 1990 et 2010 ont été évalués selon les paramètres clefs des fleuves. Ces changements reflètent la pollution pathogène (bactérie coliforme fécale), la pollution organique (demande biochimique en oxygène, DBO) et la pollution saline (total de solides dissous, TDS). Le niveau de la pollution pathogène et de la pollution organique a augmenté dans plus de 50 % des étendues fluviales sur les trois continents, tandis que la pollution saline s'est aggravée dans environ un tiers d'entre elles[2]. Cette détérioration est particulièrement préoccupante dans un sous-ensemble de ces étendues fluviales où la pollution de l'eau a augmenté jusqu'à un niveau alarmant ou présentait déjà un niveau élevé en 1990 et s'était aggravé entre 1990 et 2010.

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[1]Dans ce rapport, les sous-régions du « Global Environment Outlook » du PNUD sont utilisées pour définir « l'Amérique latine », « l'Afrique » et « l'Asie »:
Amérique Latine = Amérique centrale, Amérique du sud, Caraïbes;
Afrique = Afrique centrale, Afrique de l'est, Afrique du nord, Afrique du sud, Afrique de l'ouest, Océan indien de l'ouest;
Asie = Asie centrale, Asie du nord-est, Asie du sud, Asie du sud-est, région de l'Asie de l'ouest (péninsule arabique, Machreq)
Afrique = Afrique centrale, Afrique de l'est, Afrique du nord, Afrique du sud, Afrique de l'ouest, Océan indien de l'ouest ;
Asie = Asie centrale, Asie du nord-est, Asie du sud, Asie du sud-est, région de l'Asie de l'ouest (péninsule arabique, Machreq)
[2]Dans ce résumé, des chiffres arrondis sont utilisés pour indiquer les résultats des analyses. Considérant les incertitudes des estimations sous-jacentes, présenter des chiffres arrondis est approprié. Le texte principal présente ces estimations sous-jacentes.

Une pollution pathogène grave[3] affecte d'ores et déjà environ un tiers de toutes les étendues fluviales d'Amérique Latine, d'Afrique et d'Asie. Le nombre de populations rurales exposées à des risques sanitaires par contact avec des eaux de surfaces polluées peut atteindre des centaines de millions de personnes sur ces continents. Les femmes et les enfants comptent parmi les groupes les plus vulnérables.

On estime qu'une pollution pathogène grave (dans laquelle les concentrations mensuelles dans les cours d'eau de bactéries coliformes fécales sont > à 1000 ufc/100ml[4]) affecte environ un quart des étendues fluviales d'Amérique Latine, environ 10 à 25 pourcent des étendues fluviales africaines et environ un tiers jusqu'à la moitié des étendues fluviales asiatiques. Ainsi, pour les trois continents, c'est en Asie que l'étendue de la pollution pathogène semble être la plus forte. En prenant en compte la proportion de la population rurale à même d'entrer en contact avec les eaux de surfaces[5], on estime qu'approximativement 8 à 25 millions de personnes sont exposées au risque en Amérique Latine, 32 à 164 millions en Afrique et 31 à 134 millions en Asie. Le grand éventail de ces estimations montre que de nombreuses inconnues persistent sur le risque réel, et que les nombres de personnes exposées au risque est susceptible d'être très élevé. Ces estimations n'incluent ni les agriculteurs exposés aux eaux d'irrigation contaminées, ni les populations urbaines.

Les femmes sont particulièrement exposées au risque car elles utilisent fréquemment des eaux des fleuves et des lacs pour le nettoyage des vêtements, ainsi que pour la cuisine et l'alimentation en eau potable du foyer. Les enfants sont également particulièrement exposés au risque du fait de leurs activités ludiques dans les eaux de surfaces locales et de la tâche qui leur revient souvent de collecter l'eau pour le foyer.

Il est significatif de noter que les concentrations de bactéries coliformes fécales ont augmenté entre 1990 et 2010 dans presque deux tiers de tous les fleuves d'Amérique Latine, Afrique et Asie. Les étendues fluviales présentant une « tendance à l'augmentation particulièrement préoccupante »[6] représentent environ un quart de la totalité des kilomètres des fleuves sur ces continents où les bactéries coliformes fécales ont augmenté jusqu'à un niveau grave ou étaient à un niveau grave en 1990 et qui a empiré d'ici à 2010. Ces zones peuvent être considérées comme des zones sensibles.

Une part importante de l'augmentation est due à l'accroissement des systèmes d'égout qui déchargent les eaux usées non-traitées dans les eaux de surface. D'une part, en éliminant les eaux usées des zones peuplées, les systèmes d'égout ont réduit le risque sanitaire posé par des pratiques d'évacuation dangereuses sur la terre ferme. D'autre part, en évacuant les déchets non-traités dans les eaux de surface, ils ont transféré le risque sanitaire depuis la terre ferme jusqu'aux eaux de surface. Il a été estimé que si les systèmes d'égouts n'avaient pas été construits, les charges de coliformes fécaux dans les fleuves africains en 2010 auraient pu être moindre de 23 %. Cependant, la solution ne consiste pas à construire moins d'égouts mais à traiter les eaux usées qu'ils collectent.

Une pollution organique grave affecte d'ores et déjà environ un kilomètre sur sept de toutes les étendues fluviales en Amérique Latine, Afrique et Asie. Le haut niveau de pollution organique et sa tendance à l'augmentation constituent un sujet de préoccupation pour l'état des activités de pêche en eau douce et pour la sécurité alimentaire et les moyens de subsistance. Les groupes affectés par la pollution organique comprennent les populations rurales pauvres qui dépendent des poissons d'eau douce comme source principale de protéines de leur régime alimentaire et les pêcheurs et travailleurs à faible revenu qui dépendent des activités de pêche en eau douce pour leur subsistance.

La pollution organique est causée par le rejet de larges quantités de composés organiques décomposables dans les plans d'eaux de surface. La décomposition de ces éléments conduit souvent à une grave réduction des ressources en oxygènes, alors dissoutes, d'un fleuve dont dépendent poissons et faune aquatique.

Les poissons des eaux intérieures constituent une part importante des protéines dans le régime alimentaire des populations des pays en développement. De façon générale, la pêche dans les eaux intérieures est la sixième source de protéines animales la plus importante, mais dans certains pays en développement, la proportion des poissons des eaux intérieures compte pour plus de 50 % des protéines animales produites à l'intérieur du pays.

Les activités de pêche de capture à l'intérieur des terres sont également un moyen de subsistance majeur dans les pays en développement. La pêche à l'intérieur des terres fournit du travail à 21 millions de pêcheurs et fournit

[3]Un niveau de pollution pathogène grave est défini à la note de bas de page 5. De tels plans d'eau sont susceptibles d'avoir un niveau de pathogènes tel qu'indiqué par un haut niveau de bactéries coliformes fécales, impliquant que les populations entrant en contact avec des eaux sont exposées à un risque sanitaire élevé.
[4]L'unité standard des concentrations de coliformes fécales est l' « unité formant colonie » (ufc) pour 100 ml d'échantillon d'eau.
[5]En incluant les populations entrant en contact avec les fleuves ayant un niveau grave de pollution pathogène (x > 1000 ufc/100 ml)
[6]Une « tendance à l'augmentation particulièrement préoccupante » dans ce rapport signifie un niveau de pollution qui a augmenté jusqu'à atteindre la catégorie de pollution grave en 2008–2010 ou qui était déjà das la catégorie de pollution grave en 1990–92 et dont la concentration a augmenté d'ici à 2008–2010.

38,5 millions d'emplois se rapportant à la pêche. Presque tous prennent place dans des activités de pêche à petite échelle et sont occupés en majeure partie par des populations à bas revenu, les femmes constituant plus de la moitié de la force totale de travail. Il est en conséquence inquiétant qu'au moins 10% de toutes les mesures effectuées en Amérique latine, en Afrique et en Asie montrent des niveaux préoccupants pour au moins trois des cinq paramètres de qualité de l'eau qui sont d'importance particulière pour la santé des pêcheurs.

En 2010, on a estimé que la pollution organique grave (marquée par des concentrations mensuelles dans le cours d'eau de DBO > 8 mg/l) affecte jusqu'à environ un dixième des étendues fluviales d'Amérique latine, jusqu'à environ un septième des étendues fluviales africaines et jusqu'à environ un sixième des étendues fluviales asiatiques.

Il est également préoccupant que la pollution organique (telle qu'indiquée par une concentration en augmentation des concentrations de DBO dans les fleuves) ait augmenté entre 1990 et 2010 dans presque deux tiers de tous les fleuves et toutes les rivières d'Amérique latine, Afrique et Asie. Un sous-ensemble de ces étendues fluviales présentant une « tendance à l'augmentation particulièrement préoccupante » compte jusqu'à environ un dixième de la totalité des kilomètres de fleuves dans ces continents où les niveaux de DBO ont augmenté jusqu'à un niveau grave ou étaient à un niveau grave en 1990 et qui a empiré d'ici à 2010. Ces zones peuvent être considérées comme des zones sensibles.

Des pollutions salines graves et modérées affectent d'ores et déjà environ un dixième de toutes les étendues fluviales en Amérique latine, Afrique et Asie et est préoccupante car de hauts niveaux de salinité dégradent l'utilisation des eaux fluviales pour l'irrigation, l'industrie et d'autres usages. Les groupes affectés par la pollution saline comprennent les fermiers pauvres qui dépendent des eaux de surface comme source d'eau d'irrigation pour leurs petites propriétés.

La « pollution saline » apparaît lorsque la concentration en sels dissous et autres substances dans les fleuves et les lacs est assez élevée pour empêcher les usages habituels de ces eaux. Bien que presque tous les fleuves possèdent des teneurs en sel en raison de l'usure des sols et des roches dans leur bassin de drainage, les sociétés ont largement augmenté ces teneurs en sel en déchargeant des flux de retour d'irrigation chargés en sel, des eaux usées domestiques et des déchets miniers dans les fleuves.

La pollution saline est moins répandue que la pollution pathogène ou organique sur les continents étudiés. Néanmoins, la combinaison d'une pollution saline modérée et d'une pollution saline sévère (c.à.d. marquée par des concentrations mensuelles dans le cours d'eau de TSD > 450 mg/l) affectent un kilomètre sur vingt d'étendues fluviales en Amérique latine, jusqu'à environ un dixième des étendues fluviales en Afrique et jusqu'à environ un septième des étendues fluviales en Asie. Les eaux fluviales dans la catégorie de pollution modérée sont partiellement restreintes pour l'utilisation comme eaux d'irrigation et ne peuvent être utilisées pour des applications industrielles sans purification supplémentaire. Les fermiers pauvres qui dépendent des eaux de surface comme source d'eaux d'irrigation pour leurs petites propriétés peuvent être particulièrement touchés.

La pollution saline a augmenté entre 1990 et 2010 dans presque un tiers de tous les fleuves sur les trois continents. Un sous-ensemble de ces étendues fluviales (un petit pourcentage de tous les cours d'eau) présente une « tendance à l'augmentation particulièrement préoccupante » dans laquelle les niveaux de TSD ont augmenté jusqu'à un niveau élevé ou avait atteint un niveau important en 1990 et se sont aggravés entre 1990 et 2010.

Des charges de substances nutritives d'origine anthropique dans les grands lacs sont significatives et peuvent causer ou accélérer une l'eutrophisation de ces lacs. Les tendances de ces charges sont différentes dans différents endroits du monde.

L'eutrophisation est la sur-fertilisation de lacs et d'autres étendues d'eau, ce qui conduit à une perturbation de leurs processus naturels. L'eutrophisation des lacs est habituellement causée par des charges d'origine anthropique de phosphore, mais des charges d'azote peuvent également jouer un rôle. Plus de la moitié de ces charges totales de phosphore dans 23 sur 25 grands lacs[7] à l'échelle mondiale proviennent de sources anthropiques. En sus, la plupart des grands lacs d'Amérique latine et d'Afrique présentent des charges en augmentation. En comparaison, les charges en Amérique du nord et en Europe décroissent du fait de mesures efficaces de réduction du phosphore.

[7]Dans ce rapport, « des grands lacs mondiaux » signifient les cinq plus grands lacs en terme de surface du lac dans chacune des cinq régions du « Global Environment Outlook » du PNUD (Afrique, Asie, Europe, Amérique latine et Amérique du nord).

La cause immédiate d'augmentation de la pollution des eaux est la croissance de la charge en eaux usées des fleuves et des lacs. Les plus importantes sources actuelles de pollution varient selon les polluants. Les causes premières de la pollution croissante des eaux sont la croissance démographique, l'activité économique accrue, l'intensification et l'expansion de l'agriculture et le plus grand nombre de systèmes d'égouts accrus sans ou avec un faible niveau de traitement.

La collecte des eaux usées par les égouts réduit le contact direct des populations avec les déchets et les pathogènes et constitue en ce sens une stratégie importante pour la protection de la santé publique. Cependant, la construction d'égouts a également concentré la décharge de polluants dans les eaux de surface et déplacé la location des risques sanitaires pour les populations.

La plus importante source de pollution pathogène (charge de bactéries coliforme fécales) en Amérique latine est constituée des eaux usées domestiques des systèmes d'égouts. En Afrique, ce sont les déchets domestiques non évacués par les égouts. En Asie, ce sont les eaux usées domestiques des systèmes d'égouts, suivies de près par les déchets domestiques non évacués.

La source de pollution organique la plus importante (charge en DBO) en Amérique latine est constituée des eaux usées domestiques des systèmes d'égouts. En Afrique, ce sont les déchets domestiques non évacués par les égouts. En Asie, ce sont les eaux usées industrielles.

La plus importante source anthropique de pollution saline (charge en TSD) en Amérique latine est constituée par l'industrie, et en Afrique et en Asie par l'agriculture irriguée.

D'importantes sources de phosphore anthropiques dans les lacs principaux d'Amérique latine sont les déchets issus du bétail et les engrais inorganiques. En Afrique ce sont les déchets issus du bétail. En Asie et en Europe ce sont les eaux usées domestiques, les déchets issus du bétail et les engrais inorganiques, et en Amérique du nord les engrais inorganiques.

Bien que la pollution des eaux soit grave et s'aggrave en Amérique latine, Afrique et Asie, la majorité des fleuves sur ces trois continents est encore en bon état et il existe des solutions pour réduire plus rapidement la pollution et restaurer les fleuves qui en ont besoin.

Les points précédents se focalisaient sur les parties des fleuves présentant une qualité réduite des eaux se dégradant. Mais l'autre aspect de cette situation est que de nombreuses étendues fluviales ne sont pas encore polluées:

- Entre la moitié et les deux-tiers de tous les fleuves (en Amérique latine, Afrique et Asie) présentent un faible niveau de pollution pathogène
- Plus des trois quart présentent un faible niveau de pollution organique et
- Environ neuf dixièmes présentent un faible niveau de pollution saline.

Il est encore possible de faire en sorte que ces étendues fluviales propres ne deviennent pas lourdement polluées. Il est également possible de commencer à restaurer les fleuves qui sont déjà pollués. De nombreuses mesures peuvent être prises pour éviter l'augmentation de la pollution et restaurer les eaux douces polluées.

1. *Surveillance* – Une compréhension accrue de l'intensité et de l'étendue du défi mondial de la qualité de l'eau est nécessaire. Pour faciliter cette compréhension, il est urgent d'étendre la surveillance de la qualité de l'eau, notamment dans les pays en développement ainsi qu'au niveau international via le programme GEMS/Water.
2. *Evaluation* – Des évaluations globales nationales et internationales du défi mondial de la qualité de l'eau sont nécessaires. Ces évaluations sont nécessaires pour déterminer les emplacements prioritaires et les mesures pour lutter contre la pollution des eaux.
3. *Gestion ancienne et nouvelle et options techniques* – Les pays en développement ont la possibilité de ne pas recourir seulement au traitement traditionnel des eaux usées, mais également de recourir à de nombreuses autres options de gestion et techniques pour gérer la qualité des eaux, y compris des solutions basées sur la nature.

4. *Etablir des institutions efficaces* – Un aspect majeur de la gestion de la qualité des eaux réside dans l'établissement d'institutions qui promeuvent l'action et dépassent les obstacles au contrôle de la pollution des eaux.

Ces idées sont développées dans les points suivants:

Ce qui peut être fait: I Surveillance

Des évaluations complètes de la qualité des eaux au niveau mondial ne sont pas possibles du fait de la couverture limitée des données de la qualité des eaux pour les eaux de surfaces dans la seule base de données de la qualité des eaux à l'échelle mondiale, GEMStat.

GEMStat a une très faible densité de stations, en comparaison avec des densités minimales typiques d'environ 1,5 à 4 stations pour 10.000 km^2 de bassin fluvial aux Etats-Unis et en Europe. Dans GEMStat, 71 des 110 bassins fluviaux sur lesquels des données existent, ont une densité de 0,5 stations pour 10.000 km^2 ou moins.

La densité moyenne pour le continent d'Amérique latine est de 0,3 stations pour 10.000 km^2, pour l'Afrique elle est de 0,02 stations[8] pour 10.000 km^2, et pour l'Asie de 0,08 stations pour 10.000 km^2 pour la période comprise entre 1990 et 2010.

La priorité la plus urgente est d'étendre la couverture temporelle et spatiale des stations de surveillance plutôt que d'augmenter le nombre de paramètres collectés par les stations existantes. En considérant les coûts élevés de la surveillance, il importe de fixer des priorités pour les fleuves dont les données disponibles sont faibles, ils devraient faire en premier l'objet d'une surveillance. Les zones sensibles identifiées dans ce rapport peuvent être utilisées comme point d'appui pour décider des endroits où accroître les efforts de surveillance.

Les raisons de la faible couverture en données sont politiques, institutionnelles et techniques. Cependant, il existe de nombreuses possibilités pour une amélioration de la couverture en données de la qualité des eaux.

Une alternative à l'amélioration de la couverture est de faire usage de données de télédétection. Les séries de données actuelles couvrent des variables clefs de la qualité des eaux pour les lacs, et, dans l'avenir proche, des données seront également disponibles pour les fleuves. L'un des avantages des données sensorielles éloignées est la couverture spatiale et temporelle étendue des données. Les inconvénients incluent le nombre limité de variables pouvant être mesuré ainsi que le traitement nécessaire des données brutes.

D'autres options pour l'amélioration de la couverture des données de la qualité des eaux sont: (i) l'augmentation les efforts pour incorporer les données nationales et régionales dans les bases de données existantes, (ii) la formation de groupes de travail pour la surveillance des eaux douces nationales qui travaillent avec leurs interlocuteurs équivalents dans les autres pays pour le partage et l'utilisation des données sur la qualité des eaux, (iii) la récupération de données via des projets de science citoyenne. La science citoyenne a l'avantage d'engager un public plus large pour le nettoyage de la pollution des eaux.

Les efforts de collection des données devraient également tendre à rendre ces données largement disponibles et récupérables via une plate-forme digitale telle que UNEP Live. Les données devraient aussi être rendues largement disponibles en lien avec la surveillance et la mise en œuvre des objectifs du développement durable.

Ce qui peut être fait: II. Evaluation

Une évaluation de la qualité de l'eau à échelle mondiale complète est nécessaire pour évaluer l'état des connaissances sur tous les aspects essentiels de la qualité des eaux, afin d'établir des connections entre la qualité des eaux et d'autres enjeux de l'agenda de développement post 2015 tels que la sécurité sanitaire et alimentaire, et pour identifier des zones prioritaires pour l'étude et la prise de mesures.

L'évaluation devrait être:

- A plusieurs niveaux – avec une couverture mondiale, liée à des évaluations nationales et thématiques.
- Transparente et participative – impliquant un large nombre d'acteurs et de scientifiques.

L'évaluation devrait inclure:

- Des objectifs et des sujets sélectionnés en commun par les communautés politiques et scientifiques.
- Une analyse des options politiques pour la protection et la restauration de la qualité des eaux.

[8]Les zones arides ne sont pas incluses dans la zone continentale.

- Un accès large aux résultats en les rendant accessibles sur de nouvelles plates-formes numériques (p.ex. UNEP Live).

L’évaluation devrait également être utilisée comme opportunité pour augmenter la capacité technique des pays en développement ainsi que leur accès aux résultats scientifiques les plus récents.

Ce qui peut être fait: III. Options de gestion et techniques

De nombreuses options sont à disposition des pays en développement afin d’éviter la dégradation de la qualité des eaux de leurs fleuves et lacs. Nombre de ces options n’étaient pas disponibles ou utilisées par les pays développés lorsqu’ils ont été confrontés il y a plusieurs décennies à une similaire dégradation de la qualité des eaux.

Les options techniques principales sont:

i. *La prévention de la pollution* par laquelle la source de la pollution est évitée avant qu’elle ne devienne un problème.

ii. *Le traitement des eaux polluées*, ce qui constitue l’approche traditionnelle par la réduction de la charge de polluants avant qu’ils ne soient déchargés dans les eaux de surface.

iii. *L’usage sûr des eaux* usées par leur recyclage en vue de l’irrigation ou d’autres usages.

iv. *« Des solutions basées sur la nature », impliquant la restauration et la protection des écosystèmes*, telles que la réintroduction de terres boisées afin de réduire l’érosion et les charges de sédiments dans les fleuves, ou la restauration de zones humides pour retirer les éléments polluants des écoulements urbains et agricoles.

Ces points listent de nombreuses idées nouvelles qui n’étaient pas à disposition des pays développés faisant face à une détérioration similaire de la qualité des eaux il y a trois décennies ou plus. Parmi ces nouvelles idées, on compte: *une production industrielle plus propre, l’établissement de zones humides, des décharges à zéro effluent, et le paiement pour les services des écosystèmes des eaux d’amont boisées.*

Différentes stratégies techniques seront nécessaires pour contrôler les différents types de pollution des eaux et les sources de pollution. Cela vaut la peine d’essayer et de combiner ces stratégies en systèmes qui peuvent être appliqués à de nombreux bassins fluviaux différents.

D’une part, il a été noté ci-dessus que la principale source de pollution diffère entre les différents types de pollution des eaux. Ceci signifie qu’une option unique ne fonctionnera pas pour résoudre le défi mondial de la qualité des eaux. D’autre part, des défis de la qualité des eaux semblables apparaissent dans différents endroits du monde, même si les locations et les situations sont très différentes. En conséquence, il peut être possible de développer des systèmes différents d’options techniques qui peuvent être utilisées dans de nombreux bassins fluviaux différents pour affronter des problèmes similaires.

Ce qui peut être fait: IV-Gouvernance et institutions

Des études de cas des différents bassins fluviaux ont souligné l’importance de la bonne gouvernance et d’institutions efficaces pour la gestion de la qualité des eaux.

On compte des obstacles importants à la résolution des problèmes de pollution des eaux:

- La fragmentation de l’autorité sur un bassin fluvial,
- Le manque de capacités techniques et
- Le manque de sensibilisation de la part du public concernant les causes de la pollution des eaux.

Pour surmonter ces obstacles, l’expérience acquise par les études de cas a montré qu’une campagne d’éducation publique constitue une première bonne mesure pour le contrôle de la pollution des eaux. Une autre leçon est qu’un *Plan d’action*, convenu par tous les acteurs principaux d’un bassin fluvial constitue une mesure clef dans la restauration des rivières et des lacs. Cependant, une autre mesure institutionnelle clef pour les fleuves internationaux est d’établir un *organisme de coopération*, telles que les commissions internationales des fleuves de l’Elbe et de la Volta, afin de développer et d’exécuter un plan d’action. Dans le cas de l’Elbe, il a aussi été montré qu’une institution nationale étendue (la communauté du bassin de l’Elbe) peut fournir une plate-forme précieuse pour obtenir la coopération de tous les acteurs essentiels *nationaux* à l’intérieur d’un bassin fluvial.

Affronter le défi mondial de la qualité des eaux est étroitement lié à de nombreuses autres priorités des sociétés, telle que la sécurité alimentaire et la santé. En conséquence, des mesures pour protéger la qualité des eaux devraient être intégrées à un concept plus large de durabilité et faire partie des efforts pour réaliser les nouveaux objectifs du développement durable.

Les études de cas ont montré que le défi de la protection de la qualité des eaux est entremêlé à de nombreuses autres tâches des sociétés – fournir de l'alimentation, développer l'économie et fournir des installations sanitaires sûres. En conséquence, au cours des prochaines années, il sera très important de lier les objectifs pour la qualité des eaux avec d'autres objectifs du programme de développement durable de l'après 2015 et avec les nouveaux objectifs du développement durable.

Резюме отчёта

Основные тезисы

- Для достижения целей устойчивого развития в области здравоохранения и обеспечения продовольственной и водной безопасности, необходимо наличие достаточного количества высококачественной воды. В связи с этим уровень загрязнения вод большинства рек Латинской Америки, Африки и Азии по сравнению с 90-ми годами прошлого века вызывает озабоченность.
- Важно, чтобы меры, направленные на защиту и восстановление качества воды, осуществлялись совместно с мероприятиями для достижения Целей в области устойчивого развития и Повестки дня в области развития после 2015 г.
- Серьёзное патогенное загрязнение водных ресурсов затрагивает уже около трети рек Латинской Америки, Африки и Азии. Кроме угрозы здоровью, связанной с потреблением питьевой загрязнённой воды, многие люди подвергаются риску заболеть через контакт с загрязнённой водой во время купания, стирки одежды и выполнения других бытовых дел. Число сельского населения на указанных выше континентах, подверженных такого рода рискам, может достигать сотен миллионов.
- Серьёзные загрязнения органического характера уже наблюдаются примерно на одной седьмой части от общей протяжённости рек Латинской Америки, Африки и Азии, что вызывает озабоченность состоянием рыболовства в пресных водах и, соответственно, обеспечением продовольственной безопасности и средств к существованию.
- Умеренный и высокий уровни минерализации воды наблюдаются примерно на одной десятой части от общей протяжённости рек Латинской Америки, Африки и Азии. Это тревожная тенденция, препятствующая использованию речной воды для орошения, в промышленности и для других целей.
- Непосредственная причина увеличения загрязнения водоёмов заключается в росте объёма сбросов в реки и озёра сточных вод. Ключевые причины - рост численности населения, активная хозяйственная деятельность, интенсификация и расширение сельского хозяйства, а также увеличение объёмов неочищенных или прошедших низкий уровень обработки сточных вод.
- От ухудшения качества воды в развивающихся странах больше всего страдают следующие уязвимые группы населения: женщины, часто использующие воду из открытых водоёмов для бытовых нужд; дети, для которых открытые водоёмы служат местом игр и которые нередко ходят за водой для нужд домашнего хозяйства; сельская беднота, для которой рыба является основным источником протеина; рыбаки с низким заработком, а также работники рыбных хозяйств, для которых промысел в пресноводных водоёмах является главным средством к существованию.
- Хотя загрязнение воды и является серьёзной проблемой, и ситуация в Латинской Америке, Африке и Азии ухудшается, большая часть рек на этих трёх континентах пока находится в хорошем состоянии. Существует ряд возможностей для быстрого сокращения дальнейшего загрязнения и восстановления уже загрязнённых рек. Для выполнения этих задач требуется комплекс административных и технических мер при эффективной поддержке органов управления.
- У развивающихся стран имеется большой выбор административных и технических возможностей борьбы с загрязнением воды. Десятилетия назад многие из этих мер были недоступны или

не использовались в развитых странах, столкнувшихся с аналогичной ситуацией, связанной с ухудшением качества воды.

- Мониторинг и оценка качества воды имеют важное значение для понимания глубины и масштабов глобальной проблемы качества воды. Однако, во многих странах мира ещё недостаточно хорошо налажен сбор данных для достижения этих задач. К примеру, плотность расположения станций мониторинга качества воды в Африке в сто раз меньше, чем во всём остальном мире. Поэтому актуальна задача расширения сбора, распространения и анализа данных о качестве воды в рамках международной программы мониторинга GEMS и других водных программ. «Горячие точки» с наиболее загрязнёнными водоёмами, показанные в данном отчёте, могут быть использованы для определения приоритетов в области сбора данных.

Люди и экосистемы одинаково нуждаются как в достаточном *количестве* воды, так и в соответствующем её *качестве*. Поэтому необходимо срочно определить места, где *качество воды недостаточное или находится в зоне риска*, и включить потребность в качественной воде в концепцию безопасного водообеспечения. В данном отчёте основное внимание уделяется качеству воды и её взаимосвязи с такими целями в области развития, как здоровье, продовольственная и водная безопасность. Для того, чтобы показать эту связь, здесь рассматриваются наиболее важные проблемы качества поверхностных вод, в том числе патогенное и органическое загрязнения, минерализация и эвтрофикация. Основное внимание уделено трём континентам - Латинской Америке, Африке и Азии.

В течение последних нескольких лет повышение безопасности водообеспечения является важной международной задачей. В рамках достижения Целей в области развития и других мероприятий международное сообщество большое внимание уделяет *количественной стороне* этого вопроса путём расширения доступа населения к безопасному водообеспечению. Действительно, снабжение людей, промышленности и сельского хозяйства необходимым *количеством воды* является и должно оставаться важнейшей международной задачей.

Однако возрастает значение другого аспекта водной безопасности – обеспечение соответствующего качества пресных вод. Это вызывает определенное беспокойство в связи с тем, что качество воды в реках и озёрах во всём мире переживает значительные изменения. Возрастающее внимание, уделяемое качеству воды, отражено в различных задачах Целей в области устойчивого развития.

Качество воды значительно улучшилось во многих развитых странах, хотя ещё остаётся ряд проблем. В то же время в развивающихся странах по мере роста городского населения, уровня потребления и увеличения объёмов неочищенных сточных вод, нарастает тенденция загрязнения водоёмов. Однако, остаётся только гадать о реальной ситуации с качеством воды в пресных экосистемах в большинстве стран мира из-за отсутствия информационной базы. Поэтому в срочном порядке было необходимо проведение оценки для определения объёма и масштаба «состояния качества воды на глобальном уровне». Цель предварительного исследования - подготовка отдельных составных частей для полномасштабной оценки качества водных ресурсов мира, которые в дальнейшем можно будет расширить. Исследование также представляет собой предварительную оценку качества воды пресноводных экосистем мира с акцентом на реки и озёра трёх континентов.

Проблема загрязнения большинства рек Латинской Америки, Африки и Азии усугубилась начиная с 90-х годов XX века.[1]

Оценка изменений, произошедших за период с 1990 по 2010 гг. была проведена по ключевым параметрам, отражающим патогенное загрязнение (присутствие бактерий кишечной палочки фекального происхождения), органическое загрязнение (биохимическая потребность в кислороде; БПК) и минерализацию (общее количество растворённых твёрдых веществ; TDS). Показатели патогенного и органического загрязнения ухудшились более чем на половине общей протяженности рек всех трёх

[1]В данном отчёте под континентами Латинская Америка, Африка и Азия следует понимать следующие субрегионы в соответствии с отчётом ЮНЕП «Глобальная экологическая перспектива»:
Латинская Америка = Центральная Америка, Южная Америка, Карибский бассейн;
Африка = Центральная Африка, Восточная Африка, Северная Африка, Южная Африка, Западная Африка, западная часть Индийского океана;
Азия = Центральная Азия, Северо-Восточная Азия, Юго-Восточная Азия, Западная Азия (Аравийский полуостров и Машрик).

континентов, в то время как показатели минерализации ухудшились почти на треть.[2] Это является особым поводом для беспокойства в отношении некоторых участков рек, где загрязнение воды достигло серьёзного уровня, или там, где этот уровень наблюдался уже в 1990 г., а ухудшение показателей фиксировалось к 2010 г.

Серьёзные патогенные загрязнения[3] уже затрагивают примерно одну треть всех рек в Латинской Америке, Африке и Азии. Доля сельского населения на этих континентах, чьё здоровье подвергается опасности через контакт с загрязнёнными водами открытых водоёмов, может достигать нескольких сотен миллионов человек. К наиболее уязвимым группам населения относятся женщины и дети.

Согласно оценкам, серьёзное патогенное загрязнение (при котором ежемесячные показатели концентрации бактерий кишечной палочки в водном потоке достигают более 1000 КОЕ/100мл[4]) затрагивает около четверти рек Латинской Америки, 10–25 процентов рек Африки и от одной трети до половины рек в Азии. Соответственно, наибольшая степень патогенного загрязнения среди трёх континентов наблюдается в Азии. По оценкам, доля сельского населения, контактирующего с водами в открытых водоёмах,[5] и находящихся под угрозой, примерно составляет 8–25 млн в Латинской Америке, 32–164 млн в Африке и 31–134 млн человек в Азии. Широкий диапазон этих оценок показывает, что многое о реальной опасности ещё не известно, но в то же время указывает и на то, что число людей в зоне риска, скорее всего, очень велико. Данные оценки не включают ни фермеров, подвергающихся воздействию загрязнённых вод, используемых для орошения, ни жителей городов.

В частности, риску подвергаются женщины, часто использующие воду из открытых водоёмов для стирки одежды, питья и приготовления пищи, а также дети, для которых открытые водоёмы служат местом игр и которые нередко ходят за водой для домашних нужд.

Стоит отметить, что с 1990 по 2010 гг. показатели концентрации кишечной палочки выросли почти в двух третях всех рек Латинской Америки, Африки и Азии. Общая протяжённость участков рек, вызывающих «растущую озабоченность»[6], достигает четверти от всей протяжённости рек на этих континентах. Здесь уровень содержания бактерий кишечной палочки достиг серьёзного или уже находился на серьёзном уровне в 1990 г. и только усугубился к 2010 г. Такие зоны можно считать «горячими точками».

Рост показателей связан с расширением канализационных систем, сбрасывающих неочищенные сточные воды в открытые водоёмы. С одной стороны, канализация, отводя сточные воды от населённых пунктов, позволила снизить риск для здоровья, связанный с небезопасными санитарно-гигиеническими условиями на поверхности земли. С другой стороны, сброс неочищенных сточных вод в открытые водоёмы перенёс опасность для здоровья человека с суши на воду. Результаты исследований показывают, что, если бы не строительство канализации, содержание бактерий кишечной палочки фекального происхождения в африканских реках могло бы быть ниже на 23 процента. Тем не менее, решение заключается не в сокращении строительства канализационных коллекторов, а в очистке поступающих туда сточных вод.

Уже сегодня серьёзные органические загрязнения охватывают каждый седьмой километр рек в Латинской Америке, Африке и Азии. Высокий уровень органического загрязнения и тенденция его роста вызывает озабоченность состоянием рыболовства в пресноводных водоёмах и, следовательно, обеспечением продовольственной безопасности и средств к существованию. В группу риска входят сельская беднота, для которой пресноводная рыба является основным источником протеина, рыбаки с низким уровнем дохода, а также работники рыбных хозяйств, для которых промысел в пресноводных водоёмах является основным средством к существованию.

Причина органического загрязнения в попадании в открытые водоёмы значительных объёмов разлагаемых органических соединений, разложение которых в воде часто приводит к серьёзному снижению содержания растворённого кислорода, необходимого рыбам и прочей водной фауне.

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[2]В данном отчёте для отражения результатов анализов использованы округленные данные. С учётом неточностей в оценках, лежащих в основе отчёта, было целесообразным представить округленные показатели. Основной текст отчёта представляет данные исследований, лежащие в основе отчёта.

[3]Определение серьёзного уровня патогенного загрязнения представлено в примечании 5. Водоёмы, подвергшиеся такому загрязнению, с высокой долей вероятности, отличаются уровнем содержания патогенов, индикатором которого является высокий уровень концентрации бактерий кишечной палочки фекального происхождения. Это подразумевает, что здоровье людей, находящихся в контакте с такими водами, под угрозой.

[4]Стандартной единицей измерения уровня концентрации кишечной палочки фекального происхождения является количество «колониеобразующих единиц» (КОЕ) на 100 мл образца воды.

[4]Включает людей, контактирующих с речной водой, в которой патогенное загрязнение достигает серьёзного уровня ($x > 1000$ КОЕ/100 мл).

[4]Понятие «растущая озабоченность» в данном отчёте означает достижение категории серьёзного уровня загрязнения 2008–10 гг. или нахождение на уровне серьёзного загрязнения 1990-92 гг., а также дальнейшее ухудшение в 2008–10 гг.

Благодаря промыслу рыбы во внутренних водах обеспечивается значительная часть белка в рационе жителей развивающихся стран. На общемировом уровне внутриконтинентальное рыболовство является шестым по значимости поставщиком животного белка, при этом в некоторых развивающихся странах промысел рыбы в материковых водоёмах поставляет более 50 процентов животных белков, производимых в данных странах.

В развивающихся странах рыболовный промысел во внутренних водах также является важным источником получения дохода. Промысел обеспечивает работой 21 млн рыбаков и создаёт 38,5 млн смежных рабочих мест. Почти все рабочие места сосредоточены в мелких рыболовных хозяйствах, где в основном занята беднота, более половины которой составляют женщины. Поэтому не может не беспокоить тот факт, что, как минимум 10 процентов оценок, проведённых в Латинской Америке, Африке и Азии, дают тревожные показатели по, как минимум, трём из пяти параметров качества воды, имеющих особое значение для здорового развития рыболовного промысла.

По оценкам 2010 г., серьёзное органическое загрязнение (с ежемесячной концентрацией БПК в воде более 8 мг/л) охватывало до одной десятой доли всей протяжённости рек в Латинской Америке, до одной седьмой в Африке и до одной шестой в Азии.

Обеспокоенность вызывает и то, что уровень органического загрязнения (индикатором которого является рост концентрации БПК) с 1990 по 2010 гг. вырос почти в двух третях всех рек в Латинской Америке, Африке и Азии. Доля участков рек, вызывающих «растущую озабоченность», составляет около одной десятой от всей протяжённости рек на этих континентах, где показатели БПК достигли серьёзного уровня или находились на этом уровне загрязнения в 1990 г. и ещё более усугубились к 2010 г. Такие участки можно считать «горячими точками».

Сильный и средний уровни минерализации водных ресурсов уже затрагивает около одной десятой рек Латинской Америки, Африки и Азии, что вызывает беспокойство, так как высокий уровень минерализации негативно влияет на использование речной воды для орошения, в промышленности и для других целей. В группу риска, затронутую проблемой минерализации воды, входят малообеспеченные фермеры, вынужденные использовать поверхностные воды для орошения своих земельных участков.

Минерализация происходит тогда, когда концентрация растворённых солей и других веществ в реках и озёрах достигает высокого уровня, ограничивающего пригодность воды для использования. Несмотря на то, что воды почти всех рек содержат определенный уровень солей вследствие вымывания почвы и скальных пород в речной бассейн, человечество значительно увеличило этот уровень, сливая в реки высокоминерализованные стоки оросительных систем, бытовые сточные воды и стоки из шахт.

На исследованных континентах минерализация воды распространена меньше, чем патогенное или органическое загрязнения. Тем не менее, умеренный и высокий уровень минерального загрязнения, если рассматривать их вместе (к примеру, там, где ежемесячная концентрация в потоке растворённых твёрдых частиц превышает 450 мг/л), затрагивают каждый двадцатый километр всех рек в Латинской Америке, до одной десятой всей протяжённости рек в Африке и до одной седьмой общей протяжённости рек в Азии. Речная вода, относящаяся к категории умеренного загрязнения, частично ограничена для использования в орошении, и не может быть использована для определённых промышленных целей без дополнительной очистки. Наиболее уязвимой группой населения, по всей вероятности, являются бедные фермеры, зависящие от поверхностных вод как источника поливной воды для своих небольших наделов.

С 1990 по 2010 гг. минерализация вод увеличилась почти на одной трети от общей протяжённости рек на всех трёх континентах. Отдельные участки этих рек (несколько процентов от общей протяжённости) вызывают «растущую озабоченность», так как содержание в воде растворённых твёрдых частиц возросло до серьёзного уровня или находилось на серьёзном уровне в 1990 г. и ещё более ухудшилось к 2010 г.

Антропогенные нагрузки питательных веществ на крупные озёра имеют большое значение и могут стать причиной дальнейшей эвтрофикации этих водоёмов. Тенденции роста таких нагрузок отличаются в каждом регионе мира.

Эвтрофикацией называется пресыщение вод озёр и других водоёмов удобрениями, что приводит к нарушению естественных процессов. Эвтрофикация, как правило, вызывается антропогенным смывом в озёра фосфора, однако, свою роль играет и повышение уровня содержания азота. Более половины фосфора, попадающего в 23 из 27 крупнейших озёр[7] по всему миру, приходит туда из антропогенных источников. Таким образом, большая часть крупных озёр Латинской Америки и Африки страдают от растущего уровня содержания фосфора. Для сравнения, в Северной Америке и Европе эти показатели падают благодаря эффективным мерам по снижению уровня фосфора.

Непосредственной причиной растущего уровня загрязнения водных ресурсов является рост объёмов сброса сточных вод в реки и озёра, при этом основные источники загрязнения отличаются разнообразием загрязняющих веществ. Конечные причины увеличения уровня загрязнения - рост населения, экономическая активность, интенсификация и расширение сельского хозяйства при отсутствии или низкой степени очистки сточных вод.

Сбор сточных вод в канализации снижает прямой контакт населения с отходами и патогенными веществами и, соответственно, является важной стратегией здравоохранения. Однако строительство канализаций привело к повышению концентрации загрязняющих веществ при сбросе стоков в поверхностные воды, что сместило зону риска для здоровья населения.

Крупнейшим источником патогенного загрязнения (содержание бактерий кишечной палочки фекального происхождения) в Латинской Америке является бытовая сточная вода в коллекторах, в Африке – домашние отходы, не попадающие в канализацию, а в Азии на первом месте находятся бытовые сточные воды из канализации, за которыми с небольшим отрывом следуют бытовые отходы, не попадающие в канализацию.

Самым большим источником органического загрязнения (БПК) в Латинской Америке являются бытовые сточные воды из канализации, в Африке – бытовые отходы, не попадающие в канализацию, а в Азии – сточные промышленные отходы.

Крупнейшим антропогенным источником повышения уровня минерализации (общее содержание в воде растворённых твёрдых частиц) в Латинской Америке является промышленность, а в Африке и Азии – орошаемое земледелие.

Основным антропогенным источником повышения содержания фосфора в крупнейших озёрах Латинской Америки являются отходы животноводства и неорганических удобрений, в Африке – отходы животноводства, в Азии и Европе – бытовые сточные воды, отходы животноводства и также как и в Северной Америке – неорганических удобрений.

отя загрязнение водных источников и является серьёзной проблемой, и ситуация в Латинской Америке, Африке и Азии ухудшается, большая часть рек на этих трёх континентах пока находится в хорошем состоянии, что даёт широкие возможности для сокращения дальнейшего загрязнения и восстановления уже загрязнённых рек.

В предыдущих пунктах основной упор был сделан на обширные участки рек с плохим качеством воды и тенденцией к дальнейшему её ухудшению. Однако есть и другая сторона медали. Многие участки рек *пока ещё не подверглись загрязнению:*

- В примерно половине до двух третей общей протяженности рек (в Латинской Америке, Африке и Азии) наблюдается *низкий* уровень патогенного загрязнения;
- В более чем трёх четвертях всех рек *низкий* уровень органического загрязнения;
- Примерно в девяти десятых наблюдается *низкий* уровень минерализации.

Пока ещё есть возможность предотвратить серьёзное загрязнение этих чистых участков рек и, кроме того, начать восстановление уже загрязнённых. Существует значительное количество мер, которые можно принять с целью избежания растущего загрязнения и восстановления загрязнённых пресных вод:

1. *Мониторинг.* Необходимо более глубокое понимание интенсивности и масштаба глобальной проблемы качества воды. Для этого необходимо срочно расширить мониторинг качества воды как в развивающихся странах, так и на международном уровне через системы мониторинга воды как GEMS.
2. *Оценка.* Необходимы всеобъемлющие оценки качества воды в мире на национальных и

[7]В данном отчёте под понятием «крупнейшие мировые озёра» имеются в виду пять крупнейших по площади поверхности озёр в каждом из пяти регионов по версии «Глобальной экологической перспективы» ЮНЕП (Африка, Азия, Европа, Латинская Америка и Северная Америка).

международном уровнях. Такого рода оценки необходимы для определения приоритетов и действий, направленных на борьбу с проблемой загрязнения воды.

3. *Старые и новые административные и технические меры.* Развивающиеся страны имеют возможность не просто применять традиционные меры обработки сточных вод, но и воспользоваться гораздо большим количеством административных и технических мер для управления качеством воды, включая решения, основанные на природных процессах.
4. *Создание эффективных институтов.* Немаловажным элементом в управлении качеством воды является создание институтов, содействующих активной деятельности и преодолению барьеров для борьбы с загрязнением воды.

Данные идеи более детально освещены в представленных ниже пунктах.

I. Мониторинг

Получение всесторонней глобальной оценки качества воды не представляется возможным из-за недостатка данных о качестве поверхностных вод в единственной всемирной базе данных о состоянии качества воды GEMStat.

GEMStat обладает крайне низкой плотностью расположения измерительных станций в сравнении с принятой минимальной плотностью от 1,5 до 4 станций на 10 000 км² площади речного бассейна как, к примеру, в США и Европе. Также в GEMStat содержатся данные только о 71 из 110 имеющихся речных бассейнов, а плотность станций составляет 0,5 на 10 000 км² или даже меньше.

С 1990 по 2010 гг. средняя плотность станций в Латинской Америке составляет 0,3 на 10 000 км², в Африке – 0,02[8] на 10 000 км², а в Азии – 0,08 на 10 000 км².

Наиважнейшей задачей является расширение временного и пространственного охвата данных мониторинговыми станциями вместо увеличения количества параметров, собираемых на существующих станциях. Учитывая высокую стоимость мониторинга, необходимо правильно расставить акценты и решить, на каких реках, данных по которым недостаточно, нужно провести замеры в первую очередь. «Горячие точки», определенные в данном отчёте, могут быть использованы в качестве предварительных данных при принятии решения о том, в каком направлении расширить мониторинг.

Причины недостаточного охвата данных заключатся в политических, институциональных и технических проблемах. Однако существует множество альтернатив для улучшения охвата данных о качестве воды.

Одно из альтернативных решений для улучшения охвата данных - использование дистанционного зондирования. Актуальные записи охватывают ключевые переменные показатели качества воды в озёрах, а в ближайшее время будут доступны и данные по рекам. Преимуществом дистанционного зондирования является широкая зона охвата и сбора данных как по временным, так и по пространственным характеристикам. К недостаткам относится ограниченное число переменных показателей, по которым можно провести замеры, и обработка требуемых исходных данных.

Другие варианты улучшения охвата данных о качестве воды: (I) активные усилия по включению данных, полученных на национальном и региональном уровнях, в существующие базы данных; (II) создание национальных рабочих групп для мониторинга состояния пресных вод, в задачи которых будет входить дальнейший обмен данными о качестве водных источников со своими коллегами из других стран, (III) получение данных с помощью научных проектов отдельных лиц. Дополнительное преимущество «гражданской науки» заключается в вовлечении широкой общественности в деятельность по очистке загрязнённых вод.

Собранные данные должны широко распространяться и быть доступными на таких цифровых площадках, как UNEP Live. Также данные должны быть легкодоступными в связи с мониторингом и осуществлением Целей в области устойчивого развития.

II. Оценка

Для оценки состояния уровня знаний обо всех ключевых аспектах качества воды необходимо проведение глобальной полномасштабной оценки качества воды, что позволит осветить связи между качеством воды

[8]Без учета засушливых районов в континентальной области.

и другими вопросами, связанными с Целями в области развития после 2015 г., как здравоохранение и обеспечение продовольственной безопасности, а также для определения приоритетных направлений исследований и действий.

Оценка должна быть:

- Многоуровневой и охватывать глобальные данные вместе с национальными и тематическими оценками;
- Прозрачной и обеспечивающей участие широкого круга заинтересованных сторон и учёных.

Оценка должна включать:

- Цели и темы, совместно отобранные политиками и научными сообществами;
- Анализ вариантов политических решений для защиты и восстановления качества воды;
- Широкий доступ к результатам на современных цифровых платформах (к примеру, на UNEP Live).

Оценку также следует использовать как возможность для повышения технического потенциала развивающихся стран и обеспечения их доступа к результатам последних научных исследований.

III. Административные и технические меры

У развивающихся стран имеется множество доступных возможностей, позволяющих предотвратить ухудшение качества воды в своих реках и озёрах. Десятилетия назад многие из них были недоступны или не использовались в развитых странах, столкнувшихся с аналогичной ситуацией, связанной с ухудшением качества воды.

Основные технические параметры:

(i) *Профилактика загрязнения*, которая позволяет бороться с причиной загрязнения, прежде чем она перерастёт в проблему;

(ii) *Очистка и обработка загрязнённой воды*, являющиеся традиционным подходом к сокращению концентрации загрязняющих веществ перед тем, как они попадают в поверхностные воды;

(iii) *Безопасное повторное использование сточных вод* для орошения и других целей;

(iv) *«Природные решения», включающие восстановление и защиту экосистем,* к примеру, восстановление лесных массивов в речных бассейнах для сокращения эрозии и выброса осадочных отложений в реки или восстановление водно-болотных угодий для удаления загрязняющих веществ из городских или сельскохозяйственных стоков.

За этими подзаголовками скрывается множество новых идей, которые не были доступны для развитых стран, впервые столкнувшихся с аналогичным ухудшением качества воды около трёх десятилетий назад. В число новых идей входят *экологически чистое промышленное производство, биоинженерные очистные сооружения, нулевой сброс неочищенных сточных вод и платежи за экосистемные услуги в лесистых верховьях рек.*

Чтобы контролировать различные типы и источники загрязнения воды потребуются различные технические решения. Стоит попытаться сгруппировать и объединить эти решения в пакеты, которые можно будет применить ко многим речным бассейнам.

С одной стороны, как это было отмечено выше, основные источники загрязнения различаются по типам загрязнения воды. Это означает, что универсальное решение по принципу «одно на всех» не сработает для решения глобальной проблемы качества воды. С другой стороны, схожие проблемы, связанные с качеством воды, появляются по всему миру, несмотря на то, что места и ситуации сильно различаются. Поэтому представляется возможным разработать различные варианты пакетов технических решений, которые можно будет применять ко множеству различных речных бассейнов со схожими проблемами.

IV. Государственное управление и институты

Опыт работы в различных речных бассейнах показывает важность надлежащего государственного управления и эффективности институтов управления качеством воды.

Были установлены следующие значительные препятствия на пути решения проблемы загрязнения воды:

- Раздробленность властных структур в пределах одного речного бассейна;
- Отсутствие технического потенциала;
- Отсутствие у общественности знаний о причинах загрязнения воды.

Опыт проведённой работы показывает, что для преодоления этих и других препятствий в качестве первого шага эффективно проведение образовательной кампании, которая поможет заручиться поддержкой общественности для борьбы с загрязнением водных ресурсов. Другим уроком стал тот факт, что ключевым шагом на пути восстановления рек и озёр является согласованный со всеми главными действующими лицами в бассейне реки *план действий*. Ещё одним ключевым институциональным шагом для защиты вод рек, протекающих по территориям нескольких стран, является создание таких *совместных органов* для разработки и осуществление плана действий, как международные комиссии по рекам Эльба и Вольта. На примере Эльбы видно, что широкий охват различного рода государственных учреждений (сообщество бассейна реки Эльбы) может стать ценной площадкой для сотрудничества всех важнейших национальных субъектов в пределах речного бассейна.

Борьба с глобальной проблемой качества воды тесно связана с рядом таких приоритетных задач общества, как продовольственная безопасность и здоровье. Поэтому действия, направленные на защиту качества воды, должны быть включены в более широкую концепцию устойчивого развития и стать частью мероприятий, осуществляемых для достижения новых Целей устойчивого развития.

Опыт работы показал, что проблема защиты качества воды переплетается с рядом других задач общества, как то обеспечение продовольствием, развитие экономики и предоставление безопасных санитарных условий. Поэтому в ближайшие годы важно увязать цели в защиту качества воды с другими целями Повестки на период после 2015 года и новыми Целями в области устойчивого развития.

Resumen Ejecutivo

Puntos principales

- Para cumplir con los Objetivos de Desarrollo Sostenible, entre ellos los objetivos de salud, seguridad alimentaria y seguridad del agua, son necesarias tanto una buena calidad del agua como una cantidad adecuada de la misma. Por lo tanto, constituye una gran preocupación el hecho de que la contaminación del agua haya empeorado desde la década de 1990 en la mayoría de los ríos de América Latina, África y Asia.
- Es importante que las acciones realizadas para proteger y mejorar la calidad del agua estén relacionadas con las iniciativas que se realicen para cumplir con los Objetivos de Desarrollo Sostenible y la Agenda de Desarrollo Post 2015.
- La contaminación patógena severa ya afecta a cerca de un tercio de todos los tramos de río de América Latina, África y Asia. Además del riesgo a la salud que implica beber agua contaminada, muchas personas también corren el riesgo de contraer enfermedades por contacto con aguas superficiales contaminadas para el baño, el lavado de ropa y otras actividades domésticas. El número de habitantes de zonas rurales que corren estos riesgos puede ascender a cientos de millones en estos continentes.
- La contaminación orgánica severa ya afecta a cerca de un séptimo de todos los tramos de río de América Latina, África y Asia, y constituye una gran preocupación para el estado de la pesca de agua dulce y, por lo tanto, para la seguridad alimenticia y la subsistencia.
- La contaminación salina severa y moderada afecta a cerca de un décimo de todos los tramos de río de América Latina, África y Asia, y constituye una preocupación porque afecta el uso del agua de río para el regadío, la industria y otros propósitos.
- La causa inmediata del aumento de la contaminación del agua es el crecimiento de las cargas de aguas residuales en ríos y lagos. Las causas principales son el crecimiento de la población, el aumento de la actividad económica, la intensificación y expansión de la agricultura, y una mayor cantidad de enganches de alcantarillado con un nivel bajo o nulo de tratamiento.
- Entre los grupos más vulnerables al deterioro de la calidad del agua en los países en vías de desarrollo se encuentran las mujeres, debido a que utilizan frecuentemente aguas superficiales para actividades domésticas; los niños, porque llevan a cabo actividades recreativas en aguas superficiales locales y porque frecuentemente se les asigna la tarea de recolectar agua para el hogar; los habitantes de zonas rurales de bajos recursos que consumen pescado como fuente importante de proteína; y los pescadores y trabajadores de la pesca de bajos recursos que dependen de la pesca de agua dulce para subsistir.
- Aunque la contaminación del agua es grave y actualmente empeora en América Latina, África y Asia, la mayoría de los ríos en estos tres continentes aún se encuentra en buenas condiciones, y existen excelentes oportunidades para detener la contaminación y restablecer la calidad de los ríos contaminados. Para esta labor, se necesitará una mezcla de opciones técnicas y de gestión respaldada por una buena gobernanza.
- Una amplia gama de opciones técnicas y de gestión se encuentra al alcance de los países en vías de desarrollo para el control de la contaminación del agua. Muchas de estas opciones no se encontraban disponibles o no fueron utilizadas por los países desarrollados cuando estos se vieron enfrentados a una calidad del agua en similar deterioro hace algunas décadas.

- La monitorización y la evaluación de la calidad del agua son esenciales para entender la intensidad y el alcance del desafío mundial de la calidad del agua, aunque la cobertura de recolección de datos en muchas partes del mundo es inadecuada para este objetivo. Por ejemplo, la densidad de estaciones de medición de calidad del agua en África es cien veces menor que la densidad usada en otras partes del mundo para efectos de monitorización. Así, se debe expandir urgentemente la recopilación, distribución y análisis de datos de calidad del agua a través del programa internacional SIMUVIMA/ Agua y otras actividades. Los puntos críticos de contaminación del agua identificados en este informe pueden ser utilizados para establecer prioridades para la recolección de datos.

Las personas y los ecosistemas requieren una cantidad adecuada de agua, así como una calidad adecuada de la misma. Por lo tanto, resulta urgente evaluar en qué lugares la calidad del agua es inadecuada o se encuentra en riesgo e incorporar la necesidad de agua de buena calidad al concepto de seguridad del agua. El presente informe se enfocará en la calidad del agua y su relación con objetivos de desarrollo tales como salud, seguridad alimentaria y seguridad del agua. Para establecer esta conexión, el informe revisará los principales problemas de calidad del agua en aguas superficiales, entre ellos la contaminación patógena, la contaminación orgánica, la contaminación salina y la eutrofización. Nos concentraremos en tres continentes: América Latina, África y Asia.

El fortalecimiento de la seguridad del agua ha sido una prioridad internacional durante los últimos años. A través de los Objetivos de Desarrollo del Milenio y otras iniciativas, la comunidad internacional ha priorizado el aspecto *cantidad* de la seguridad del agua incrementando el acceso de las personas a un abastecimiento seguro de agua. Sin duda que abastecer una *cantidad* apropiada de agua a las personas, a la industria y a la agricultura es, y debe seguir siendo, una importante prioridad internacional.

Sin embargo, otra dimensión de la seguridad del agua se vuelve cada vez más importante: asegurar que el agua dulce posea una *calidad* adecuada. Lo anterior constituye una preocupación pues la calidad del agua de los ríos y lagos del mundo está sufriendo cambios importantes. La prioridad cada vez más grande que se le da a la calidad del agua se refleja en varias de las metas de los Objetivos de Desarrollo Sostenible.

La calidad del agua ha mejorado notablemente en muchos países desarrollados, aunque algunos problemas persisten. Mientras tanto, en los países en vías de desarrollo la tendencia es al aumento de la contaminación del agua a medida que la población urbana crece, el consumo material aumenta y los volúmenes de aguas residuales no tratadas se expanden. No obstante, la situación real de la calidad del agua en los ecosistemas de agua dulce en muchas partes del mundo es solo objeto de especulación debido a la falta de información básica. De esta forma, se necesita urgentemente una evaluación que identifique el alcance y la escala del "desafío mundial de la calidad del agua". El presente Pre-Estudio tiene como objetivo proporcionar algunas de las piezas esenciales para una evaluación mundial a gran escala de la calidad del agua que puedan ser transformadas en una evaluación completa. El informe también presenta una estimación preliminar de la situación de la calidad del agua en los ecosistemas de agua dulce del mundo, con énfasis en los ríos y lagos de tres continentes.

La contaminación del agua ha empeorado desde la década de 1990 en la mayoría de los ríos de América latina, África y Asia.[1]

Se han estimado los cambios entre 1990 y 2010 en los parámetros clave de los ríos que reflejan la contaminación patógena (bacteria coliforme fecal), la contaminación orgánica (demanda bioquímica de oxígeno; DBO), y la contaminación salina (total de sólidos disueltos; TDS, por sus siglas en inglés). El nivel de contaminación patógena y orgánica empeoró en más de 50 por ciento de los tramos de río en los tres continentes, mientras que la contaminación salina empeoró en casi un tercio[2]. Este empeoramiento genera especial preocupación en un subgrupo de estos tramos de río en los que la contaminación del agua ha alcanzado un nivel severo, o ya se encontraba en un nivel severo en 1990 y en 2010 se ha encontrado peor.

[1]En el presente informe se usan las siguientes subregiones de las "Perspectivas del Medio Ambiente Mundial" del PNUMA para definir "América Latina", "África" y "Asia": América Latina = América Centrral, América del Sur y el Caribe; África = África Central, África Oriental, África Septentrional, África Meridional, África Occidental, Océano Índico Occidental; Asia= Asia Central, Asia Nororiental, Asia Meridional, Asia Suroriental, región de Asia Occidental (Península Arábiga, Mashriq).

[2]En este resumen, se usan cifras redondeadas para los resultados de análisis. Es adecuado presentar resultados redondeados considerando las incertidumbres de las estimaciones subyacentes. El texto principal presenta estas estimaciones subyacentes.

La contaminación patógena severa[3] ya afecta a cerca de un tercio de todos los tramos de río de América Latina, África y Asia. El número de habitantes de zonas rurales cuya salud corre peligro por el contacto con aguas superficiales contaminadas puede llegar a los cientos de millones en estos continentes. Entre los grupos más vulnerables se encuentran mujeres y niños.

Se estima que la contaminación patógena severa (en la que las concentraciones mensuales en caudal de bacteria coliforme fecal son de > 1000 cfu/100ml[4]) afecta a cerca de un cuarto de los tramos de río de América Latina, a cerca de 10 a 25 por ciento de los tramos de río de África y a cerca de entre un tercio y la mitad de los tramos de río de Asia. Así, de los tres continentes, el alcance de la contaminación patógena parece ser mayor en Asia. Considerando la fracción de población rural que tiene probabilidades de entrar en contacto con aguas superficiales[5], se estima que aproximadamente entre 8 y 25 millones de personas se encuentran en riesgo en América Latina, entre 32 y 164 millones en África, y entre 31 y 134 millones en Asia. El amplio rango de estas estimaciones muestra que aún existen muchas dudas sobre el riesgo real, pero también que las cifras de personas en riesgo probablemente son muy altas. Estas estimaciones no incluyen a agricultores expuestos a aguas contaminadas de regadío ni a la población urbana.

La mujeres corren un riesgo particular debido a que utilizan frecuentemente aguas de ríos y lagos para lavar ropa, cocinar y beber en el hogar. Niños y niñas también corren un riesgo acentuado pues llevan a cabo actividades recreativas en aguas superficiales locales y también normalmente se les asigna la tarea de recolectar agua para el hogar.

Cabe destacar que la concentración de bacteria coliforme fecal ha aumentado entre 1990 y 2010 en casi dos tercios de todos los ríos de América Latina, África y Asia. Los tramos de río con una “tendencia al alza de especial preocupación”[6] conforman cerca de un cuarto de los kilómetros totales de los ríos en estos continentes donde los niveles de bacteria coliforme fecal habían alcanzado un nivel severo en 1990 y se encontraban en un nivel peor en 2010. A esta áreas se las puede considerar puntos críticos.

Una gran parte del aumento se debe a la expansión de los sistemas de alcantarillado que descargan aguas residuales no tratadas en aguas superficiales. Por un lado, retirando las aguas residuales de las zonas pobladas, las alcantarillas han reducido el riesgo a la salud que constituyen las prácticas inseguras de saneamiento en tierra. Por otro lado, descargando aguas residuales no tratadas en aguas superficiales, han transferido el riesgo a la salud desde la tierra hacia las aguas superficiales. Se estimó que si no se hubiesen construido alcantarillas, las cargas de coliforme fecal en los ríos de África en 2010 podrían haber sido 23 por ciento menor. La solución, sin embargo, no es construir menos alcantarillas, sino tratar las aguas residuales que estas recogen.

La contaminación orgánica severa ya afecta a cerca de uno de cada siete kilómetros de todos los tramos de río de América Latina, África y Asia. El alto nivel de contaminación orgánica y su tendencia al alza son una preocupación que afecta a la industria de la pesca de agua dulce y, por lo tanto, la seguridad alimentaria y la subsistencia. Los grupos afectados por la contaminación orgánica incluyen los habitantes de zonas rurales de bajos recursos que dependen del pescado de agua dulce como fuente principal de proteína en la dieta, y pescadores y trabajadores de la pesca de bajos recursos que dependen de la pesca de agua dulce para subsistir.

La contaminación orgánica es causada por el depósito de grandes cantidades de compuestos orgánicos degradables en los cuerpos de aguas superficiales. La descomposición de estos compuestos normalmente conlleva una grave reducción de los recursos de oxígeno disuelto de un río de los que dependen peces y otra fauna acuática.

Los peces de aguas interiores constituyen una parte importante de las proteínas de la dieta de las personas de países en vías de desarrollo. Mundialmente, la pesca de agua dulce es la sexta fuente más importante de proteína animal, pero en algunos países en vías de desarrollo la pesca en aguas interiores es responsable por más de 50 por ciento de la proteína animal producida por país.

La pesca de agua dulce también es una importante fuente de subsistencia en los países en vías de desarrollo. La pesca de agua dulce en estos países da empleo a 21 millones de pescadores y genera 38,5 millones de empleos relacionados, casi todos ellos en pequeñas empresas pesqueras y ocupados mayoritariamente por personas de bajos recursos, de las cuales más de la mitad son mujeres. Por este motivo es alarmante que al menos 10% de

[3]El nivel severo de contaminación patógena se define en la Nota al Pie 5. Tales cuerpos de agua tienen la probabilidad de presentar niveles de patógenos como indica un alto nivel de bacteria coliforme fecal, lo que implica que las personas que entran en contacto con estas aguas están expuestas a un alto riesgo a la salud.
[4]La unidad de medida estándar de concentración de coliforme fecal son las “unidades formadoras de colonias” (cfu, por sus siglas en inglés) por cada 100 ml de muestra de agua.
[5]Esto incluye a las personas que entran en contacto con ríos que tienen un nivel severo de contaminación patógena (x > 1000 cfu / 100 ml)
[6]“Tendencia al alza de especial preocupación” en este informe significa un nivel de contaminación que aumentó a categoría de contaminación severa en 2008-2010 o que ya se encontraba en dicha categoría en 1990–1992 y continuó aumentando su concentración en 2008–2010.

todas las mediciones de América Latina, África y Asia muestren niveles preocupantes para al menos tres de cinco parámetros de calidad del agua de especial relevancia para la salud de las empresas de pesca.

En 2010, se estimó que la contaminación orgánica severa (en la que las concentraciones mensuales en caudal de DBO son > 8 mg/l) afectó hasta cerca de un décimo de los tramos de río de América Latina, hasta cerca de un séptimo de los tramos de río de África, y hasta cerca de un sexto de los tramos de río de Asia.

También genera gran preocupación que la contaminación orgánica (como demuestran las crecientes concentraciones en río de DBO) haya aumentado entre 1990 y 2010 en casi dos tercios de todos los ríos de América Latina, África y Asia. Un subgrupo de estos tramos de río con una "tendencia al alza de especial preocupación" conforma cerca de un décimo del total de kilómetros de los ríos de estos continentes en los que los niveles de DBO aumentaron a un nivel severo, o en los que ya se encontraban en un nivel severo en 1990 y se han encontrado peor en 2010. Estos ríos pueden ser considerados puntos críticos.

La contaminación salina severa y moderada ya afecta a cerca de un décimo de todos los tramos de río de América Latina, África y Asia y genera preocupación porque los altos niveles de salinidad afectan el uso de aguas de río para el regadío, la industria y otros propósitos. Los grupos afectados por la contaminación salina incluyen los agricultores de bajos recursos que dependen de aguas superficiales para el regadío de sus pequeños terrenos.

La "contaminación salina" ocurre cuando la concentración de sales disueltas y otras sustancias en ríos y lagos es lo suficientemente alta para interferir en el uso de estas aguas. Aunque casi todos los ríos tienen cierto contenido de sales debido al desgaste de los suelos de su cuenca hidrográfica, la sociedad se ha encargado de aumentar estos niveles descargando en los ríos caudales de retorno de agua de regadío, aguas residuales domésticas y vertidos de la minería.

La contaminación salina es menos común que las contaminaciones patógena y orgánica en los continentes estudiados. No obstante, la contaminación salina moderada y severa juntas (en las que las concentraciones mensuales en caudal de TDS son > 450 mg/l) afectan a uno de cada veinte kilómetros de río en América Latina, hasta cerca de un décimo de los tramos de río en África, y hasta cerca de un séptimo de los tramos de río en Asia. El agua de río dentro de la categoría de contaminación moderada se reserva parcialmente para el uso en regadío, y no se le puede dar ciertas aplicaciones industriales sin una purificación adicional. Los agricultores de bajos recursos que dependen de aguas superficiales como fuente de agua de regadío para sus pequeños terrenos podrían verse particularmente afectados.

La contaminación salina ha aumentado entre 1990 y 2010 en casi un tercio de todos los ríos de los tres continentes. Un subgrupo de estos tramos de río (un pequeño porcentaje de todos los tramos de río) presenta una "tendencia al alza de especial preocupación" en la que los niveles de TDS alcanzaron un nivel severo en 1990, o se ya encontraban en un nivel severo en 1990 y se han encontrado peor en 2010.

Las cargas antropogénicas de nutrientes en lagos importantes son significativas y podrían causar o empeorar la eutrofización en estos lagos. Las tendencias de estas cargas son diferentes en diversas partes del mundo.

La eutrofización es la fertilización excesiva de lagos y otros cuerpos de agua que conlleva una alteración de sus procesos naturales. La eutrofización de los lagos normalmente es causada por cargas antropogénicas de fósforo, aunque las cargas de nitrógeno también se encuentran implicadas. Más de la mitad de las cargas totales de fósforo en 23 de 25 lagos importantes[7] de todo el mundo proviene de fuentes antropogénicas. En comparación, dichas cargas están disminuyendo en América del Norte y Europa debido a la implementación de medidas efectivas de reducción de fósforo.

La causa inmediata del aumento de la contaminación del agua es el crecimiento de las cargas de aguas residuales en ríos y lagos. Las fuentes actuales de contaminación más importantes varían de contaminante en contaminante. Las principales causas del aumento de la contaminación del agua son el crecimiento de la población, el aumento de la actividad económica, la intensificación y expansión de la agricultura, y el aumento de sistemas de alcantarillado con un nivel bajo o nulo de tratamiento.

La recolección de aguas residuales en el alcantarillado reduce el contacto directo de las personas con residuos y patógenos y, de esta forma, es una estrategia importante para proteger la salud pública. Sin embargo, la

[7]En este informe "lagos importantes de todo el mundo" se refiere a los cinco mayores lagos en términos de área superficial en cada una de las regiones definidas por el PNUMA en las "Perspectivas del Medio Ambiente Mundial" (África, Asia, Europa, América Latina y América del Norte).

instalación de alcantarillas también ha concentrado la descarga de contaminantes en aguas superficiales y ha transferido el lugar del riesgo para la salud de las personas.

La mayor fuente de contaminación patógena (cargas de bacteria coliforme fecal) en América Latina son las aguas residuales domésticas de alcantarillas, en África son los residuos domésticos sin alcantarillado, y en Asia son las aguas residuales domésticas de alcantarillas seguidas de cerca por los residuos domésticos sin alcantarillado.

La mayor fuente de contaminación orgánica (cargas de DBO) en América Latina son las aguas residuales de alcantarillas, en África y en Asia es la agricultura de regadío.

La mayor fuente antropogénica de contaminación salina (cargas de TDS) en América Latina es la industria, y en África y Asia la agricultura de regadío.

Fuentes importantes de fósforo antropogénico en los lagos más importantes en América Latina son los residuos de ganadería y fertilizantes inorgánicos, en África son los residuos de ganadería, en Asia y Europa es el agua residual doméstica, residuos de ganadería y fertilizantes inorgánicos, y en América del Norte son los fertilizantes inorgánicos.

Aunque la contaminación del agua es grave y está empeorando en América Latina, África y Asia, la mayoría de los ríos de estos tres continentes aún se encuentra en buenas condiciones, y existen excelentes oportunidades para detener la contaminación y restablecer la calidad de los ríos que necesitan mejorar.

En los puntos anteriores el foco fueron los diversos tramos de río en los que la calidad del agua es baja y continúa en deterioro. Pero la otra cara de la moneda es que muchos tramos *aún no han sido contaminados:*

- Cerca de entre la mitad y dos tercios de todos los tramos de río (en América Latina, África y Asia) tienen un nivel *bajo* de contaminación patógena,
- Más de tres cuartos tienen un nivel *bajo* de contaminación orgánica, y
- Cerca de nueve décimos tienen *baja* contaminación salina.

Aún es posible evitar que estos tramos limpios de río sean altamente contaminados. También es posible comenzar a restablecer la calidad de los tramos de río que ya se encuentran contaminados. Se pueden realizar muchas acciones para evitar el aumento de la contaminación y recuperar las aguas dulces contaminadas:

1. *Monitorización* — Se necesita una mejor comprensión sobre la intensidad y el alcance del desafío mundial de la calidad del agua. Para alcanzar dicha comprensión, se debe expandir la monitorización de la calidad del agua urgentemente, especialmente en los países en vías de desarrollo, y especialmente a nivel internacional a través del programa SIMUVIMA/Agua.
2. *Evaluaciones* — Se necesitan evaluaciones completas nacionales e internacionales del desafío mundial de la calidad del agua. Se necesitan estas evaluaciones para identificar los lugares prioritarios y las acciones que se deben realizar para tratar la contaminación del agua.
3. *Nuevas y antiguas opciones técnicas y de gestión* — Los países en vías de desarrollo tienen la oportunidad de no emplear el tratamiento tradicional de aguas residuales y también de hacer uso de nuevas y muchas más opciones técnicas y de gestión para gestionar la calidad del agua, entre ellas soluciones naturales.
4. *Establecimiento de instituciones efectivas* — Parte esencial de la gestión de la calidad del agua es el establecimiento de instituciones que promuevan acciones y superen las barreras para controlar la contaminación del agua.

A continuación elaboramos las ideas anteriormente mencionadas:

Qué se puede hacer: I. Monitorización

No es posible realizar evaluaciones completas de la calidad mundial del agua debido a la baja calidad de la cobertura de recolección datos de calidad del agua de aguas superficiales en GEMStat, la única base de datos mundial de calidad de aguas.

GEMStat tiene una densidad muy baja de estaciones en comparación con las densidades mínimas típicas de cerca de 1,5 a 4 estaciones por cada 10.000 km^2 de área de cuenca hidrográfica en EE.UU. y Europa. En GEMStat, 71 de las 110 cuencas hidrográficas que poseen datos tienen una densidad de 0,5 o menos estaciones por cada 10.000 km^2.

La densidad promedio para América Latina es de 0,3 estaciones por cada 10.000 km^2, para África de 0,02 estaciones[8] por cada 10.000 km^2 y para Asia 0,08 estaciones por cada 10.000 km^2 en el periodo entre 1990 y 2010.

La principal prioridad es expandir la cobertura espacial y temporal de las estaciones de monitorización en lugar de aumentar el número de parámetros recolectados en las estaciones existentes. Considerando los altos costos de la monitorización, es importante establecer prioridades respecto a los ríos con deficiencia de datos que se deben monitorizar primero. Los puntos críticos identificados en este informe pueden ser utilizados como referencia para decidir dónde expandir las iniciativas de monitorización.

Las razones de la baja cobertura de recolección de datos son políticas, institucionales y técnicas. No obstante, existen muchas alternativas para mejorar la cobertura de recolección de datos de calidad del agua.

Una alternativa para mejorar la cobertura es hacer uso de datos de teledetección. Los grupos actuales de datos cubren variables de calidad del agua esenciales para lagos, y en un futuro cercano estarán disponibles datos para ríos. Una ventaja de la teledetección es la amplia cobertura espacial y temporal de la recopilación de datos; las desventajas incluyen el número limitado de variables que se puede medir y el procesamiento de los datos brutos que se requiere.

Otras opciones para mejorar la cobertura de recolección de datos de la calidad del agua son: (i) aumentar los esfuerzos para incorporar los datos nacionales y regionales a las bases de datos existentes, (ii) establecer grupos de trabajo de monitorización de agua dulce nacional para trabajar con sus contrapartes en otros países en la divulgación y uso de los datos de calidad del agua, (iii) consultar datos a través de proyectos científicos cívicos. La ciencia cívica tiene la ventaja adicional de involucrar a un público más numeroso en la eliminación de la contaminación del agua.

Las iniciativas de recolección de datos también deben apuntar a hacer que estos datos estén disponibles en diversos lugares y puedan ser consultados a través de plataformas digitales como "UNEP Live". Los datos también deben estar disponibles en diversos lugares en conexión con la monitorización y la implementación de los Objetivos de Desarrollo Sostenible.

Qué se puede hacer: II. Evaluación

Se necesita una Evaluación Mundial de Calidad del Agua a gran escala para evaluar el estado de los conocimientos sobre todos los aspectos esenciales de la calidad del agua, para establecer vínculos entre la calidad el agua y otros asuntos del Desarrollo Post 2015 tales como la salud y la seguridad alimentaria, y para identificar áreas de prioridad para estudios y acciones.

La evaluación debe ser:

- Multinivel — de cobertura mundial vinculada a evaluaciones nacionales y evaluaciones temáticas.
- Transparente y participativa — que implique una amplia gama de actores clave y científicos.

La evaluación debe incluir:

- Objetivos y temas que sean seleccionados en conjunto por las comunidades política y científica.
- Un análisis de las opciones políticas para la protección y el restablecimiento de la calidad del agua.
- Acceso amplio a los resultados poniéndolos a disposición en nuevas plataformas digitales (por ejemplo, "UNEP Live").

La evaluación también debe ser considerada una oportunidad de aumentar la capacidad técnica de los países en vías de desarrollo y su acceso a los más recientes resultados científicos.

Qué se puede hacer: III. Opciones Técnicas y de Gestión

Existen muchas opciones al alcance de los países en vías de desarrollo para evitar el deterioro de la calidad del agua de sus ríos y lagos. Muchas de estas opciones no existían o no fueron utilizadas por los países desarrollados cuando estos se enfrentaron a un similar deterioro de la calidad de sus aguas hace algunas décadas.

[8] Las áreas de tierra firme no se incluyen en el área continental.

Las principales opciones técnicas son:

(i) *Prevención de la contaminación* en la que se evite la fuente de contaminación del agua antes de que se transforme en un problema.

(ii) *Tratamiento de aguas contaminadas* que constituye el enfoque tradicional para la reducción de las cargas de contaminantes antes de que sean descargadas en aguas superficiales.

(iii) *Uso seguro de aguas residuales* reutilizándolas para el regadío y otros propósitos.

(iv) *"Soluciones naturales" que impliquen la restauración y protección de ecosistemas* tales como la reforestación de cuencas para reducir la erosión y las cargas sedimentarias en ríos o la restauración de humedales para eliminar contaminantes de los vertidos urbanos y agrícolas.

Dentro de cada sección existen muchas ideas nuevas que no estaban al alcance de los países desarrollados cuando tuvieron que enfrentarse por primera vez a un deterioro similar de la calidad del agua hace tres o cuatro décadas. Entre estas nuevas ideas se encuentran: *producción industrial más limpia, humedales artificiales, cero descargas de efluentes,* y *pago por servicios de ecosistema de cabeceras de río forestadas.*

Se necesitarán diferentes estrategias técnicas para controlar diversos tipos de contaminación del agua y fuentes de contaminación. Vale la pena intentar y agrupar estas estrategias en paquetes que puedan ser aplicados a diferentes cuencas hidrográficas.

Por un lado, se mencionó anteriormente que las principales fuentes de contaminación difieren entre los diferentes tipos de contaminación del agua, lo que significa que una solución "de talla única" no funcionará para resolver el desafío mundial de la calidad del agua. Por otro lado, en todas partes del mundo surgen problemas similares con la calidad del agua incluso si los lugares y situaciones son diferentes. Por lo tanto, se podrían desarrollar diferentes paquetes de opciones técnicas que puedan ser usados en diferentes cuencas hidrográficas para lidiar con problemas similares.

Qué se puede hacer: IV. Gobernanza e Instituciones

Estudios de caso de diferentes cuencas hidrográficas señalan la importancia de una buena gobernanza e instituciones efectivas para gestionar la calidad del agua.

Se descubrió que algunos importantes obstáculos para enfrentar los problemas de contaminación del agua incluyen:

- La fragmentación de la autoridad dentro de una cuenca hidrográfica,
- Falta de capacidad técnica, y
- Falta de consciencia por parte del público sobre las causas de la contaminación del agua.

Para superar estos y otros obstáculos, la experiencia de los estudios de caso demostró que una campaña pública de educación es una primera medida para obtener apoyo para el control de la contaminación del agua. Otra conclusión es que un *Plan de Acción,* acordado por todos los actores principales dentro de una cuenca hidrográfica, es un paso clave para establecer un *cuerpo colaborativo* tal como las comisiones internacionales de los ríos Elba y Volta para desarrollar y ejecutar un plan de acción. En el caso del Elba, también se demostró que una institución nacional de gran alcance (la Comunidad de la Cuenca Hidrográfica del Elba) puede proporcionar una valiosa plataforma para obtener la cooperación de todos los actores *nacionales* principales dentro de una cuenca hidrográfica.

El trabajo con el desafío mundial de la calidad del agua está directamente relacionado a muchas otras prioridades de la sociedad tales como la seguridad alimentaria y la salud. Por lo tanto, las acciones para proteger la calidad del agua deben estar insertas en el concepto más amplio de sostenibilidad, y ser parte de las iniciativas para alcanzar los Objetivos de Desarrollo Sostenible.

Los estudios de caso señalaron que el desafío de la protección de la calidad del agua está interconectado con muchas otras tareas de la sociedad —el abastecimiento de alimentos, el desarrollo de la economía y el saneamiento seguro—. Por lo tanto, dentro de los próximos años será muy importante vincular las objetivos para la calidad del agua con otros objetivos de la Agenda Post 2015 y los nuevos Objetivos de Desarrollo Sostenible.

A Snapshot of the World's Water Quality: Towards a global assessment

Chapter 1–5
Literature

1 Introduction

At the 1992 Earth Summit, freshwater was highlighted in Agenda 21 as a topic of worldwide concern (UN, 1992). Since then, the crucial role played by freshwater in global development, global health, and in sustainability, have been highlighted many times and action has been called for in several international summits. While a strong message emerged from these summits about freshwater in general, the same cannot be said about the worldwide challenge of poor water quality. For example, the Millennium Summit in 2000 produced the Millennium Development Goals (MDGs) (UN, 2000) which focused on urgently needed improvements to drinking water and sanitation but did not specifically call for improvements in water quality. Yet, adequate quantities of good quality freshwater are essential for human health, food security (particularly inland fisheries) and the aquatic environment itself. Twenty years after Agenda 21, the United Nations Conference on Sustainable Development, Rio +20, again placed water at the core of sustainable development. This time, the outcome document "The Future We Want" (UN, 2012) recognised water as being linked to several key global challenges and highlighted the need to reduce water pollution, improve water quality and reduce water loss.

At the United Nations Sustainable Development Summit in New York in September 2015, the General Assembly adopted 17 Sustainable Development Goals (SDGs), which aim to build on the MDGs and complete what they did not achieve (UN, 2015). Goal 6 "Ensure availability and sustainable management of water and sanitation for all" (UN, 2015) specifically calls for sustainable withdrawals, access to adequate quantity for all and an improvement in water quality by 2030. For the first time, there is an acknowledged need to protect aquatic ecosystems and to preserve ambient water quality. Progress towards this goal will need to be monitored and currently indicators for monitoring ambient water quality are still being developed and agreed upon. UN-Water, the inter-agency coordination mechanism for all freshwater and sanitation related matters, is co-ordinating various actions within the UN system that will contribute to the implementation of the SDGs, including monitoring of water quality (through GEMS/Water – see below), as well as providing advice and support on mechanisms for protecting water bodies and aquatic ecosystems through projects such as the production of the Compendium of Water Quality Regulatory Frameworks: Which Water for Which Use (UN-Water, 2015a) and the International Water Quality Guidelines for Ecosystems (UNEP, 2015c).

Sources of good quality water for drinking and domestic use, whether surface or groundwater, are fundamental to human health. In some world regions between 70 per cent and 85 per cent of the population rely on surface waters as their source of drinking water (Morris et al. 2003) although in some countries it can be 90 per cent or more. Consumption of water containing pathogens or elements that are potentially toxic can lead to health impacts ranging from discomfort to death (WHO, 2011). Pathogens in human sewage that contaminate surface and groundwaters used for drinking or food preparation, recreation or irrigation of food crops, are responsible for many diseases, especially diarrheal diseases such as cholera. Recent estimates suggest that 58 per cent of total deaths from diarrhoea (which is amongst the top ten causes of death worldwide) in low- and middle-income countries are due to poor quality drinking water, together with inadequate sanitation and hygiene (WHO, 2014b). Although this figure has improved from the estimate of 88 per cent in 2000, water bodies contaminated with human excreta and used for other human activities (such as drinking, cooking and cleaning, recreation and irrigation) pose a serious threat to the health of the water users, especially women and children as articulated in Chapter 3.

The essential services that aquatic ecosystems provide for human society, either directly or indirectly, were identified by the Millennium Ecosystem Assessment (2005a) and recently highlighted again in the World Water Assessment Programme (WWAP) report "Water for a Sustainable World" (WWAP, 2015). These essential services include water for drinking and irrigation, purification of wastewaters, fisheries for food, hydroelectricity, flood regulation, wetland plants for fuel and construction, and water and nutrient cycling. Up until relatively recently, interest in water quality was focused purely on direct human uses with little effort being directed towards monitoring or maintaining water quality for the benefit of the natural communities of aquatic organisms, i.e. ecosystems. But these ecosystems are important not only from the ethical standpoint of conserving biodiversity, but also because they are an important source of food and livelihood for many people in developing countries. As noted in Chapter 3, inland fisheries are a major source of animal protein in many parts of the developing world. Poor water quality disturbs the balance of aquatic ecosystems, often resulting in changes in fish species and declines in valuable fish stocks. Contamination with organic matter from domestic and food waste, and increases in nutrient levels from agricultural activities, are two of the major threats to inland fisheries, combined with reduced water levels and interruptions to migration routes by dams and weirs (Welcomme et al., 2010; FAO, 2014).

What is causing water pollution?

Water quality is naturally influenced by the climatological and geochemical location of the water body through temperature, rainfall, leaching, and run-off of elements from the Earth's crust. However, most surface water bodies around the world are also affected to some extent by impacts from human activities, particularly the discharge of waste products (including sewage) or addition of sediments, salts and minerals with run-off from agriculture and urban settlements. Chapter 3 articulates the extent of this impact for key water quality indicators. Even in remote locations, water in lakes contains traces of toxic compounds carried in the atmosphere from waste discharges in industrialised regions.

Domestic and municipal wastewater

Human sewage contains pathogens, organic matter, and chemicals used by people, such as pharmaceutical products. Human and animal excreta can potentially contain a variety of transmissible pathogens, such as viruses, bacteria, protozoa and worms. The occurrence of these pathogens depends on geographical location and the occurrence of the disease in the local population. Practically speaking, it is not possible to monitor water for the presence of all potential pathogens, whereas it is relatively simple to detect the presence of faecal matter by the presence of faecal coliform bacteria (see Chapter 3). Globally, such indicators are used to indicate contamination by faecal matter and the possibility of pathogens being present, and they are an essential indicator for risks arising from contact with surface waters and drinking water.

Organic matter in sewage or in manure and food waste is naturally degraded in water bodies by chemical and microbiological activity (see Chapter 3). These degradation processes use up the dissolved oxygen (DO) in the water, causing stress for many aquatic organisms including fish species that require oxygen for respiration. The demand for oxygen in a water body is used as an indicator of organic matter pollution through the biochemical oxygen demand (BOD) test. This test is widely used to determine the impact of sewage releases into rivers. Severe organic pollution, as it is sometimes called, can lead to complete deoxygenation (anoxia), in which very few organisms can survive. Low DO levels also lead to chemical reactions that result in the release or formation of other toxic compounds such as ammonia and hydrogen sulphide in sediments and bottom waters. Ammonia is also a common component of excretion products and can be found in high concentrations in sewage. It is therefore often measured in polluted water bodies because it is particularly toxic to fish (see Box 3.3).

Agriculture and other land-based activities

Intensification of agricultural production to meet growing food demands leads to pressure on water resources for irrigation and to degradation of surface water quality from run-off carrying fertilisers and pesticides from agricultural land. Groundwaters can also be contaminated with agricultural chemicals through infiltration. Sometimes the abstraction of water for irrigation substantially reduces available surface water volumes and contributes to declining water quality by returning water that is contaminated with salts, fertilisers and pesticides. The increased levels of minerals and salts damage the ecosystem (Cañedo-Argüelles et al., 2013) and make the water less suitable for other uses, particularly irrigation (see Chapter 3).

One of the most studied and best understood impacts on water bodies is the increase in nutrients arising from land-based activities resulting in eutrophication and the associated changes in aquatic ecosystems, both freshwater and coastal (Schindler, 2006; Smith et al., 2006). In most pristine water bodies, levels of the nutrients nitrogen and phosphorus are low, arising only from the leaching of minerals or from decomposition of living matter. Higher levels are typically an impact of human activity, particularly fertiliser run-off from agricultural activities and the discharge of sewage effluents (see Chapter 3). The resulting eutrophication enhances productivity, which can have negative consequences for water use, such as growth of nuisance plants and algal blooms, changes in ecosystem structure and fish species, and deoxygenation when algal blooms decompose (Box 3.4; Schindler, 2006). Rivers ultimately carry their burden of pollutants, including sediments and nutrients, to the coastal zone and, increasingly, eutrophication is being detected in coastal waters (e.g. Borysova et al. 2005). The first global assessment of water quality in 1988 highlighted that eutrophication was already a global problem then (UNEP/WHO, 1988; Meybeck et al., 1989) and, with increasing demand for food production and wastewater disposal over the last three decades, eutrophication is still a major water quality issue today (Millennium Ecosystem Assessment, 2005b).

Wastewater from many land-based sources including agriculture, industry and domestic sewage carry dissolved salts and minerals to surface waters. The concentration and nature of these dissolved salts, such as chlorides and sulphates, varies according to the source. However, in high concentrations they upset the natural chemical balance of the receiving water, leading to salinisation and making the water unfit for particular uses (especially industrial uses) and for sensitive aquatic organisms. This is sometimes called "salinity pollution". Salinisation of freshwater is occurring at the global scale and can be detected by the relatively simple measure of total dissolved solids (TDS) (see section 3.4).

Industrial activities and emerging pollutants

Social and economic development depends on access to adequate quantities of good quality water for manufacturing and production processes, and the treatment and assimilation of waste products. Some industrial processes, such as the production of pharmaceutical compounds, require very high quality water and others, such as paper production require large quantities. Meeting these needs in the future will be a major challenge if current levels of water use and degradation continue (WWAP, 2015).

As far back as the 1970s it was realised that the discharge of waste products containing metals and chemical compounds was impacting the aquatic environment, particularly the aquatic food chain and predatory animals and birds. Many metals (e.g. mercury, cadmium, arsenic) and most synthetic organic compounds (e.g. PCBs, pesticides) are toxic to living organisms, including people, at high enough concentrations. This issue has been partly addressed by the inclusion of guideline levels for metals and compounds in the WHO Guidelines for Drinking-Water Quality (WHO, 2011). Practically speaking, only the most toxic and persistent compounds are measured in water bodies on a regular basis, apart from in drinking water, because the range of possible compounds is huge, the concentrations are usually low, and the techniques for measurement expensive (Petrovic, 2014). The availability of such data at a global scale is therefore sparse, even though for some countries it is widely available (Hughes et al., 2012). Today, new forms of toxic compounds are being evaluated for their potential to reach the aquatic environment and to lead to potential damage to aquatic systems or even human health through consumption of contaminated water (Corcoran et al., 2010). These new and emerging compounds include excreted and metabolised pharmaceutical products, such as hormones and different classes of drugs. The range of potential compounds that could be monitored is huge and currently there are few monitoring programmes that routinely include them. The water quality situation with regards to these compounds should be dealt with in future assessments.

Need for data and monitoring to support assessment and to support the identification of solutions

Most nations are concerned primarily with the quality of their own waters, except in situations where water bodies cross national boundaries and international agreements or programmes have been put in place. Monitoring is often directed specifically towards the safety of drinking water or control of waste discharges, and is guided by national or local policy and legislation. With increasing environmental awareness in the 1970s it was realised that water quality at a global scale was inevitably likely to deteriorate and a means of monitoring this over time was needed in order to define and set global priorities for protection of water resources. The 1972 Stockholm Conference on the Human Environment called for the establishment of a global water monitoring programme and in 1978 GEMS/Water (Global Environment Monitoring System for Water) was set up as an inter-agency programme under the United Nations Environment Programme (UNEP), World Health Organization (WHO), World Meteorological Organization (WMO) and United Nations Environmental, Scientific and Cultural Organization (UNESCO). The intention was to collect global water quality data and to increase the capacity of developing countries to undertake the necessary monitoring. In the 1980s a first attempt was made to use the GEMS/Water database to carry out a global assessment of water quality. However, the inconsistent spatial and temporal coverage of the data, together with large variations in the range of water quality variables reported to the database meant that the first global water quality assessment (UNEP/WHO, 1988; Meybeck et al., 1989) had to rely on the use of other data sources, together with the results of special studies published in the scientific literature. Nevertheless, the assessment highlighted a number of water quality issues that were occurring on a global scale, e.g. eutrophication, organic matter pollution from sewage and elevated nitrate in groundwaters (Meybeck et al., 1989) and which have been further specified in later studies based on GEMS/Water data (e.g. UNEP 2008). Today the situation is unfortunately very similar. But this report combines the limited amount of data with modelling to successfully obtain a first picture of the water quality situation in rivers throughout Latin America, Africa, and Asia. Moreover, there are now monitoring programmes in some world regions that are intended to track the long-term changes in these issues at the river basin scale, to identify new issues and to provide the information that will assist in identifying solutions (e.g. Liska et al., 2015 for the Danube River basin). It has now been 27 years since the first and only global water quality assessment. The time is overdue to again assess where the world stands with regards to the quality of its freshwaters.

How to read the report

This report addresses the need to assess the current world water quality situation so as to identify the scope and scale of the "global water quality challenge". This is a pre-study of a full assessment. The first objective of this pre-study is to provide some of the building blocks for a full-scale world water quality assessment. The second objective is to present a preliminary estimate of the water quality situation of freshwater ecosystems in the world, with a focus on rivers and lakes on three continents.

Since it is a pre-study and not a full assessment the scope of the report is limited. It focuses on a small number of important water quality problems in surface freshwaters – pathogen pollution, organic pollution, salinity pollution and eutrophication, and their relevance to human health, food security, and livelihoods. Likewise it concentrates on a small, but important set of impacts of these water quality problems: i) the threat posed by pathogen pollution to people coming into contact with contaminated surface waters, ii) the impact of organic pollution on inland fisheries and their connection to food security, iii) the impact of salinity pollution on limiting water use for irrigation, and (iv) the impact of human activities on the loading of nutrients to lakes. Because it is only a pre-study it is not feasible to cover all parts of the world in the same detail. In particular, the analysis of water quality in rivers concentrates on the continents of Latin America, Africa and Asia because of the fewer assessments available about water quality on these continents as compared to North America, Europe or Australia.

As noted above, the report takes a combined data- and model-driven approach, which makes best use of available information and compensates for the limitations of both approaches (see Chapter 3). Observed data come from the UNEP Global Environment Monitoring System for Water (GEMS/Water), and modelling results from the global WaterGAP/WorldQual model.

To describe and analyse the world water quality situation, the "DPSIR" conceptual framework is used, which divides different aspects of a system into linked "drivers", "pressures", "states", impacts" and "responses". This framework is used to structure the material in the report, but is not referred to explicitly in the report.

The report is structured into five chapters, including this Introduction. Chapter 2 evaluates the availability of global data and gives an example of use of these data for in-stream water quality analysis; Chapter 3 gives first estimates of water quality problems on three continents using the combined data-model approach to determine the scale of the water quality challenge, to set priorities for action in hot spot areas, and for monitoring; Chapter 4 presents eight case studies of water quality issues at the basin level that illustrate the wide range of water quality challenges and how they are being met; and Chapter 5 outlines the wide range of options to meet the water quality challenge and raises critical issues that need to be considered to meet this challenge.

As a whole, the report addresses especially persons interested in the methodology proposed, the exemplary results presented and lessons learned – in organisations dealing with global water related issues, in water authorities worldwide or in academia – by providing a sweeping view of some important aspects of the global water quality challenge and pointing the way to a needed full assessment of the world water quality situation.

2 State of observational knowledge

Aim of this chapter

- To review the availability of water quality data at the international level and suggest how to make more data available.

Main messages

- Data are essential for developing, monitoring and evaluating water resources management strategies
- New technologies and monitoring strategies will simplify data acquisition and strongly expand data availability in the near future
- The Global Environment Monitoring System (GEMS) is a suitable platform to aggregate global water quality data
- At present, the GEMStat database is a critical source of data because it has sparse spatial and temporal coverage and its data holdings do not have a high level of coherence.
- Further developing and strengthening GEMS/Water, and giving it clear institutional objectives and mandates, will increase the global availability of water quality data and enable a reliable global assessment of water quality.
- The hot spot areas of pollution identified in this report can be used as input in deciding where to expand monitoring efforts

2.1 Why do we need global data?

Understanding the global and regional patterns of water quality, both in the past and present, is necessary if we are to come to grips with risks to water security and ways to minimize these risks. Furthermore, this knowledge is a basis for future projections of water quality under the influence of global change.

The observational data needed for this understanding must capture the temporal dynamics of water quality components and have to be coherent over local, catchment and global spatial scales. The selection of key water quality parameters is an equally important task. They should cover the major characteristics of the freshwater system including its physical characteristics, oxygen balance, nutrient status, mineral composition and presence of specific pollutants. They should also reflect the influence of anthropogenic pressures and impacts.

In order to retrieve reliable information from large data bases with data driven methodologies (such as analytical statistics, time series or spatial analysis) there is a need for complementary meta-information regarding hydrology, sampling location, analytical methodologies and quality assurance.

Currently, water quality monitoring programmes and available data bases are usually based on water quality samples collected at specific times and locations and their subsequent laboratory analysis. In the near future it is expected that these traditional techniques will be complemented by remote sensing data, which will become available at spatial resolutions covering whole river networks and lakes of various sizes. The next generation of hyperspectral sensors will provide information that can be linked to a wide set of water quality parameters and that will require ground truthing of the spectral signals.

Furthermore, autonomous water quality monitoring techniques are developing rapidly and will allow for new approaches for setting-up large scale monitoring networks. Photosensors have been miniaturised, and dropped in price, and are now widely available for popular electronic devices such as smartphones. Due to this development, water users and citizens could be much more closely involved in future monitoring efforts. Therefore, future data bases for water quality will build on the existing systems, but may expand significantly with regard to methodologies, sources of information and therefore spatial and temporal coverage.

2.2 What data are available from GEMS/Water?

2.2.1 GEMS/Water Programme and GEMStat

The GEMS/Water Programme, established in 1978, is the primary source for global water quality data. Today, GEMS/Water consists of several entities[1] and is oriented towards building knowledge on inland water quality issues worldwide. Key activities include data collection, research, assessment and capacity building. The twin goals of the programme are to improve water quality monitoring and assessment capacity in participating countries, and to determine the state and trends of regional and global water quality.[2]

The data from participating countries are made available within the GEMS/Water online database, GEMStat. Formerly located in Canada, the responsibility of GEMStat moved to the Federal Institute of Hydrology (BFG) in Germany in 2014. At present, GEMStat includes data from more than 100 countries, and contains approximately five million entries for lakes, reservoirs, wetlands and groundwater systems.

2.2.2 Review of data availability (status 2014)

The availability of data in GEMStat was assessed for a selection of parameters of particular importance to the status of water quality of inland freshwaters. In particular the spatial and temporal coverage of data was evaluated. A complete list of the data available for this study (river basins, stations per river basin, number of measurements, number of measured parameters, time frame) is given in Appendix A. The station densities and temporal coverage of data on the river basin scale are depicted in Figure 2.1. Overall, data is available for some 110 river basins worldwide for the time period of 1990 to 2010. Data from one third of these river basins are older than 10 years.

To judge the adequacy of the density of stations, other water quality monitoring programs in the world can be considered. For example, according to the European Water Framework Directive – WFD (European Commission, 2000), the legally binding instrument for water policy in Europe, "surveillance monitoring" aims to evaluate long-term changes in natural conditions and changes resulting from widespread anthropogenic activities. In general, the station density of surveillance monitoring has a minimum of one station per 2,500 km² within a river basin, equivalent to four stations per 10,000 km². At these stations, the monitoring frequency for physico-chemical parameters (e.g. temperature, pH, nutrients, salinity, and oxygen) is four times per year. The station density and frequency of measurements for "operational" monitoring (for assessing the current status and short term changes of waterbodies) could be much higher in order to achieve an acceptable level of confidence and precision.

In the United States, a monitoring programme in the State of South Carolina has a station density of 3.8 stations per 10,000 km² (U.S. EPA, 2003)[3] and another in the State of Wisconsin has an average density of 1.6 stations per 10,000 km² (Anon, 1998)[4].

Compared to the above examples which range from around 1.5 to 4 stations per 10,000 km², the densities of stations in the GEMStat data base (Figure 2.1) are very low. In GEMStat, 71 out of the 110 river basins with data have a density of 0.5 stations per 10,000 km² or less. Only 57 countries report data in the time period of 1990 to 2010. The average density for the Latin American continent is 0.3 stations per 10,000 km², for Africa 0.02 stations per 10,000 km², and for Asia 0.08 stations per 10,000 km² during the time period between 1990 and 2010. Against this background, it is of course difficult to obtain a representative and valid assessment of the water quality for an entire river basin. Furthermore, the selection of water quality parameters measured was not consistent, and the frequency of measuring water quality parameters is very variable. Depending on the parameter, the range is from 1 to 12 measurements per year, parameter and station. The average monitoring frequency for Latin America and Africa is 4, and for Asia 5.5 measurements per year, parameter and station. Because of the huge data gap and the high variability of data metrics, a valid comparison of water quality status or trends between catchments is not feasible with the current data base. A proposal on how to further develop and improve the utility of the GEMStat data is described in Box 2.1.

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[1]The GEMS/Water Global Program Coordination Unit in Nairobi, Kenya, the GEMS/Water Capacity Development Centre at the University of Cork, Ireland and the GEMS/Water Data Centre at the Federal Institute of Hydrology, Koblenz, Germany.

[2]*http://www.gemstat.org*

[3]These sites target the most downstream access of each of the Natural Resource Conservation Service (NRCS) 11-digit watershed units in the state, as well as the major waterbody types that occur within these units. For example, if a watershed unit ends in estuarine areas at the coast, integrator sites are located in both the free-flowing freshwater portion and the saltwater area.

[4]One station with a disproportionally large drainage area was left out of the average of the 43 recommended stations.

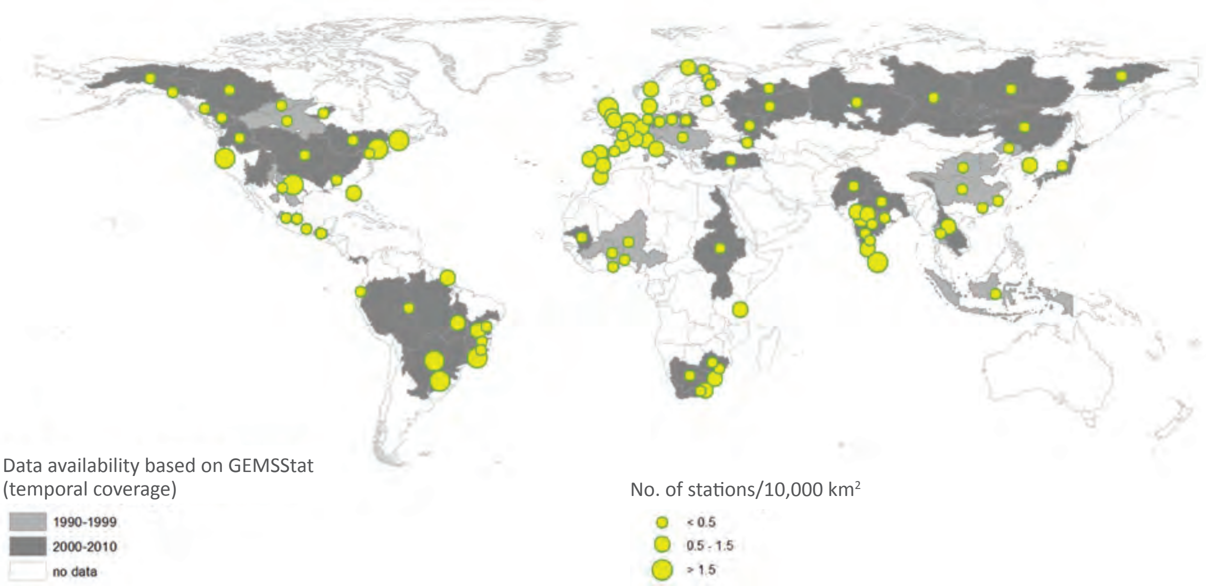


Figure 2.1: Temporal coverage (grey shading) and station density (size of circles) of GEMStat data (Data source: GEMStat, 2014; GIS data source: GRDC, 2007).

Box 2.1: Utility of GEMS data on the way towards a world water quality assessment

Water quality data of GEMStat should be used together with robust, valid, reliable and comparable methods to comprehensively assess global water quality. Using the concentration of a specific parameter in a river basin, water quality could be classified for given levels or ranges of concern. These data need to be clearly linked to the functionality of riverine ecosystems and food security issues with respect to water quality requirements for freshwater fish and invertebrates such as crayfish or mussels.

It is important to know baseline concentrations of water quality parameters so that temporal trends of water quality can be tracked. A trend analysis could indicate an improvement, deterioration or stagnation in the quality of water for a specific time period.

As a simple example, thresholds were selected to classify the water quality of river basins in two categories, above and below “levels of concern”. While thresholds were mainly derived from established water quality requirements of a healthy fish fauna, compliance with the levels of concern could also be interpreted as lower risk for food security.

For the analyses of trends, and taking into account the sparse temporal coverage of data, median concentrations of the water quality parameters were calculated for the decades 1990 to 1999 and 2000 to 2010. Non-parametric statistical tests indicated whether the differences between the time periods were insignificantly or significantly changing (increasing or decreasing). The methods employed for the analysis took into account the heterogeneity of GEMStat data by focusing on robust metrics and are therefore widely applicable.

The following map (Figure 2.2) visualises an example of a risk classification for the parameter dissolved oxygen in river basins where data are available. The top map indicates whether the mean oxygen concentration of all measurements in a river basin under consideration are above or below an example threshold “level of concern” (7 mg/l)[5], and the bottom map shows the trend of data. Fewer river basins appear in the trend analysis in the lower map because several river basins were lacking data for either 1990–1999 or 2000–2010. Dissolved oxygen concentrations (1990-1999) were at or below the level of concern (7 mg/l) at various stations in Latin America, Asia and India. A decreasing trend of dissolved oxygen was observed in stations in Eastern Europe and India.

[5]“Level of concern” in this chapter is used to mean the pollutant concentration above (or below) which significant negative impacts occur. In this report these concentrations are derived from water quality standards from official sources such as government departments or UN agencies. This level of concern is derived from guidelines for temperate zones. The potential impacts have to be evaluated in the framework of regional climatic and other conditions.

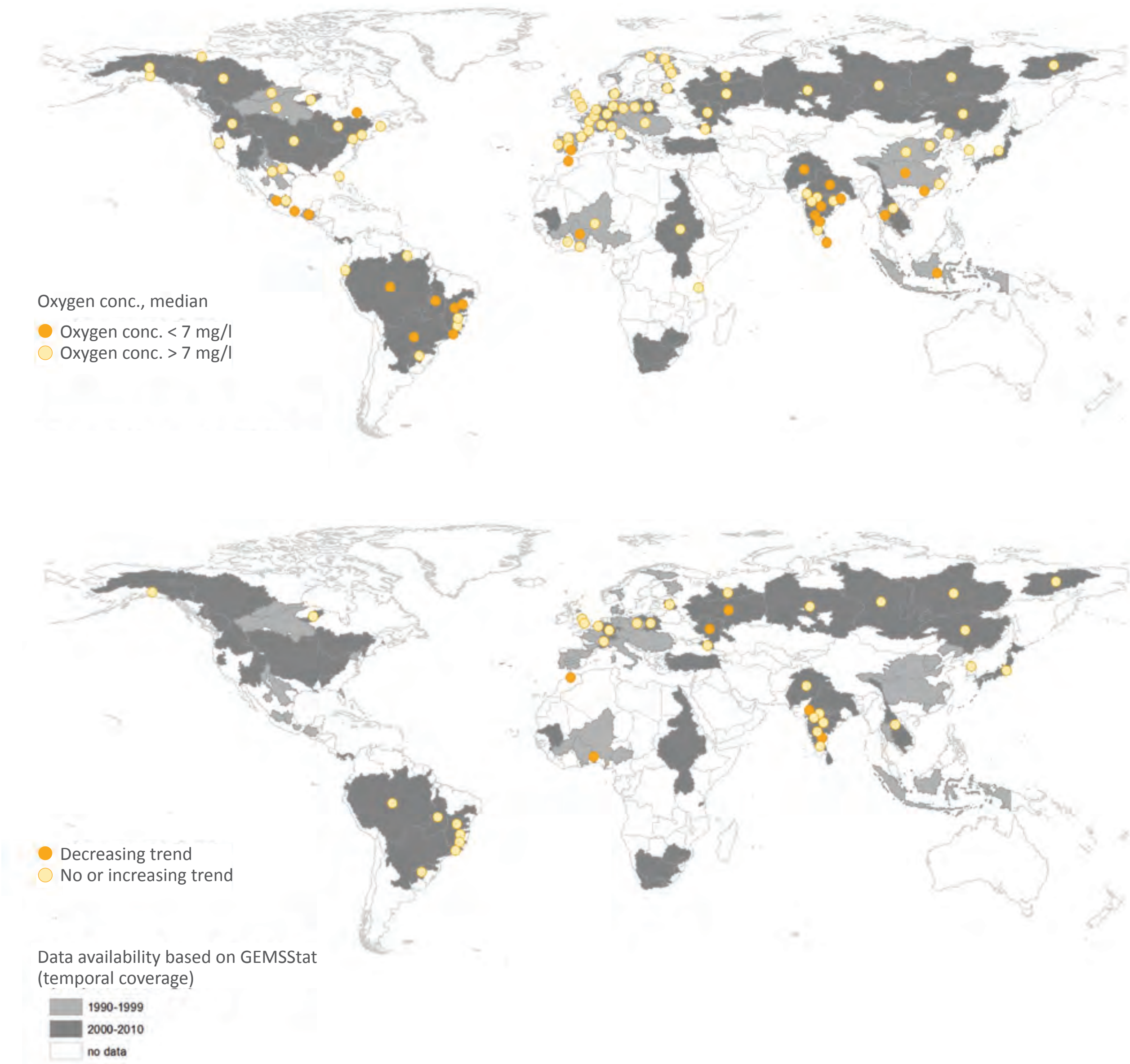


Figure 2.2: Example of risk classification for dissolved oxygen by comparing measured levels with a level of concern (above), and decadal trends (below) for major river basins. Data source: GEMStat, 2014. Light grey river basins: data available until 1999. Dark grey river basins: data available until 2010.

2.3 Can data from the scientific literature help fill the data gap?

One option to supplement the sparse data in GEMStat is to use data from the scientific literature. To assess the feasibility of this option 120 reports and publications on water quality in Africa were reviewed. To judge the suitability of data in these publications for assessments the following attributes were noted: availability of precise sampling location (GIS-data), temporal and spatial coverage of data, adequacy of information on analytical methods, and the number of water quality parameters. For this, only publications were studied that provided measured data.

The conclusion was that the data published for Africa are very dissimilar and disparate. Most published data are aggregated over long time periods and/or over several sampling stations. Furthermore, specific locations of sampling stations are usually not available and the selection of parameters was restricted. Overall, they were not comparable with GEMStat data which are based on monitoring results and raw data. On the other hand, data from scientific literature can be used to supplement GEMStat data for the purpose of model testing and preparing model inputs and they are used for this purpose in Chapter 3.

2.4 What is the potential of remote sensing?

Part of the solution to the urgent global data gap is to derive water quality information from remote sensing products. Satellite sensors potentially offer reproducible and globally consistent earth observation data with a high scientific standard (Bukata, 2005). Therefore, remote sensing can provide data where it is too expensive to monitor water quality or at locations that are remote.

Space-born remote sensing can provide data of selected water quality parameters at spatial scales and with temporal resolutions that exceed the density of ground based monitoring stations by several orders of magnitude. Examples for the next generation of satellite missions are: hyperspectral HyspIRI (Hyperspectral Precursor and Application Mission, launch in 2010, pixel resolution 60x60m, combination of hyperspectral and thermal sensors), the multispectral missions (Copernicus mission, Sentinel 2 & 3, launch in 2016) and the hyperspectral Environmental Mapping and Analysis Program (EnMAP) starting in 2018. The latter will have a pixel resolution of 30 m x 30 m and a scanning capacity of 30 km x 5,000 km per day following sun synchronous orbits (EnMAP, 2015). This would allow for the comparative analysis of a given location on the earth's surface within four days.

Because the optical sensors detect reflected sunlight, parameters which have an effect on the optical properties of water can be deciphered. For this purpose, the spectral signatures have to be analysed with optical models that depict the relationship between the reflectance and the concentration of relevant water quality constituents (ZhongPing, 2006). Remote sensing platforms can identify and quantify several key water quality indicators:

- sea surface temperature,
- chlorophyll a (an indicator of the concentration of algae),
- various ecologically important phytoplankton groups including potentially toxic algal blooms in eutrophic coastal and inland waters,
- secchi depth / transparency,
- coloured dissolved organic compounds,
- turbidity, different fractions of suspended mineral and organic particles, and
- sediment dynamics in estuaries, tidal flats, wetlands, and mangrove forests.

Most efforts at collecting water quality data from space-born remote sensing platforms have focused on the oceans and coastal areas rather than rivers and lakes. Collecting and interpreting data of inland waters is a big challenge because of the higher complexity of the optical signal from freshwaters and the relatively smaller dimensions of many inland surface water bodies and river networks. Rivers often exhibit turbidity levels of one or more orders of magnitudes higher than coastal or marine environments at a high temporal dynamics. Furthermore, humic and organic substances interfere spectrally with the measurement of parameters such as turbidity and transparency (Olmanson et al., 2014). Moreover, to acquire data for smaller rivers and streams, a much higher spatial resolution is needed than for oceans or coastal areas. However, few available sensor data with a sufficiently high spatial, spectral and radiometric resolutions became available recently, such as Sentinel-2 (10-20 m) and Worldview-2/3 (1–2 m) data, in combination with robust physics based retrieval algorithms reflecting the complex interplay of extreme concentration ranges and applicable for a wide range of previous and upcoming satellite sensors (Heege et al., 2014) .

For water quality assessments, the potential usability of remote sensing data of lakes is better than that of river networks. Because of larger surface areas and typically higher clarity of lakes, remote sensing data are available from a larger set of satellite missions, including Sentinel-2, Landsat, and MODIS, covering a wider range of spatial resolutions or spectral information. Currently, remote sensing platforms can provide diverse information about lake characteristics, especially clarity, transparency, coloured dissolved organic matter, chlorophyll and other algal pigments (e.g. Matthews et al., 2010, Chawira et al., 2013).

A great advantage of space-born remote sensing is that it can provide a long-term, simultaneous record of water quality in water bodies over large regions. For example, Landsat images show the "clarity" parameter of more than 10,000 lakes in Wisconsin (USA) for a time period of more than 20 years (Olmanson et al., 2014).

Despite the many advantages of remote sensing acquisition of water quality data, the following limitations should be kept in mind:

- The water quality parameters that can be measured by remote sensing are small in number and limited to those which influence the optical properties of the water.

- The application of remote sensing for water quality assessments of rivers is further limited by the spatial resolution and spectral information of the satellite missions in place and the complexity of the optical properties of running waters.
- The potential of remote sensing for water quality assessments of lakes is higher than that of rivers because of their larger size and the lower complexity of water properties and conditions.
- Water quality parameters such as chlorophyll-a and algae bloom indicators can be directly derived from remote sensing data. Other water quality information requires models that convert spectral signals from remote sensing platforms to water constituents. Empirical models require ground-truthing of remote sensing with ground-based measurements, while physical based models derive optical properties also harmonized and independent of in-situ measurements, as proven for lakes e.g. by the EU Glass (Global Lakes Sentinel Services) project (GLASS, 2016; EOMAP, 2016).
- A prerequisite for successful ground-truthing is the availability of good quality surface water quality measurements on high spatial and temporal resolution. Thus an aquatic sensor network is required providing systematically monitored water quality parameters that can be stored in global databases and made accessible for calibration and validation of remote sensing data.
- Future satellite-born remote sensing platforms will have higher spatial resolutions and hyperspectral optical signals and will therefore be much more applicable to the assessment of inland waters. However, it is important to combine this new generation of satellite data with ground-based measurements (Wireless Ad-hoc Sensor Networks for Environmental Monitoring; Mollenhauer et al., 2015) so that the greatest value can be derived from these data.

2.5 How can more data be made available?

1. Incorporating existing national and regional monitoring data

Following technological advancements and legal obligations, more and more countries are providing their monitoring data publicly and online. However, this is mostly limited to developed countries with a strong technical focus. Furthermore, most of these countries have developed their own data exchange formats and access methods that complicate transfer of data into GEMStat. In order to promote the interoperability of data on the international scale, members of the joint WMO/OGC Hydrology Domain Working Group are standardizing open data exchange formats and web services such as WaterML2 and Sensor Observation Services. These steps will lay the foundations for a globally distributed water resources information system. GEMS/Water is not only aiming to support the standardisation process, but also to implement these standardised formats and services at the national and sub-national scale to enhance data flows.

UNEP is currently developing the Indicator Reporting Information System (IRIS), a web-based platform that allows countries to share their environmental datasets, derive indicators and produce reports. Starting in 2015, GEMS/Water will support the rollout of the IRIS by working with countries to further improve the spatial and temporal coverage of their water quality data. Provided that the IRIS will be adopted by countries, it could become a key component in providing access to selected national water quality monitoring data.

2. Setting up national freshwater monitoring working groups

The current GEMS/Water networking and data collection strategy is based on the network of National Focal Points (NFPs), which have the responsibility to facilitate the data flow between GEMS and national states. However, frequent personnel changes at the NFPs hamper communication and data flows. One approach to overcome this barrier is to set up national freshwater monitoring working groups including governmental and scientific representatives who provide a link between national monitoring activities and regional and global assessment programs. On the regional level, newly established GEMS/Water regional hubs (as recently set up in Brazil) can support the maintenance and extension of the Global Monitoring Network and increase the exchange of data.

3. Raising awareness with political instruments

On the political level, UNEP and other UN-Water partner organisations can increase awareness of water quality issues and gaps in water quality monitoring coverage. Declarations such as Resolution 1/9 of the United Nations Environment Assembly on water quality data exchange help to further improve data availability.

4. Retrieving data from citizen science projects and remote sensing based water quality data

New data sources from citizen science and remote sensing are becoming increasingly available and could supplement governmental monitoring data (Box 2.2).

The recently established Water Quality Community of Practice uunder the "Integrated Global Water Cycle Observations" theme of the Group of Earth Observations has supported the development of algorithms to derive water quality data from optical satellite imagery. As noted above, physical constraints and the limited spatial resolution of the satellite sensors restrict their use to a subset of water quality parameters (turbidity, total suspended solids, chlorophyll a) in lakes and other large freshwater bodies. However, recent and future satellite missions such as Sentinel 2 with their improved spatial and temporal resolution will enable the development of new algorithms that cover rivers and smaller inland water bodies. GEMS/Water is supporting this work by coordinating the collection of calibration and validation data by the network partners with the aim of creating operational remote sensing water quality data services in collaboration with major space agencies.

Box 2.2: What is Citizen science?

Citizen science is the practice of public participation and collaboration in scientific research in order to further knowledge. Through citizen science, people share and contribute to data monitoring and develop and expand collection programmes. Collaboration in citizen science involves scientists and researchers who develop and coordinate the programme and unpaid volunteers such as students, amateur scientists, or teachers.

One example is Volunteer Water Quality Monitoring within the National Water Resource Project at the Universities of Wisconsin and Rhode Island in the United States.[6] The goal of this project is to expand and strengthen the capacity of existing extension volunteer monitoring programmes and support development of new groups. This project includes the training of volunteers in monitoring water quality and developing internet and web-based tools for data management. In 2005, this project engaged 8,600 trained volunteers in monitoring lakes, wells, rivers, estuaries and beaches. In total, the project involves 30 separate collaborative programmes in 30 different states. Local and regional programme coordinators are responsible for the expansion of the programme.

Another example is the development by the Delft University of Technology of new mobile sensing methods for water quality monitoring for use in citizen science projects. Delft is developing "indicator strips" as a convenient and practical way for volunteers to collect water quality data.[7]

A third example is the "World Water Monitoring Challenge" (WWMC) run by Earth Echo International, an environmental education organisation in collaboration with the Water Environment Federation and the International Water Association. As part of this program, volunteers are encouraged to test the quality of their local waterways and share their findings. To facilitate this, the WWMC sells individual and classroom water-testing kits for measuring temperature, acidity (pH), clarity (turbidity) and dissolved oxygen. Each kit contains an informative instruction book and enough reagents to repeat up to 50 tests. The location of stations, data and further information are made accessible to the public on an interactive web site.[8]

5. Setting priorities for monitoring

Considering the high costs of monitoring, it is important to set priorities for collecting field data. The hot spot areas identified in Chapter 3 for pathogen, organic and saline pollution can be used as input in deciding where to expand monitoring efforts.

[6] *http://www.usawaterquality.org/volunteer/*
[7] *http://www.citg.tudelft.nl/en/about-faculty/departments/watermanagement/sections/water-resources/leerstoelen/wrm/research/all-projects/msc-research/current-msc-research/application-of-citizen-science-and-mobile-sensing-in-water-quality-monitoring/*
[8] *http://www.monitorwater.org/default.aspx*

3 Water pollution on the global scale

Aim of this chapter

To gain a global overview of water quality problems in the surface waters of three continents.

Main messages

- A "combined data driven/model driven approach" is used to assess water quality on three continents and make the best use out of both measurement data (GEMStat) and modelling results (WorldQual).
- Severe pathogen pollution already affects around one-third of all river stretches in Latin America, Africa and Asia. The number of people at risk to health by coming into contact with polluted surface waters may range into the hundreds of millions on these continents. Among the most vulnerable groups are women and children.
- Severe organic pollution already affects around one-seventh of all river stretches in Latin America, Africa and Asia and is of concern to the state of the freshwater fishery and its importance to food security and livelihood. Countries reliant on inland fisheries as a food source should be vigilant about increasing organic pollution. Groups affected by organic pollution include local poor rural people that rely on freshwater fish as a main source of protein in their diet and poor fishers that rely on the inland fishery for their livelihood.
- Severe and moderate salinity pollution already affects around one-tenth of all rivers in Latin America, Africa and Asia and is of concern because high salinity levels impair the use of river water for irrigation, industry and other uses.
- Anthropogenic loads of phosphorus to the majority of major lakes are significant and may cause or accelerate eutrophication and disrupt the natural processes of these lakes. Most of the largest lakes in Latin America and Africa have increasing phosphorus loads.
- The immediate cause of increasing water pollution is the growth in wastewater loadings to rivers. Different pollutants have different predominant sources. The ultimate drivers of increasing water pollution are population growth, increased economic activity, intensification and expansion of agriculture, and increased sewerage with inadequate treatment.

3.1 Introduction: A combined data and modelling approach

The water quality of the world's rivers and lakes is undergoing important changes. As described in Chapter 1, water quality has markedly improved in many developed countries, although some problems persist such as eutrophication and water contamination by micropollutants and heavy metals. Meanwhile, in developing countries the tendency seems to be towards increasing water pollution as urban populations grow, material consumption increases and the volume of untreated wastewater volumes multiplies. This chapter examines the extent and trends in water pollution worldwide with a focus on Latin America, Africa and Asia. It also describes the combined data-driven and model-driven approach used to obtain these estimates. The methodology takes into account two major factors: First, that a considerable amount of measurement data is necessary for the assessment of three continents, but an adequate amount of data is not available from the GEMStat database (as noted in Chapter 2). Nevertheless, GEMStat is the most comprehensive data set available and should be exploited in any assessment. Secondly, great progress has been made over the last fifteen years in modelling global and continental water resources (e.g. Sood and Smakhtin, 2015) and advancing the assessment of water resources in ungauged or poorly-gauged river basins (Sivapalan et al., 2003). Therefore, modelling results are used to fill in the data gaps in the GEMStat data base. The combined data-driven and model-driven approach (Figure 3.1) makes the best use out of both measurement data and modelling results and is used throughout Chapter 3:

i. GEMStat data are used for a preliminary analysis of the water quality situation of each continent. Since there are large spatial and temporal gaps in these data they were used in aggregate form to compute the statistical occurrence of different levels of pollutants. Results from this statistical analysis are presented as frequency diagrams and "box-and-whisker plots" in this chapter (see Figure 3.2 for example).

ii. GEMStat data are used together with additional data from the scientific literature to test and calibrate the "WorldQual" model. WorldQual is a computational scheme for simulating water pollution loadings to rivers and key water quality parameters in rivers around the world (See Appendix B). WorldQual is part of the WaterGAP modelling framework which has been used for over a decade to estimate hydrological characteristics of rivers worldwide (Alcamo et al., 2003; Flörke et al., 2013; Müller Schmied et al., 2014; Schneider et al., 2011; Verzano et al., 2012).

iii. After testing and calibration, WorldQual is used to comprehensively compute water quality data. This includes data-sparse areas and during time periods not covered by GEMStat (See, for example, Figure 3.1). In this way, WorldQual acts as a tool to fill in the gaps of the GEMStat data. WorldQual calculations provide a detailed picture of the spatial and temporal distribution of water pollution on the three continents.

iv. Hot spot areas identified through this approach can then be used as input in deciding where to expand monitoring efforts.

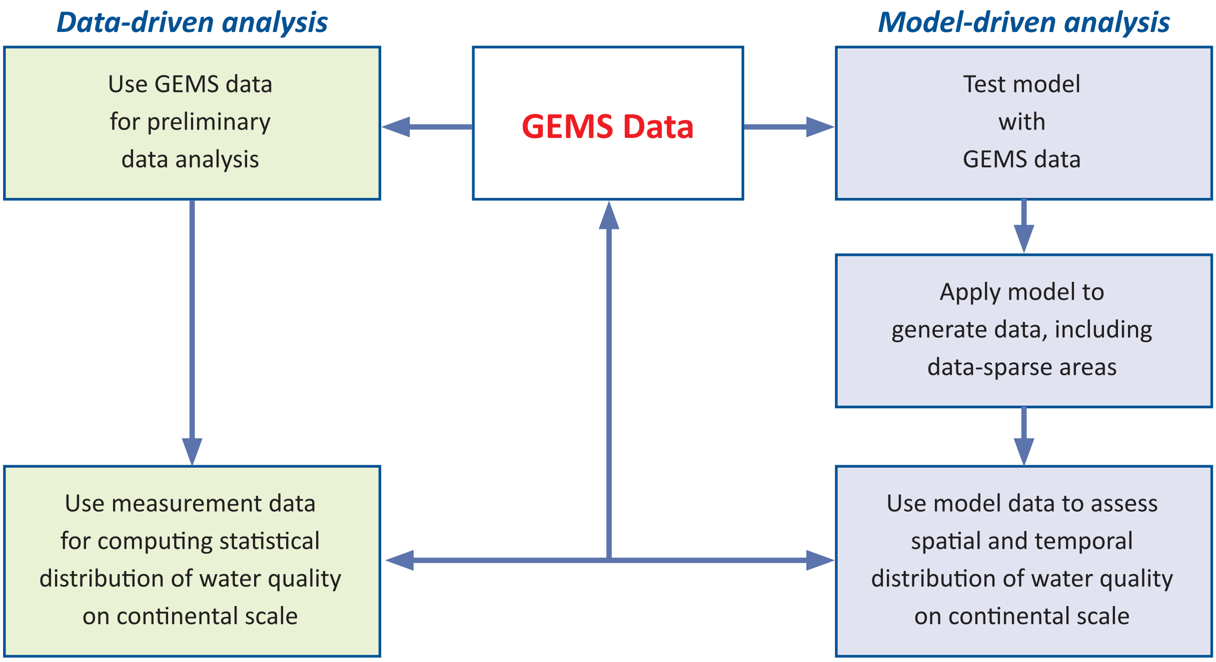


Figure 3.1: The "combined data-driven/model-driven" approach of this pre-study.

3.2 Pathogen pollution and the health risk

3.2.1 What health risks are related to polluted water?

Water is obviously crucial to human health. The WHO advises that at least 7.5 litres per day per person are necessary to meet "the requirements of most people under most conditions" and at least another 20 litres per day to cover basic hygienic needs (WHO, 2015a). Of course, the quality of this water must also be high to avoid diseases. UNICEF (2008) estimates that 3.4 million people die each year from diseases associated with pathogens in water, including cholera, typhoid, infectious hepatitis, polio, cryptosporidiosis, ascariasis and diarrhoeal diseases (Stanwell Smith, 2002; WHO, 2014b; WHO, 2008; WHO, 2006). Worldwide about 4 billion cases of diarrhoea are caused each year by the ingestion of water contaminated by faecal matter, as well as by inadequate sanitation and hygiene (WHO, 2014b), and of these cases 1.8 million are fatal. Worldwide more than 40 million people were treated for schistosomiasis in 2013 (WHO, 2015b) and as many as 1.5 billion people are infected with soil-transmitted helminth infections (WHO, 2015c). All of these diseases are largely excreta-related and many of them are due to the presence of human waste in water.

How do people get exposed to dangerous pathogens in water? An obviously important route is by drinking contaminated water. Recognizing the importance of the public health threat of drinking unclean water, the international community has been striving to reach the Millennium Development Goal of halving the number of people without access to a safe drinking water supply by 2015. As a result of these efforts, 2 billion people have gained access to safe water since 1990 (WHO/UNICEF, 2014a; WHO/UNICEF, 2015). A new set of international objectives, the "Sustainable Development Goals" include new ambitious objectives for clean water and health (UN, 2015b).

While the international community has goals for reducing the number of people exposed to unclean drinking water, less attention has been paid to another important route through which people are exposed to pathogens, namely through direct contact with polluted rivers, lakes and other surface waters (WHO, 2003). In this report, particular attention is paid to this route. The poor in rural areas of developing countries often use surface waters for bathing, for washing clothes, as a source of cooking water and sometimes for drinking water. In both developing and developed countries surface waters are used for recreational bathing, for fishing and as a water supply for irrigation.

Many different types of pathogens in water, including protozoan, parasites, bacteria and viruses, cause diseases. Since it is too costly to measure all types of pathogens everywhere, most monitoring studies of polluted water focus on one or a few types of indicator organisms that suggest the presence of pathogens. Here one of the most common indicators is used, "faecal coliform bacteria". Although most faecal coliform bacteria are in themselves not harmful, they are associated with faeces of humans and animals. Moreover, high levels of these bacteria are usually correlated with the presence of dangerous pathogens (WHO, 2001; Savichtcheva & Okabe, 2006). Several countries have acknowledged the connection between faecal coliform bacteria and health risks by setting limits for faecal coliform bacteria in their water bodies (Appendix B).

To assess the level of pathogen pollution, it is necessary to refer to a benchmark for safe and unsafe faecal coliform bacterial levels. Benchmarks used in this study are shown in Table 3.1. The boundaries of these classes are derived from the water quality standards of 17 countries (Appendix B).

Table 3.1: Classes of pathogen water pollution according to river concentrations of faecal coliform bacteria assigned in this report. Concentration is expressed in conventional units of "coliform-forming units per 100 millilitres" (cfu/100 ml). Based on water quality standards of 17 countries listed in Appendix B.

Water pollution class	Faecal coliform concentration (cfu/100 ml)	Description
Low pollution	$x \leq 200$	Generally suitable for contact (including, e.g. swimming and bathing)
Moderate pollution	$200 < x \leq 1,000$	Only suitable for contact during irrigation and fishing activities, but not for other contact
Severe pollution	$x > 1,000$	Generally unsuitable for contact

3.2.2 What is the level of pathogen pollution?

GEMStat analysis

Since the data from GEMStat are too sparse to analyse pathogen pollution in spatial or temporal explicit details (see Section 2.2.2) they were consolidated into general statistical distributions on a continental basis for the period 2000 to 2010. (Table 3.2 and Figure 3.2). The median concentration of faecal coliform bacteria in African rivers based on a sparse number of measurements (N=215) is 1,500 cfu/100 ml. Therefore, it is considerably higher than the severe pollution level (Table 3.1) derived from the national water quality standards listed in Appendix B. The medians for Latin America (N = 1,725) and Asia (N = 4,131) are a factor of ten lower and, therefore, in the low pollution class. In Africa, about 50 per cent of all measurements exceed the severe pollution level of 1,000 cfu/100 ml, in Asia and Latin America about 25 per cent (Figure 3.2, right). Therefore this sparse data set indicates that a substantial fraction of river waters is polluted.

Modelling analysis

Building on the analysis of the GEMStat data, the results from the modelling analysis provide a more detailed picture of the spatial and temporal distribution of faecal coliform bacteria on the three continents.

Figure 3.3 shows an example of average monthly levels of faecal coliform bacteria from February 2008–2010[1] according to the water pollution classes in Table 3.1. Stretches of rivers in the "severe pollution" class are marked in red and occur on all continents, especially in Asia with many river stretches in southwest and eastern Asia. This is in agreement with Evans et al. (2012) and UNEP (2010) who emphasised that faecal coliform pollution of rivers from domestic sources is a major problem in Asia because of inadequate access to sanitation and connections to sewers.

However, it is not advisable to focus on results from a single month because it is well known that the level of water pollution varies from month to month due to the influence of different monthly river basin conditions on a river's capacity to dilute wastewater, on the die-off rate of bacteria in streams, and on the pollution washed-off from land surfaces. Therefore, it is also important to estimate the month-to-month variation of faecal coliform bacteria throughout the year. Table 3.3 provides estimates of the length of river stretches affected by pathogen pollution taking into account the month-to-month variation of river pollution. Around 261,000 to 327,000 km of Latin America's rivers, or about one-quarter of all river stretches, are in the severe pollution class. For Africa, the estimate is around 200,000 to 343,000 km, or around one-fifth to one-quarter of its river stretches, and for Asia around 493,000 to 793,000 km, amounting to about one-third to one-half of its entire river stretches.

Another way of judging the intensity of pollution is to estimate the number of months in a year in which severe pollution occurs. In general, the higher the frequency of high pollution levels, the greater the potential threat to people who come into contact with surface waters. Figure 3.4 shows the frequency of months per year in different river stretches in which severe pollution levels occurred from 2008 to 2010. Here, river stretches with severe pollution in six or more months each year are considered "hot spot areas". These include river stretches particularly along the western and eastern South American coastlines, in North Africa, the Middle East, and southern and eastern Asia.

Also of interest are the temporal trends in river pollution from 1990 to 2010[2]. As will be seen in Section 3.2.4, loadings of faecal coliform bacteria have increased over the last two decades on the average in Latin America, Africa and Asia. Apparently, although sanitation coverage has increased and treatment levels have improved in some countries (UNICEF, 2014), the efforts being made were not sufficient to reduce faecal coliform loadings reaching surface waters (see Box 3.2).

One consequence is that in-stream concentrations of faecal coliform bacteria have increased over this period throughout almost all of Latin America (59 per cent), Africa (63 per cent) and Asia (69 per cent) (Figure 3.5). In total, 64 per cent of the river stretches on these three continents have an increase in faecal coliform bacteria. A subset of these river stretches with an "increasing trend of particular concern" amount to 25 per cent of the total kilometres of rivers in Latin America, 18 per cent in Africa, and 51 per cent in Asia where faecal coliform levels increased to a severe level, or were at a severe level in 1990 and had worsened by 2010. These can be considered hot spot areas. Above, an alternative definition for "hot spot areas" was used, namely, river stretches having severe pathogen pollution for six months or more per year. It turned out that there is a considerable overlap in the river stretches that are hot spots according to both sets of criteria (Table 3.4). Particular attention should be paid to these areas in further efforts at monitoring and investigating pathogen river pollution.

[1]Results are presented for an average February over a three year period (2008–2010) to avoid presenting anomalous results caused by unusual weather conditions in a particular month and year.
[2]Here and elsewhere in the modelling analysis the water quality conditions during the three-year period 2008 to 2010 were examined rather than only those of 2010. A three year period is used to filter out unusual monthly water flow conditions that might lead to unusually high or low levels of in-stream concentrations of pollutants. The focus of this assessment was to determine the overall average state of water quality in rivers rather than the worst or best conditions.

Table 3.2: Overview of data availability and statistical values for faecal coliform bacteria in the time period 2000–2010. Data source: GEMStat. SD = Standard deviation. Units: [cfu/100 ml]

Continent	No. of stations/ 10,000 km²	No. of measurements	Median	10th percentile	90th percentile	SD
Latin America	0.027	1,725	135	0	17,410	367,514
Africa	0.001	215	1,500	93	46,000	112,006
Asia	0.036	4,131	140	3	4,000	135,742

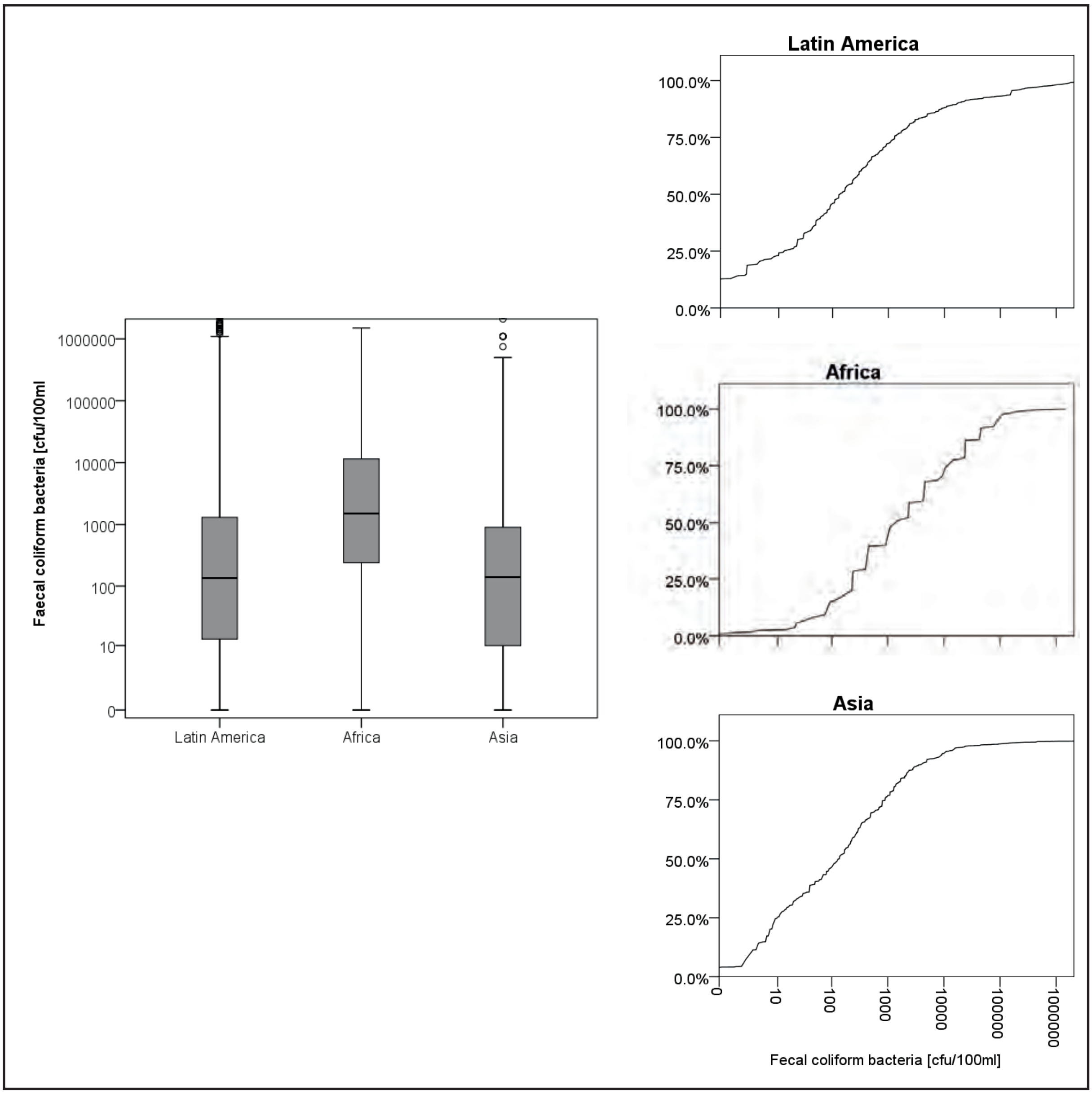


Figure 3.2: Statistical distributions of all GEMStat faecal coliform data in Latin America, Africa and Asia for the period 2000–2010. Box-and-whisker plots (left) and cumulative frequencies (right). The upper and lower boundaries of the boxes in the box-and-whisker plots indicate the 25th to 75th percentile and the line in between these boundaries the median (50th percentile).

Table 3.3: Length and percentage of river stretches (km) within various pathogen pollution classes. The minimum and maximum monthly stretches within the period of 2008 to 2010 are indicated.[a]

Water pollution class	Faecal coliform concentration (cfu/100 ml)	Latin America (min, max)	Africa (min, max)	Asia (min, max)
Low pollution	x ≤ 200	722,000–785,000 60–65%	965,000–1,122,000 63–74%	553,000–886,000 35–56%
Moderate pollution	200 < x ≤ 1,000	157,000–160,000 ~13%	203,000–216,000 13–14%	203,000–236,000 13–15%
Severe pollution	x > 1,000	261,000–327,000 22–27%	200,000–343,000 13–23%	493,000–793,000 31–50%

[a]Minimum and maximum estimates are the lowest and highest monthly estimates per continent in the 36-month period from 2008 to 2010. These are the ranges which correspond to the cases in which severe pollution is at a minimum or maximum on a continental basis.

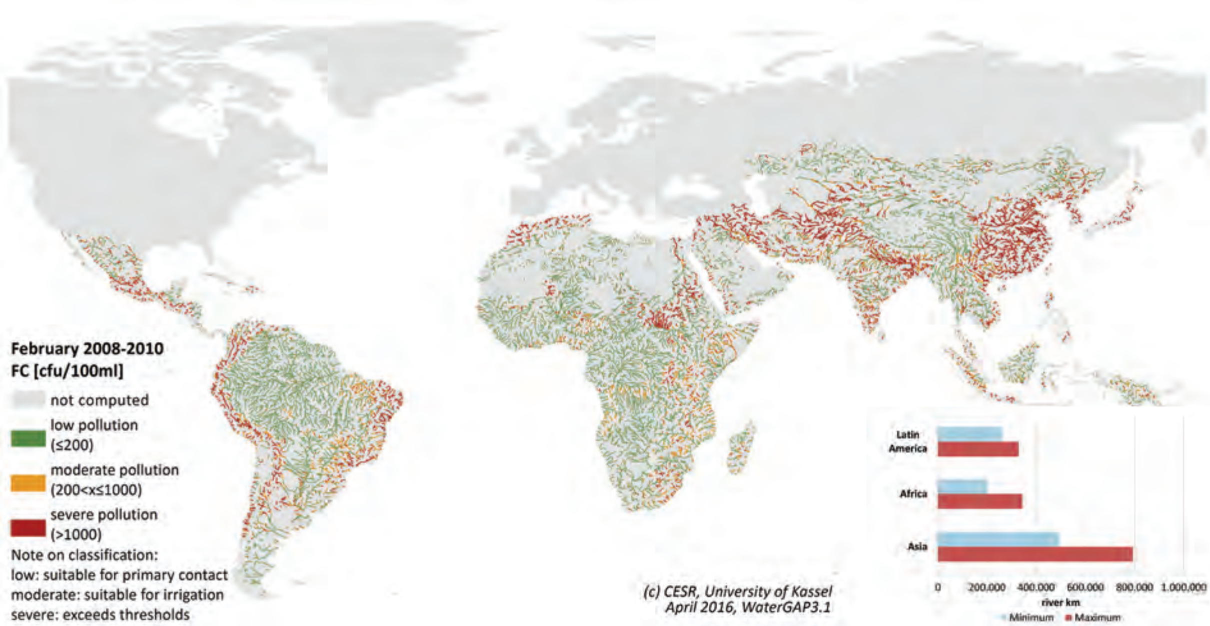


Figure 3.3: Estimated in-stream concentrations of faecal coliform bacteria (FC) for Latin America, Africa and Asia for February 2008–2010. Bar charts show minimum and maximum monthly estimates of river stretches in the severe pollution class per continent in the 36-month period from 2008–2010, corresponding to data in Table 3.3.

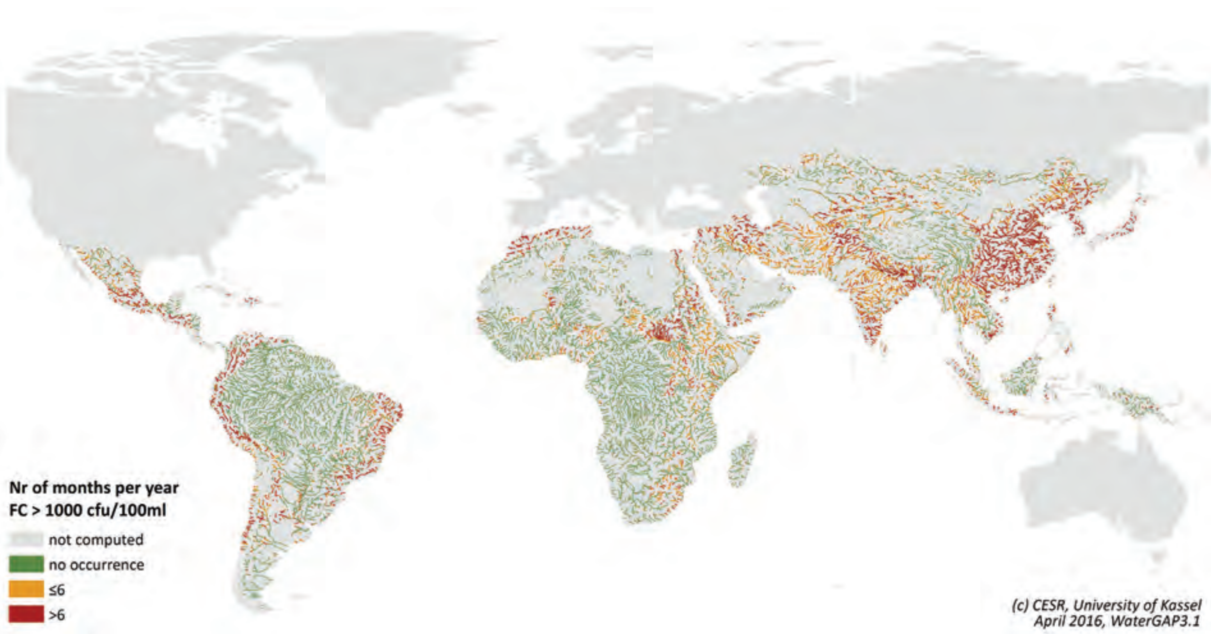


Figure 3.4: Frequency (months/year) in which "severe pollution" levels of faecal coliform bacteria occur in different river stretches over the period from 2008–2010.

[3]"Increasing trend of particular concern" in this report means a pollution level that increased into the severe pollution category in 2008-2010, or was already in the severe pollution category in 1990–1992 and further increased in concentration by 2008–2010.

Figure 3.5: Trend in faecal coliform bacteria levels in rivers between 1990–1992 and 2008–2010. River stretches marked with orange or red have increasing concentrations between these two periods. River stretches marked red have an "increasing trend of particular concern"[3].

Table 3.4: Hot spot areas of faecal coliform pollution appearing in both Figure 3.4 and Figure 3.5.

• Central America • West coast of Latin America • Upland river basin on Argentina border • East coast of Latin America • Northwest Africa • Nile river basin	• Some river stretches in Southern Africa • Middle East • Ganges river basin • Some river stretches in Southern India • Many river stretches in East Asia

Box 3.1: Estimating the rural population coming in contact with severe pathogen pollution

The following method was used to estimate the size of the rural population coming in contact with surface water severely polluted with faecal coliform bacteria (> 1000 cfu/100 ml). First, data on the percentage of rural population using surface waters for bathing, washing or as main water source were gathered from various case studies in developing countries (e.g. Brazil, China, Ghana, and Nigeria). Secondly, national data on the percentage of rural population using surface water as drinking water were compiled from the WHO/UNICEF Joint Monitoring Programme (JMP). The JMP data were used as a proxy of the percentage of rural people using surface water and as a lower limit of estimates for each country since the JMP data were found to be usually smaller than literature data from these countries. To make an upper limit for each country, the JMP estimate for a particular country was multiplied by a factor of 1.94. The factor 1.94 is the median ratio between literature values in various case studies from different countries and the JMP national value of the country where the case studies took place. In this way, lower and upper estimates were derived of the percentages of rural population in each country that regularly comes in contact with surface waters.

Next, the subset of rural people was estimated who not only use surface water but also may come into contact with polluted water. Using the gridded population data base from HYDE (version 3.1; Klein Goldewijk, 2005; Klein Goldewijk et al., 2010) and UNEP (2015a) the rural population living in proximity of river stretches in the "severe pollution" category of faecal coliform bacteria[a] (i.e. within one grid cell, or approximately 10 km, of the respective river stretches) was estimated. For each country, the number of rural people living in proximity of the severe pollution was multiplied by the upper and lower estimates of the percentage of rural people using surface waters. As a result the estimates in Table 3.5 were obtained.

This procedure may lead to an overestimate of the people exposed to pathogen pollution because people obviously avoid, if possible, surface waters that are grossly polluted. On the other hand, the number of people exposed may be underestimated because urban populations are not taken into account, and because the percentage of people using surface waters near rivers is likely to be proportionately higher than the national average percentage data coming from the JMP data base.

[a]For these estimates the river stretches in the severe pollution category for faecal coliform bacteria in the median month (on a continental basis) over the 36-month period during 2008-2010 were used.

3.2.3 People at risk of pathogen river pollution

A very important question in assessing the world water quality situation is the number of people at health risk through contact with surface waters. Unfortunately, no authoritative global estimates exist. Many published studies (See Appendix B) estimate that 5 per cent or more of rural inhabitants in many developing countries regularly come into contact with surface waters. It is expected that the exposure of the rural population to contaminated surface water through bathing, clothes washing, etc. will be much larger than the exposure of the urban population because urban populations tend to be more often serviced with public water supply and tend to have less access to surface waters.

The number of rural people coming in contact with polluted surface waters was estimated as described in Box 3.1. For Latin America, the number of people is estimated to be approximately 8 to 25 million people, for Africa around 32 to 164 million, and for Asia around 31 to 134 million people (Table 3.5). The ranges reflect the uncertainties of these first estimates, which are based on literature and the JMP database. Despite the uncertainties, the message of these estimates is that at least up to hundreds of millions of people may be at a health risk because of their contact with polluted surface waters.

While both men and women use surface waters for bathing, women are at particular risk because of their frequent usage of water from rivers and lakes for cleaning clothes and collecting water for cooking and drinking in the household (Adeoye et al., 2013; Barbir and Prats-Ferret, 2011; Gazzinelli et al., 1998; Kabonesa and Happy, 2003; Lindskog and Lundqvist, 1989; Manyanhaire and Kamuzungu, 2009; Sow et al., 2011; Thompson et al., 2003). Children are also at particular risk because of their play activities in local surface waters and also because they often have the task of collecting water for the household (Adeoye et al., 2013; Aiga et al., 2004; Choy et al., 2014; Engel et al., 2005; Gazzinelli et al., 1998; Kabonesa and Happy, 2003; Lindskog and Lundqvist, 1989; Sow et al., 2011; Thompson et al., 2003).

Using polluted water for irrigation also poses a health risk to both the farmers who come in direct contact with the water and the consumers of fruits and vegetables irrigated with polluted water (FAO, 1997).

Table 3.5: Estimated number of people (in millions) living in rural areas coming in contact with surface waters that were severely polluted. Estimates for period 2008 to 2010.

Latin America (min, max)	Africa (min, max)	Asia (min, max)
8.1–24.8	31.7–164.3	30.6–133.7

3.2.4 Sources of faecal coliform bacteria

Many factors influence the level of faecal coliform bacteria in rivers. One is the capacity of the river to dilute wastewater loadings of bacteria; another is the die-off rate of these bacteria as it is affected by temperature, sunlight and their settling rates. These factors are taken into account as described in Appendix B.

A very important factor, and one that society can influence considerably, are wastewater loadings into surface waters. Several sources of loadings are taken into account as shown in Table 3.6. These loadings depend on the waste produced per person, the type of sanitation, the degree to which sanitation systems are connected to sewers, and the level to which sewage is treated. Controlling levels of faecal coliform bacteria loadings at the source is the key to providing microbiologically safe drinking water and surface waters (see Chapter 5).

Most of the faecal coliform pollution in Latin America comes from sewered domestic wastes (81 per cent) followed by non-sewered domestic sources. Collection of domestic sewage and its untreated delivery to rivers has contributed to bacterial pollution in rivers. Rivers flowing through densely-populated urban and industrial areas are more likely to be contaminated by faecal coliform bacteria (see Figure 3.8) and tend to fall into the "severe pollution" category for faecal coliform bacteria. Other sources of faecal coliform loadings are urban surface runoff and wastewater discharges from the manufacturing sector.

For Africa, the majority of faecal coliform bacteria come from non-sewered domestic sources (56 per cent) followed by sewered domestic sources (41 per cent) from scattered settlements. Sub-Saharan countries have the lowest levels of sanitation coverage. In this region, 644 million people had no access to an improved sanitation facility in 2012 (WHO/UNICEF, 2014a).

In Asia, about half the faecal coliform bacteria comes from sewered domestic waste. The other half comes from non-sewered domestic waste sources from scattered settlements. Only about one-third of all wastewater in Asia is treated; the lowest treatment rates are in South Asia (about 7 per cent) and Southeast Asia (about 14 per cent). According to the Report of the WHO/UNICEF Joint Monitoring Programme on Progress on Drinking Water and Sanitation (WHO/UNICEF, 2014a), more than 1 billion people have no access to an improved sanitation facility in Southern Asia, including 792 million people in India. Due to the high population density together with a low-level coverage of improved sanitation and treatment, faecal coliform loadings are considerable and cause severe pollution in many rivers in Asia.

As noted earlier, the levels of faecal coliform bacteria in rivers have been estimated to increase over the last two decades because of increases in loading. On the continental average basis, from 1990 to 2010 loadings have increased by 64 per cent in Latin America, by 97 per cent in Africa and by 86 per cent in Asia (Figure 3.7). Faecal coliform loadings increased mainly because of the large increase of domestic wastes, both sewered and non-sewered. Main driving forces of these increases have been the growth of population and growing sewer connections without treatment of wastewater. It is likely that loadings of faecal coliform bacteria to rivers would have been lower if the new sewer systems had not been built (See Box 3.2).

Box 3.2: Faecal coliform loadings to rivers are higher because of the lack of wastewater treatment.

As noted in the text, pathogen pollution has increased over large stretches of rivers over the past decades. A large fraction of the increase is due to the expansion of sewer systems that discharge wastewater untreated into surface waters. If the sewer systems had not been built, it is likely that the loadings of faecal coliform bacteria to Africa's rivers would have been around 23 per cent lower than they are now (See Figure 3.6 below). This is because the new sewers deliver human wastes to rivers that would otherwise have remained (unsafely) on the land.

On one hand, by taking the wastewater away from populated areas, the sewers have reduced the health risk posed by unsafe sanitation practices on land. On the other hand, by dumping sewage untreated into surface waters, they have transferred the health risk from the land to surface waters.

The solution, however, is not to build fewer sewers, but to treat the wastewater they collect.

Figure 3.6 shows faecal coliform loadings for Latin America, Africa and Asia in 2010 according to two sets of assumptions. The left bar of each continent is the best estimate for 2010. This estimate takes into account increasing rates of connections to sewer systems (as described in Appendix B). The right bar is an estimate assuming that connection rates to sewers did not increase after 1990. The difference between this estimate and the best estimate shows the impact of expanding sewer systems on faecal coliform loadings.

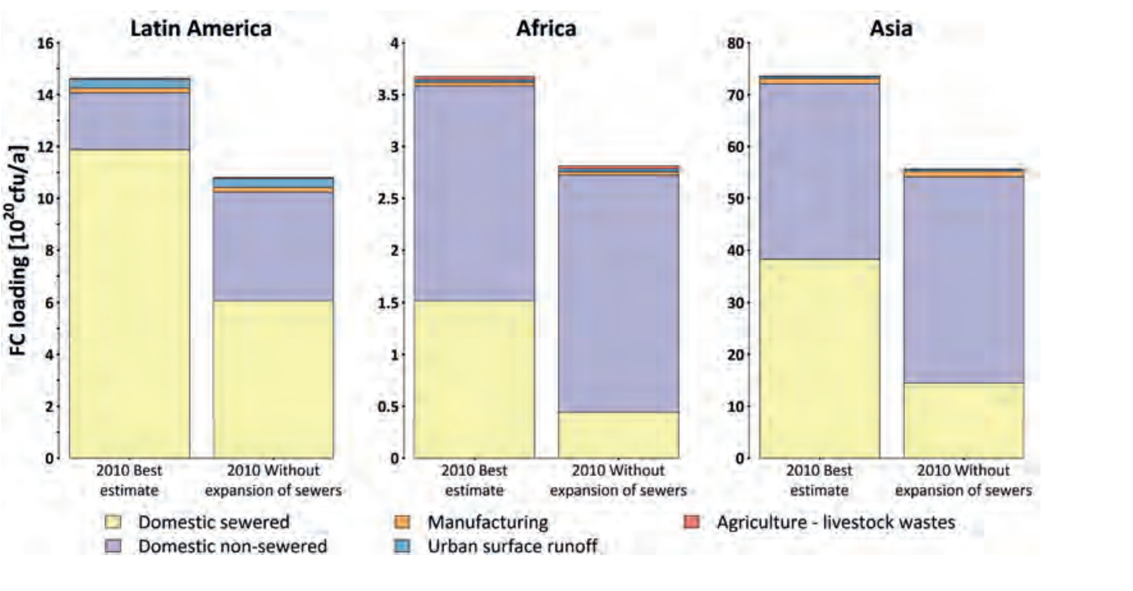


Figure 3.6: Faecal coliform bacteria loadings for Latin America, Africa and Asia for two sets of assumptions: the "best estimate 2010" and "without expansion of sewers".

Table 3.6: Categories of faecal coliform bacteria loadings accounted for in estimates of in-stream concentrations.

- Domestic sewered (point sources)
- Domestic non-sewered – hanging latrines (point sources); domestic septic tanks, pit toilets, open defecation (diffuse sources)
- Manufacturing (point sources)
- Urban surface runoff (diffuse sources)
- Agriculture – animal wastes (diffuse sources)

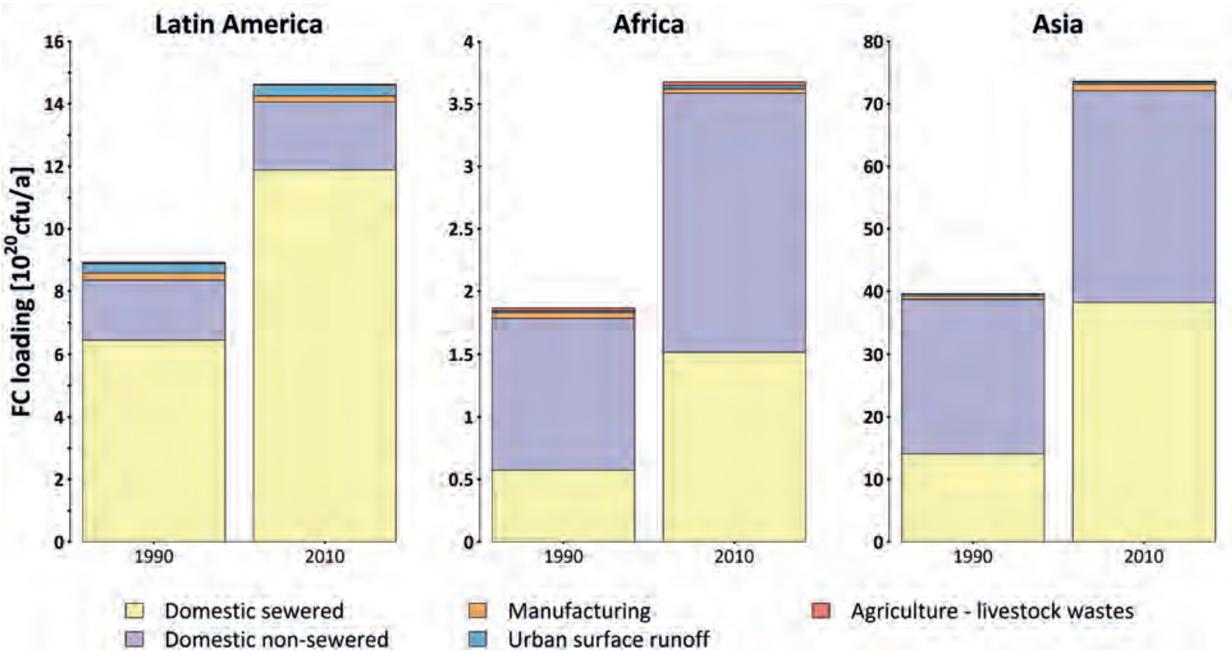


Figure 3.7: Faecal coliform bacteria loadings for Latin America, Africa and Asia for 1990 and 2010.

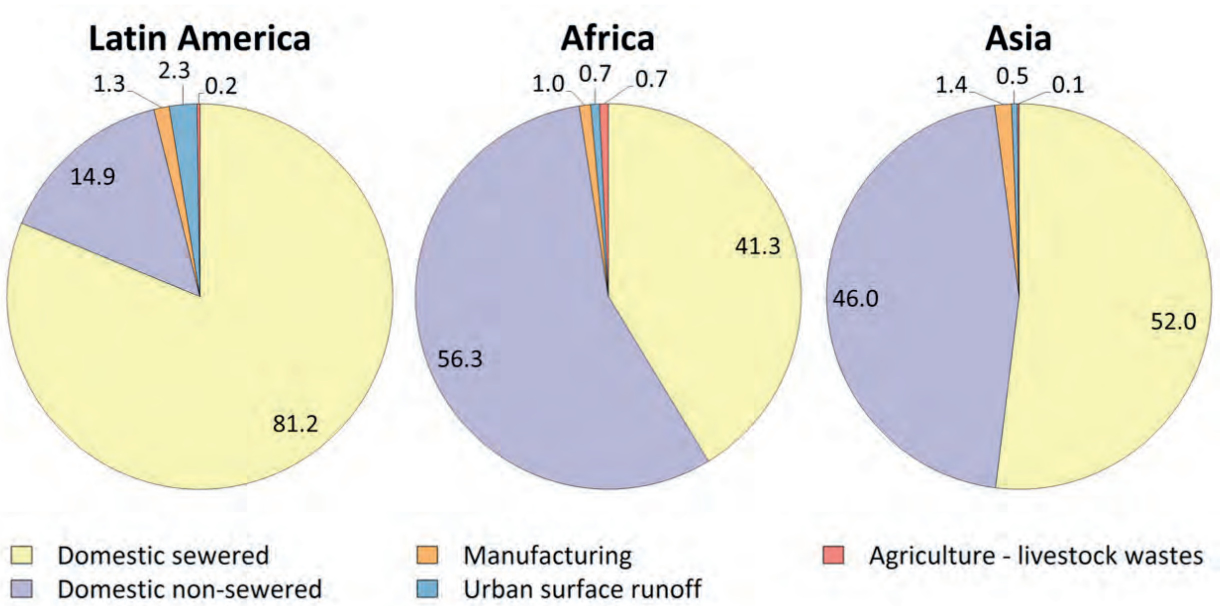


Figure 3.8: Distribution of faecal coliform loadings according to source for 2010. Units: percentage.

3.3 Organic pollution and the threat to the inland fishery and food security

3.3.1 What is organic pollution?

The health of fish and aquatic fauna is threatened by many changes to the natural state of water bodies, including the destruction of their habitat, contamination with trace toxic substances, and "organic pollution". Here the focus is on "organic pollution"[4], a common term used to describe the set of processes associated with depletion of dissolved oxygen in a water body (e.g. EEA, 2015; Lobo et al., 2015; Noel & Rajan, 2015; Gao et al., 2013; Vidal et al., 2013; Haury et al., 2006; FAO, 1996). Organic pollution occurs when an excess of easily biodegradable matter enters surface waters. The decomposition of this matter by bacteria and other microorganisms consumes oxygen and depletes dissolved oxygen from the water column. The depletion of dissolved oxygen has a very negative effect on aquatic fauna, especially fish and benthic invertebrates, which rely on this oxygen for their survival and functioning.

There are many different causes of organic pollution. The main causes in rivers near heavily populated and industrialised areas are discharges of domestic and industrial wastewater which typically contain large quantities of biodegradable or oxidisable substances.

Another cause, particularly where rivers are impounded, is eutrophication. In this case, large loads of nutrients into the river from domestic and agricultural sources stimulate the growth of algae in the slow moving reaches of rivers behind dams. When the algae die off they are decomposed by bacteria and other microorganisms which deplete the oxygen resources of the river. Organic pollution is also caused by the wash off of animal wastes into rivers, urban runoff, and other sources.

We begin this subchapter with a discussion of inland fisheries because they are particularly threatened by organic pollution.

3.3.2 The importance of inland fisheries to food security

Inland fisheries represent an invaluable and often irreplaceable contribution to food security for hundreds of millions of people in poor, rural communities around the world (FAO, 2003; World Bank et al., 2010). The reported global inland fisheries harvest in 2012 was 11.6 million tonnes (FAO, 2014), although these harvest figures are widely acknowledged to be grossly underestimated in many countries (FAO, 2012).

Globally, fish from inland waters is the sixth most important supplier of animal protein (Welcomme, 2010). Locally, the inland fish catch can be a much more significant source, especially for populations living near rivers and lakes and in land-locked countries (Welcomme, 2010). For example, the catch of inland fish accounts for 44 per cent of the animal protein produced in Malawi, 64 per cent in Bangladesh and Cambodia, and 66 per cent in Uganda (2007 figures from Welcomme, 2010).

China, Bangladesh, India, and Myanmar recorded the highest inland catch both in Asia and the world with over 1 million tonnes each in 2010, while Cambodia, Myanmar and Uganda had the highest consumption per person with 27, 20, and 12 kg/capita for 2010, respectively (Welcomme, 2011).

These fisheries harvest hundreds of aquatic species from almost all freshwater ecosystems (Welcomme, 2011). They are characteristically informal in nature, require no or low entrance fees, minimal start-up costs and equipment, and need only basic skill levels to participate. Thus, inland capture fisheries are an important source of livelihoods and employment in developing countries. For the period of 2010 to 2012, FAO (2014) estimated that inland fisheries provided employment for 21 million fishers. Inland fisheries also provided 38.5 million jobs in post-catch processing and other related activities (World Bank et al 2010). Almost all of these jobs were in small scale fisheries, occupied by mostly low-income people, with over half of the total workforce being women (World Bank et al., 2010).

[4]Should not be confused with problem of "persistent organic pollutants" (POP) which are "chemical substances that persist in the environment, bioaccumulate through the food web, and pose a risk of causing adverse effects to human health and the environment"(UNEP, 2015b).

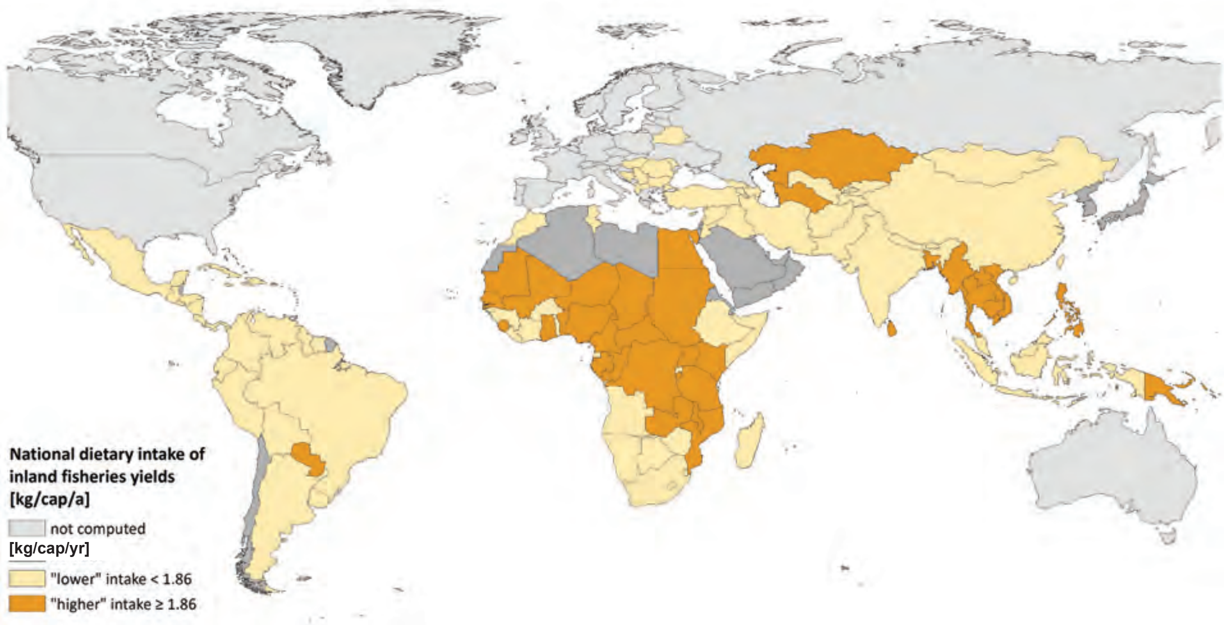


Figure 3.9: National dietary intake of inland fisheries yields (kg/capita/2010).
Data Source: FishstatJ (FAO, 2014), country population data (World Bank)

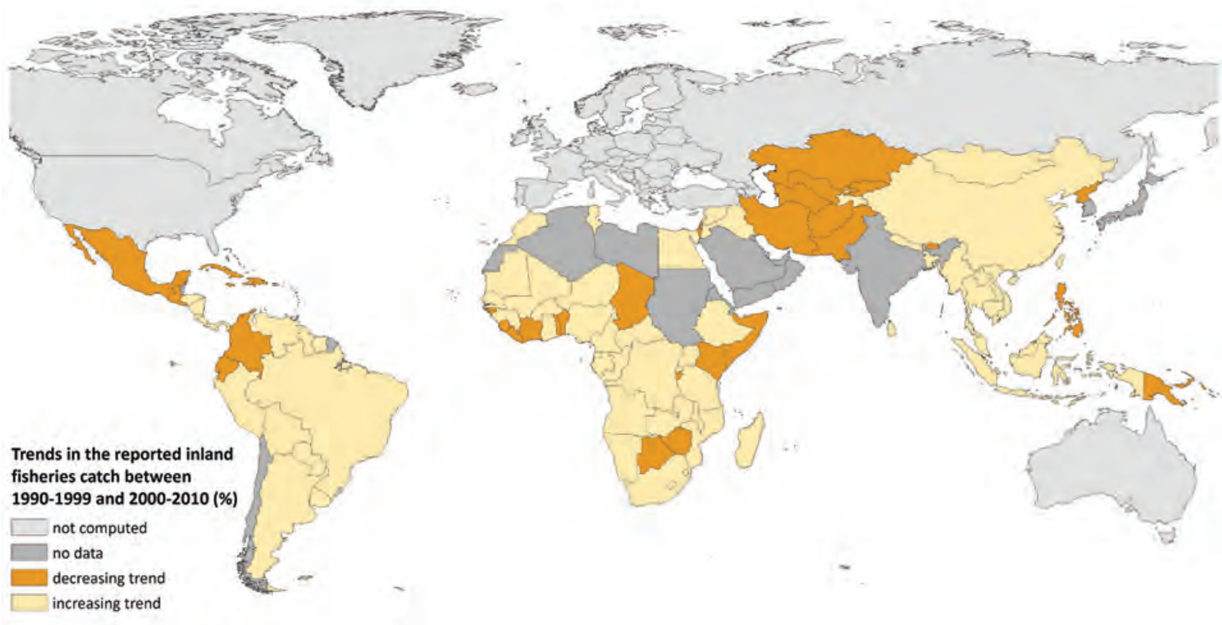


Figure 3.10: National inland fisheries catch trend between the time periods 1990–1999 and 2000–2010.
Data Source: FishstatJ (FAO, 2014).

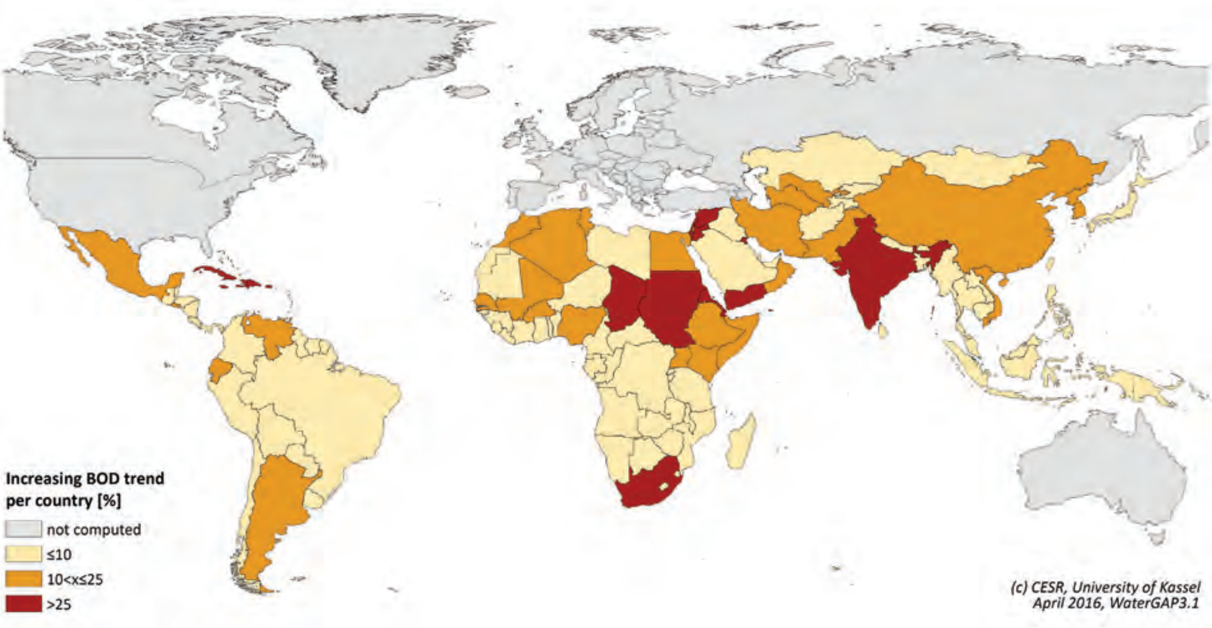


Figure 3.11: Percentage of river stretches in each country with "increasing trend of BOD of particular concern" meaning that in these stretches the pollution level increased into the severe pollution category in 2008–2010, or that they were already in the severe pollution category in 1990–1992 and further increased in concentration by 2008–2010 (cf. Figure 3.15).

Catches are either utilised for direct consumption, used in bartering agreements, or sold at local markets providing additional access and availability to community members not directly involved in the fishery (World Bank, 2010). The large, dispersed scale that inland fisheries typically operate on also helps to maintain supply stability and avoid disruptions on a local scale, as can post-harvest processing such as drying and salting or refrigeration of excess product in more developed areas.

As inland fisheries provide an essential source of protein and micronutrients for millions of people across the developing world, it is of interest where they have the greatest relevance to food security. One indicator is the *national dietary intake of freshwater catches* per capita, which provides an approximation of the level of consumption as well as the potential availability of fishery resources for individuals (Figure 3.9). This indicator assumes all aquatic products from inland fisheries are consumed in-country, which is true for most situations (FAO, 2003). It must also be noted that the consumption of inland fisheries resources are generally higher in rural regions, particularly in communities residing adjacent to lake and river networks, than in major city settlements.

Considering all developing countries with reported inland fisheries catch data, 36 per cent were identified as being at a "higher vulnerability", with most of these countries located in Central and West Africa and Southeast Asia (Box 3.3).

Another important factor relevant to inland fisheries and food security is the *trend in inland fish catches* (Figure 3.10). Global reported inland fisheries catches have been increasing steadily since 1950 at a rate of 2.9 per cent per year (Welcomme, 2011). The country trends of inland fish catches were calculated in order to determine if catches were increasing or decreasing since 1990. Decreasing catches in a country dependent on fish consumption may indicate an increasing risk to food security. Of course, they may also reflect a population becoming more wealthy and preferring not to consume inland fish. Increasing catches may indicate somewhat higher food security. On the other hand, if catches increase beyond the sustainable levels for the fishery, then fish populations may strongly depleted and this would pose an even greater risk to food security. In general, it is difficult to interpret the meaning of a decreasing or increasing catch, and it should be used only as a very preliminary indicator of the status of a fishery.

The national catch trend for developing countries indicates that 62 per cent of the countries considered have increasing catches while 38 per cent reported decreasing ones. An overview of the results shows countries with a decreasing trend in Central Asia and the Middle East, Central America, the Caribbean and some Northern countries of South America as well as in various countries throughout Africa (Figure 3.10).

Box 3.3: Proposed methodology for computing indicators relevant to the status of the inland fishery

One of the main objectives of this pre-study towards a World Water Quality Assessment was to develop a concept for the identification of regions where inland fisheries are vulnerable to water quality deterioration, and where food security may be reduced.

First, preliminary indicators of inland fisheries (Section 3.3.2) and water quality (Box 3.3) are developed. Secondly, these indicators are linked to evaluate how and where water quality degradation has an impact on the capacity of inland fisheries and their relation to food security on a global scale (Figure 3.12). As an example, a preliminary comparison is made in Section 3.3.3 of inland fishery indicators (national dietary intake and national fish catch trends) and a water quality indicator (location of "increasing BOD trends of particular concern").

For preliminary estimates of inland fishery indicators, existing data from international databases such as FAO (Fishery and Aquaculture Global Statistics – FishstatJ), and The World Bank (country population data), were used. The calculations considered only freshwater fish with aquaculture data excluded.

To calculate the indicator "national dietary intake of inland fisheries" (kg/capita/2010), the total reported inland fisheries catch per country was divided by country population. The data were then categorised into "higher" or "lower" intake based on the calculation of the 75th percentile of countries reporting inland fisheries yields. In that regard, countries were classified as being either at a "higher intake" level with ≥ 1.86 kg/capita/yr or a "lower intake" with < 1.86 kg/capita/yr.

The indicator "national inland fisheries catch trend" was calculated by comparing average decadal yields from 1990–1999 with 2000–2010. Decadal averages were used because of large year-to-year fluctuations. This is a very approximate indicator of the possible status of inland fishery resources because it does not indicate the specific reasons for an increasing or decreasing trend. Furthermore, additional factors will be considered including the development level of a country and the occurrence of over-fishing.

The data used for these indicators were only available on a country scale in the FAO Fishstat database. However, there is a need to downscale the indicators to the river basin or lower scale so that they can be related to water quality and other river conditions. This will allow for a more detailed investigation of the threat of increasing water pollution to fish populations of particular importance to food security.

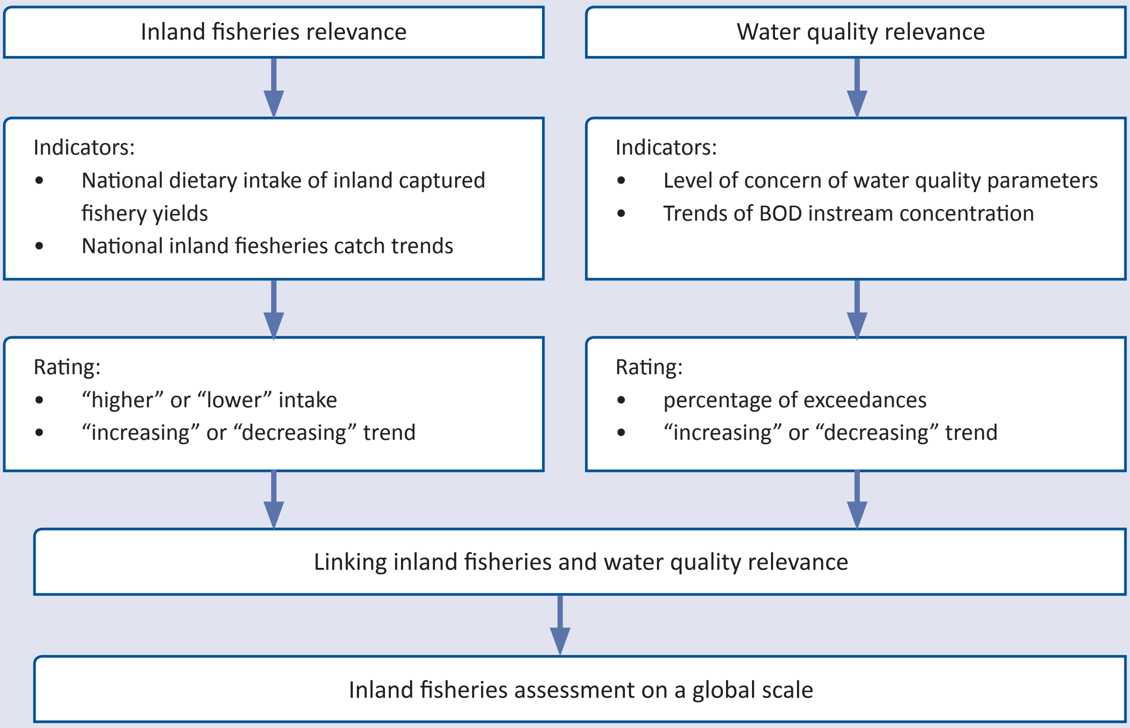


Figure 3.12: Preliminary scheme for assessing the status of inland fisheries with regard to water quality degradation.

3.3.3 What is the level of organic pollution?

As already noted, organic pollution is of particular concern because it threatens the functioning of inland fisheries and aquatic ecosystems in general. Here, results from GEMStat concerning water quality levels in Latin America, Africa, and Asia and how they relate to the health of the inland fishery are examined first. Then a closer look is taken at the spatial and temporal dimensions of one of these indicators, biochemical oxygen demand (BOD).

GEMStat analysis

Certain water quality parameters related to organic pollution are particularly relevant to the health of the inland fishery (see Box 3.4). These parameters are: dissolved oxygen, biochemical oxygen demand (BOD), ammonia, chloride, and pH. The second-to-last column of Table 3.7 presents levels of concern for these five key parameters, with particular consideration given to the tolerance levels of fish. Values outside these limits indicate a high risk to the reproduction, growth, respiration, and feeding of fish. Because of the very wide variety of fish in Latin America, Africa, and Asia; these "levels of concern"[5] are only a very general guide to their tolerance limits.

Table 3.7 presents the percentage of stations where the five key parameters are at levels of concern. Since there is a wide variation in the spatial and temporal coverage of the different parameters, only general conclusions can be drawn from this analysis:

- In Latin America, at least 10 per cent of the measurements for dissolved oxygen, ammonia, and pH exceed levels of concern for these parameters.
- In Africa, at least 20 per cent of the measurements for dissolved oxygen, BOD, and chloride exceed these levels.
- In Asia, at least 10 per cent of the measurements for dissolved oxygen[6], BOD[7], ammonia, chloride, and pH exceed these levels.
- In Table 3.7, ranges are given for the level of concern for BOD. For the more stringent level, 10 per cent of the measured BOD data in Latin America, 40 per cent in Africa, and 15 per cent in Asia are at a level of concern for BOD.

In conclusion, at least 10 percent of measurements from all three continents show levels of concern for at least three out of five water quality parameters of particular importance to the health of fisheries. Together, these results point to an overall picture of concern regarding water quality and the inland fisheries of Latin America, Africa, and Asia.

Modelling analysis

After the examination of results for five water quality parameters with the help of the GEMStat database, the spatial and temporal trends of one of these indicators, BOD, was looked at more closely. BOD is often taken as the principle indicator of organic pollution (Box 3.4). As for faecal coliform bacteria in Section 3.2.2, the WorldQual model is used to compute the monthly concentration of BOD in Latin America, Africa, and Asia from 1990 to 2010.

Based on water quality guidelines from 11 different countries (Appendix B), BOD results were clustered into the three water quality classes shown in Table 3.8. Figure 3.13 shows an example of average monthly levels of BOD for February 2008-2010 clustered into three classes. Severely polluted river stretches include northern and eastern parts of Latin America, northern and eastern Africa as well as many parts of Asia.

Figure 3.13 shows the modelled BOD in-stream concentrations on a monthly average basis for February 2008–2010. However, it is known that levels of BOD vary from month to month because of changing dilution capacity, temperature-related BOD decay, and runoff of pollutants. Figure 3.14 shows the frequency of months each year in which severe BOD pollution levels occur from 2008 to 2010. As for faecal coliform bacteria, it is assumed that the more frequently high BOD levels occur throughout the year the greater the impacts of high BOD levels. Therefore, river stretches with severe pollution during six months or more each year are taken as an indication of hot spot areas. According to this definition, hot spots appear in Central America, eastern South America, Northeast Africa, South and East Asia.

Table 3.9 shows the length of river stretches with different levels of BOD pollution, taking into account the month-to-month variation of BOD. A range of 60,000 to 117,000 km of Latin America's rivers, equivalent to about one-tenth of its total river stretches, are in the severe pollution class. In Africa, 132,000 to 234,000 km, or around one-sixth of its river stretches, are in the severe river pollution class, and in Asia 168,000 to 268,000 km, or also about one-sixth of all of its river stretches.

Figure 3.15 shows the trend in BOD river concentrations between the early 1990s and late

[5]"Level of concern" in this report is used to mean the pollutant concentration above (or below) which significant negative impacts occur. In this report, these concentrations are derived from water quality standards from official sources such as government departments or UN agencies.
[6]Considering an intermediate value of the range in Table 3.7.
[7]Considering an intermediate value of the range in Table 3.7.

2000s. BOD concentrations have increased in 54 per cent of the river stretches in Latin America, 62 per cent of the river stretches in Africa, and 71 per cent of the river stretches in Asia. In total, 63 per cent of the river stretches on these three continents have an increased BOD concentration.

River stretches marked with red in Figure 3.15 have an "increasing trend of particular concern". In these river stretches, the concentration of BOD increased into the severe pollution category in 2008-2010, or it was already in the severe pollution category in 1990-1992 and further increased in concentration by 2008-2010. These river stretches amount to 6 per cent of the total lengths of rivers in Latin America, 12 per cent in Africa and 13 per cent in Asia and could also be considered hot spot areas. The overlap of hot spot areas according to this definition and the definition used earlier (Figure 3.14 and Figure 3.15) is shown in Table 3.10. River basins listed in this table could be considered as BOD hot spot areas with high confidence since they appear as hot spots according to two different definitions. These areas should be paid particular attention in further monitoring and investigation efforts of organic river pollution.

To sum up the modelling analysis of BOD, results show that the lengths of river stretches with high BOD levels on all three continents are in the hundreds of thousands of kilometres, and that most stretches of rivers also have increasing concentrations.

Preliminary comparison of inland fishery indicators with a BOD indicator

The BOD hot spots ("increasing areas of particular concern") shown in Figure 3.15 are also of importance to inland fisheries because these areas have both a high and an increasing level of BOD. High levels of BOD often coincide with low levels of dissolved oxygen and threaten the local survival of fish and other aquatic fauna (Box 3.4). Figure 3.11 summarizes these data on a country level so that they can be compared to the earlier maps of country-scale consumption of fish and trends in fish catch (Figure 3.9 and Figure 3.10).

A comparison of the three maps indicates two subsets of countries whose inland fisheries may be particularly vulnerable to increasing organic pollution:

- One subset of 10 countries[8] has both a higher consumption of fish from the inland fishery and increasing organic pollution (>10 per cent as indicated by Figure 3.11) (with increasing or decreasing catch).
- A second subset of 16 countries[9] has decreasing catch together with increasing organic pollution (>10 per cent).

The combination of indicators may indicate an increasing risk to the inland fisheries of these countries. At a minimum, it is worthwhile for these countries to be vigilant against increasing water pollution endangering their inland fisheries and the food security and livelihoods they provide.

Box 3.4: Water quality parameters of concern to health of inland fisheries

Dissolved oxygen (DO) is a fundamental water quality parameter (UNEP, 2008) related to the sustainability of freshwater fisheries and aquatic ecosystems integrity. A minimum level of dissolved oxygen is needed to prevent lethal and sub-lethal (physiological and behavioural) effects on fish and other higher organisms (CCME, 1999). While dissolved oxygen is depleted by the decomposition of organic matter and may be completely consumed under excessive organic loads, it also can also show high supersaturation caused by the photosynthesis of algae and other aquatic flora under eutrophic conditions. The solubility of oxygen in water strictly depends on the temperature and decreases with increasing temperatures. Both parameters are ecological key factors which control the occurrence and geographical spread of species. For this reason, two levels of concern for fish communities adapted to cold or warm water are given in Table 3.7.

Biochemical oxygen demand (BOD) is a key indicator of organic pollution (EEA, 2015) and indicates high levels of biodegradable organic matter in the water. High BOD loads usually cause significant depletions of dissolved oxygen and deleterious effects on fish and other biota. One example is the Tietê River in Brazil, presented as a case study in Chapter 4. The Tietê picks up large loads of organic wastes from

[8] Chad, Kenya, Mali, Nigeria, Senegal, Vietnam, Sudan, Turkmenistan, Uganda, Egypt.
[9] Chad, Cuba, Dominican Republic, Ecuador, El Salvador, Haiti, Iran, Israel, Jamaica, Kenya, North Korea, Mexico, Pakistan, Somalia, Turkmenistan, Uzbekistan

domestic and industrial sources as it flows through the city of São Paulo. These loads reduce dissolved oxygen levels in the river to levels as low as 2 mg/l and the low level of dissolved oxygen together with the presence of other pollutants has drastically reduced the number and diversity of fish species in the river around the city.

It should be noted that high BOD *is not always correlated* with low dissolved oxygen and threats to fish *in the vicinity of wastewater discharges.* Dependent on river conditions, dissolved oxygen could be at a satisfactory level at the entry point of BOD discharged into a river because of the time dependent biochemical degradation of the organic matter. Furthermore, under high nutrient loading and eutrophic conditions the biomass of algae or macrophytes may significantly contribute to the BOD loading. However, high levels of BOD in aquatic ecosystems are typically associated with significant oxygen depletion and therefore, the German national water quality guidelines indicate that low oxygen levels and periodic fish kills may be expected at BOD concentrations greater than 8 mg/l (LAWA, 1998).

Another key indicator of organic pollution (EEA, 2015) and of particular concern to fish health is *ammonia*. *Ammonia* exists in two forms in water – un-ionized (NH_3) and ionized (NH^{4+}). Ammonia is taken up as a nutrient by aquatic plants and is typically oxidized to nitrate through the process of "nitrification" which consumes oxygen. In higher concentrations, ammonia is of concern for two major reasons. First, it is toxic to fish, particularly in its un-ionized form (NH_3). The pH of the river or lake plays an important role here, because the higher the pH the higher the percentage of the total ammonia which is dissociated into its toxic un-ionized form. Secondly, the respiration due to nitrification may lower the oxygen levels of running and stagnant waters below ecological thresholds.

Chloride is another parameter of concern to the status of the fishery. High chloride concentrations can impair the "osmoregulation" (internal regulation of water and salts) of fish and other organisms and impair their survival, growth, and/or reproduction (CCME, 1999). Chloride can originate from many sources, including those associated with organic pollution such as domestic wastewater. Hence it is sometimes present in high concentrations when BOD levels are also high. But chloride in rivers and lakes also has other sources not usually associated with organic pollution such as road salts used in developed countries for de-icing roads, drainage flows coming from irrigated farmland, and sea spray.

The *pH* of a river or lake is also of concern to the inland fishery. Above we described that at high pH ammonia is dissociated in its toxic un-ionized form. Water with low pH interferes with the ability of fish to take up oxygen, changes the acid-base regulation at the gills, and has other deleterious effects on the physiology of fish (Matthews, 1998). High pH can reduce the ability of fish to excrete ammonia or regulate their internal ion balance (Carpenter et al., 2012). Low pH in lakes and smaller streams is often not associated with organic pollution, but with another water quality problem, namely acidification. Acidification is caused by "acid deposition", i.e. the atmospheric deposition of acidifying sulphur and nitrogen compounds, into a lake (Heard et al., 2014; Rubin et al., 1992). Acid deposition can stimulate the release of aluminium and other heavy metals from soils into lakes where they pose an additional threat to the health of fish. Exceptionally low or high pH in rivers can result from the discharge of domestic or industrial wastewater containing acidic or alkaline compounds.

Table 3.7: "Levels of concern" of water quality parameters with respect to inland fisheries and percentage of measurements exceeding the levels of concern in Latin America, Africa and Asia in the time period 2000-2010. Data from GEMStat. Water quality standards are listed in Appendix B.

Dissolved Oxygen (mg/l)					
Continent	No. of stations/ 10,000 km²	No. of measurements	Median (all data)	Levels of concern	Percentage of data exceeding the levels of concern
Latin America	0.145	5,200	6.3	x < 5[a] / x < 7[b]	17.1%[a] / 51.9%[b]
Africa	0.002	289	6.9	x < 5[a] / x < 7[b]	23.8%[a] / 40.8%[b]
Asia	0.052	7,380	7.0	x < 5[a] / x < 7[b]	7.1%[a] / 26.3 %[b]
BOD (mg/l)					
Continent	No. of stations/10,000 km²	No. of measurements	Median (all data)	Levels of concern	Percentage of data exceeding the levels of concern
Latin America	0.053	2,957	2.0	4 < x < 8 / x > 8	4.8% / 4.7%
Africa	0.001	236	3.3	4 < x < 8 / x > 8	23.3% / 21.6%
Asia	0.058	5,329	1.7	4 < x < 8 / x > 8	14.7% / 4.8%
Ammonia (mg/l)					
Continent	No. of stations/10,000 km²	No. of measurements	Median (all data)	Levels of concern	Percentage of data exceeding the levels of concern
Latin America	0.216	2,664	0.08	x > 0.3	12.4%
Africa	0.012	1,581	0.04	x > 0.3	6.4%
Asia	0.045	3,045	0.04	x > 0.3	15.7%
Chloride (mg/l)					
Continent	No. of stations/10,000 km²	No. of measurements	Median (all data)	Levels of concern	Percentage of data exceeding the levels of concern
Latin America	0.115	3,541	5.3	x > 120	0.25%
Africa	0.014	1,482	51.7	x > 120	29.0%
Asia	0.042	2,735	17.0	x > 120	12.9%
pH (-)					
Continent	No. of stations/10,000 km²	No. of measurements	Median (all data)	Levels of concern	Percentage of data exceeding the levels of concern
Latin America	0.155	5,449	7.2	x ≤ 6.5 / x ≥ 8.5[b]	20.0% / 1.7%
Africa	0.014	1,639	8.1	x ≤ 6.5 / x ≥ 8.5[b]	0.1% / 13.8%
Asia	0.052	7,615	7.5	x ≤ 6.5 / x ≥ 8.5[b]	4.4% / 5.6%

[a]Criteria for warm water biota; measurements with temperature > 20°C and oxygen < 5 mg/l O_2
[b]Criteria for cold water biota; measurements with temperature < 20°C and oxygen < 7 mg/l O_2

Table 3.8: Classes of organic water pollution according to river concentrations of BOD used in this report. Concentration is expressed in mg/l and based on water quality standards of 11 countries listed in Appendix B.

Water pollution class	BOD concentration (mg/l)	Description*
Low pollution	x ≤ 4	Indicates river stretches with low organic load and usually sufficient oxygen supply and high species diversity.
Moderate pollution	4 < x ≤ 8	River stretches with moderate organic load but possibly critical oxygen conditions; suspended discharges occur but have no major effect on biota.
Severe pollution	x > 8	River stretches where depletion of dissolved oxygen can be extreme, likely resulting in fish kills.

*derived from the German national water quality guidelines

Table 3.9: Length and percentage of river stretches (km) within various organic pollution classes. The minimum and maximum monthly stretches in the period of 2008 to 2010 are shown.

Water pollution class	BOD concentration (mg/l)	Latin America (min, max)	Africa (min, max)	Asia (min, max)
Low pollution	x ≤ 4	959,000–1,038,000 86–91%	1,238,000–1,349,000 81–89%	1,237,000–1,342,000 78–85%
Moderate pollution	4 < x ≤ 8	33,100–52,000 3–4%	44,000–53,000 3–4%	72,000–77,000 4–5%
Severe pollution	x > 8	60,000–117,000 6–10%	132,000–234,000 7–15%	168,000–268,000 11–17%

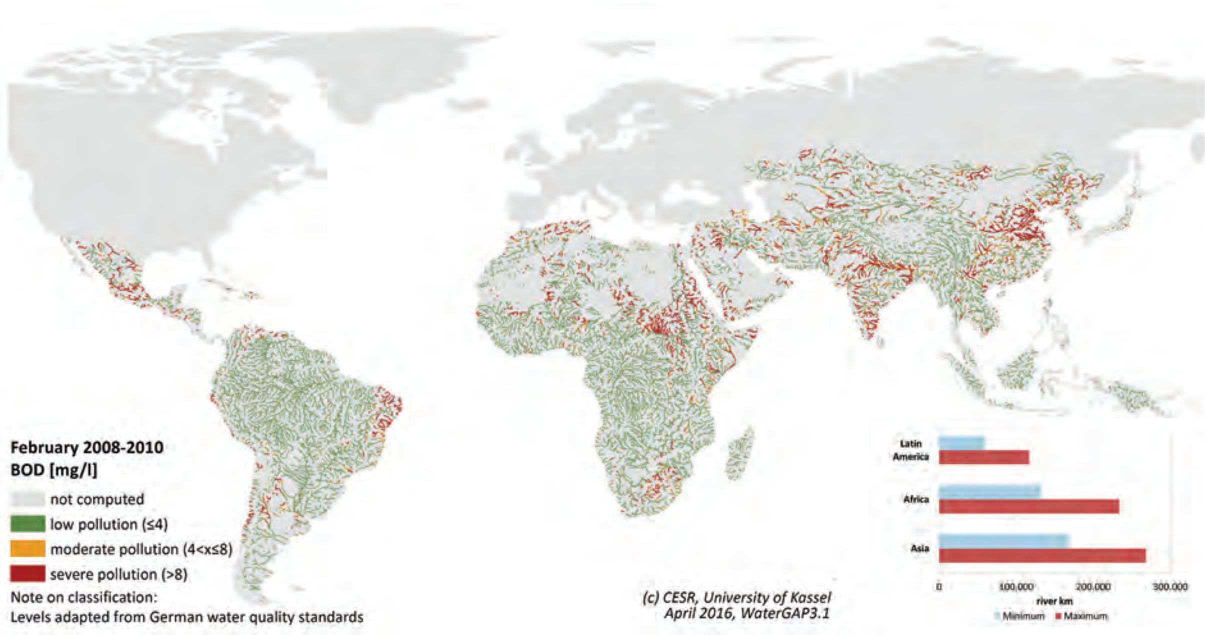


Figure 3.13: Estimated in-stream concentrations of biochemical oxygen demand (BOD) for Latin America, Africa, and Asia for February 2008–2010. Bar charts show minimum and maximum monthly estimates of river stretches in the severe pollution class per continent in the 36-month period from 2008–2010, corresponding to data in Table 3.9.

To sum up, the GEMStat analysis showed that 10 per cent or more of all measurements in Latin America, Africa, and Asia had levels of key water quality parameters that are of concern to the health of inland fisheries. The modelling analysis of BOD on these continents confirmed these results, showing that 6–17 per cent of the river stretches or hundreds of thousands of river kilometres were in the severe pollution class, with the majority of streams having increasing concentration. One overarching conclusion is that countries who rely on their inland fisheries as an important food source should be vigilant about the increasing level of organic pollution.

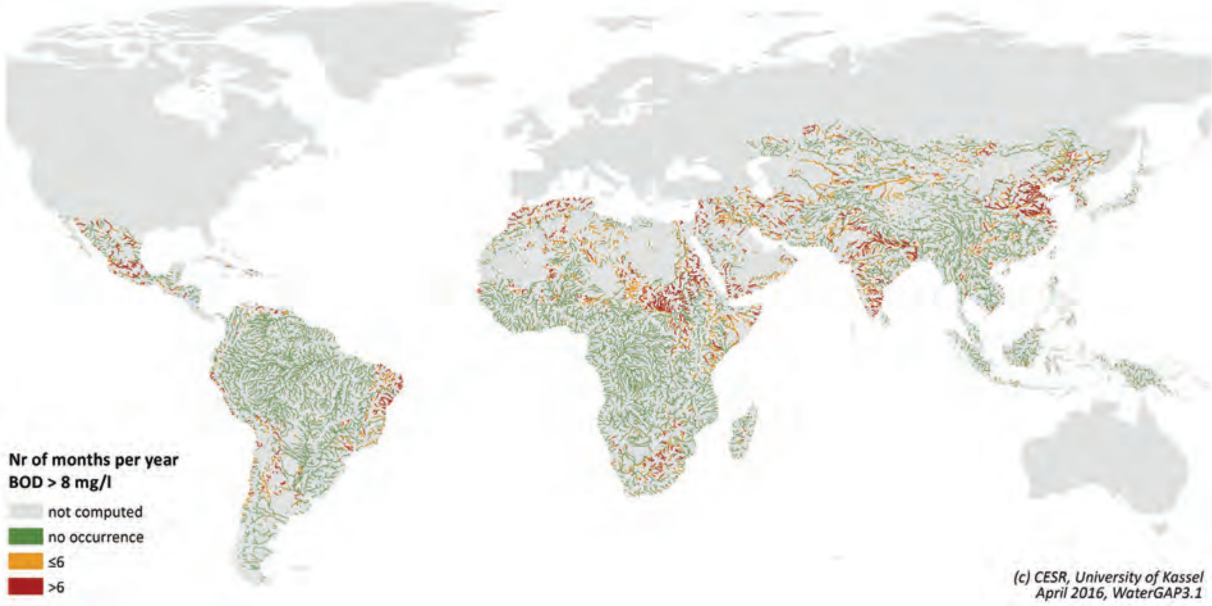


Figure 3.14: Frequency (months/year) in which "severe pollution" levels of biochemical oxygen demand occur in different river stretches over the period 2008–2010.

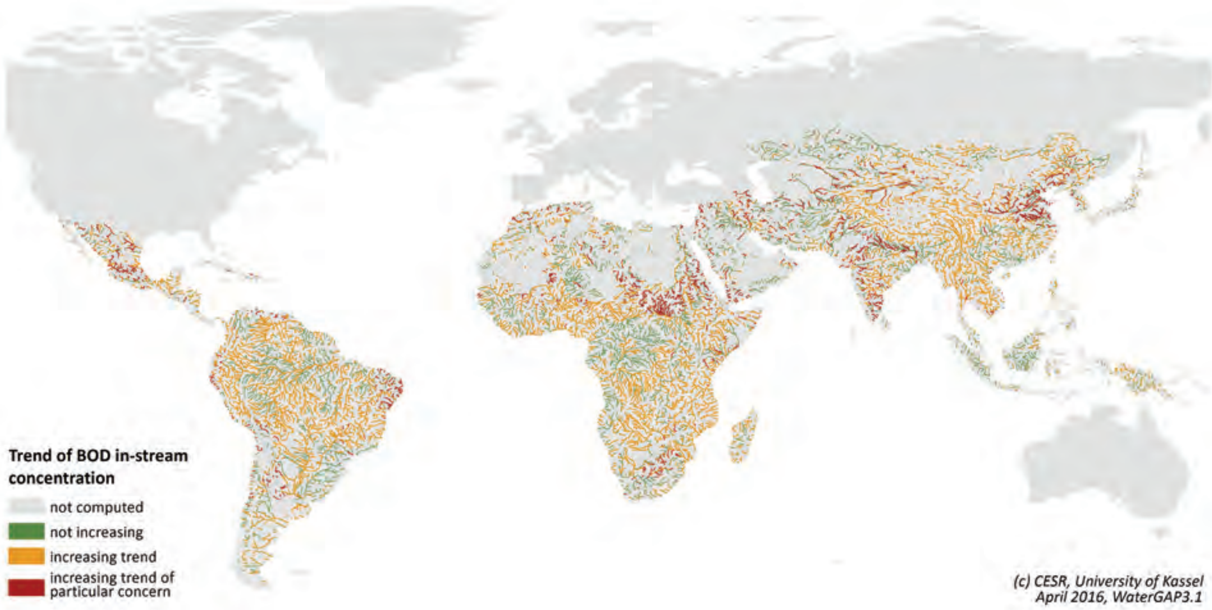


Figure 3.15: Trend in BOD concentrations in rivers between 1990–1992 and 2008–2010. River stretches marked with orange or red have increasing concentrations between these two periods. River stretches marked with red have an "increasing trend of particular concern" meaning that in these stretches the pollution level increased into the severe pollution category in 2008–2010, or that they were already in the severe pollution category in 1990–1992 and further increased in concentration by 2008–2010.

Table 3.10: Selected hot spot areas of organic pollution appearing in both Figure 3.14 and Figure 3.15.

- Central America
- Some river stretches in Northwest Africa
- Vaal river basin
- Limpopo river basin
- River stretches in the Middle East
- Indus river basin
- Ganges river basin
- Some river stretches in Southern India
- Haihe, Huaihe and Yellow river basins

3.3.4 Sources of organic pollution

Several sources of BOD loading are taken into account as shown in Table 3.11. These loadings depend on the waste loadings per person, the type of sanitation, the degree to which sanitation systems are connected to sewers and wastewater is treated, and the loadings washed-off from agricultural land and urban surfaces. Controlling levels of organic loadings at the source is the key to reducing or preventing anthropogenic wastewater intakes into surface waters (see Chapter 5).

Estimates of loadings of organic pollution on a continental basis for the years 1990 and 2010 are shown in the bar charts in Figure 3.16. As noted earlier, the levels of organic pollution in rivers have been estimated to increase over the last two decades because of increases in loadings of BOD. On the continental average basis, loadings have increased by 30 per cent in Latin America, 65 per cent in Africa, and 95 per cent in Asia. The continental average data, however, mask important differences between sub-regions which may differ depending on the rate of population growth, as well as the extent of agricultural and industrial activities.

The increase in BOD loadings is mainly driven by population growth, urbanisation, increasing generation of industrial wastewater and livestock production. With the help of model results it is not only possible to analyse the change in loadings over time, but also to analyse the causes of high in-stream concentrations and to identify the main contributing sectors.

Figure 3.17 shows the main sources of organic pollution according to the three regions for the year 2010. In Latin America about 60 per cent of the total loadings originated from domestic sewered sources while only 11 per cent can be allocated to the domestic non-sewered sector. Wastewater from manufacturing industries accounts for 28 per cent of the loadings, while the contribution from the agricultural sector and urban surface runoff to BOD loadings is about 2 per cent. High loadings from point sources, like sewered domestic wastewater and manufacturing wastewater, indicate that wastewater is probably collected, but not sufficiently treated.

The main sources of BOD loadings in Africa are non-sewered (49 per cent) and sewered (36 per cent) domestic sources from urban and rural populations. In total 85 per cent of loadings are from domestic sources (Figure 3.17). Approximately 13 per cent of BOD loadings in rivers originate from the discharge of wastewater from manufacturing facilities.

In Asia, the domestic sector contributes 54 per cent to the total BOD loadings in 2010, of which about 29 per cent come from sewered sources and 25 per cent from non-sewered sources. Compared to the other continents, a high share of BOD loadings, namely 45 per cent, comes from wastewater produced in the manufacturing sector.

Table 3.11: Categories of organic pollution loadings accounted for in total BOD loadings.

- Domestic sewered (point sources)
- Domestic non-sewered-hanging latrines (point sources); Domestic septic tanks, pit toilets, open defecation (diffuse sources)
- Manufacturing (point sources)
- Urban surface runoff (diffuse sources)
- Agriculture – livestock wastes (diffuse sources)

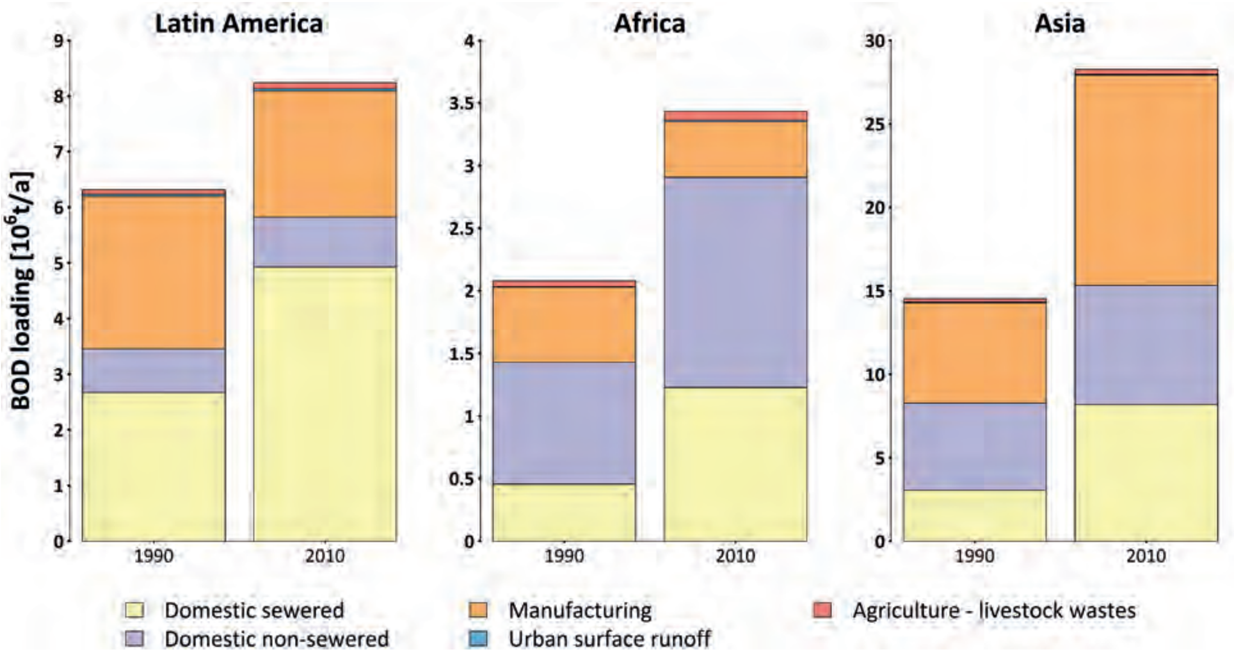


Figure 3.16: BOD loadings for Latin America, Africa, and Asia for 1990 and 2010. Units: tons/year.

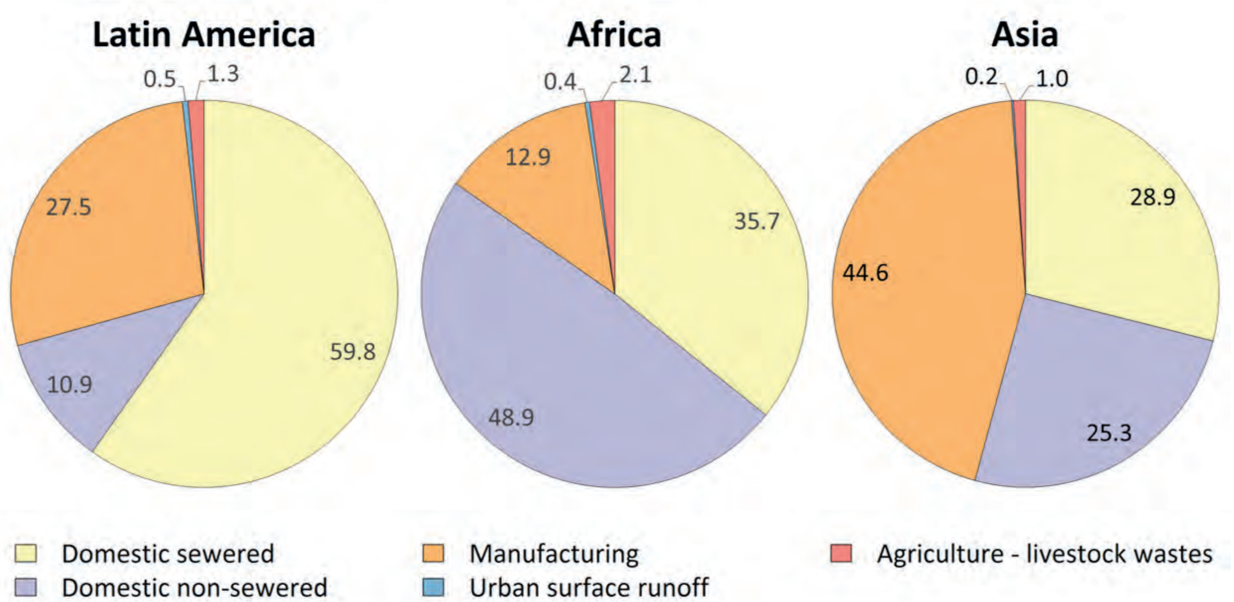


Figure 3.17: Distribution of BOD loadings according to source for 2010. Units: percentage.

3.4 Salinity pollution and impairment of water use

3.4.1 What is salinity pollution and how does it impair water use?

Salinity pollution occurs when the concentration of dissolved salts and other dissolved substances in rivers and lakes is high enough to interfere with the use of these waters. In freshwaters, salinity is commonly defined and measured as the mass of "total dissolved solids" (TDS) in a litre of water, with units of milligrams per litre (mg/l).[10] This is also the approach used in this report.

All freshwaters have a natural background level of salts due to the weathering of soils and rocks in their drainage basin. In drainage basins underlain by granite, the weathering rate is relatively low, and, accordingly, the natural level of salinity in rivers in such areas is low. In drainage basins with clay soils, weathering is much higher, and also water salinity tends to be proportionately higher. Close to the sea, rivers acquire salt by mixing with tidal ocean waters or from precipitation containing traces of sea salt. Therefore, even without human interference, some rivers have relatively high salinity levels. In these naturally saline rivers and lakes, aquatic and riparian ecosystems have adapted to these saline levels.

Society artificially increases the concentration of salinity by discharging domestic, industrial, and agricultural wastes into rivers and lakes. As will be seen in Section 3.4.3, important anthropogenic sources of salinity are irrigation return flows, domestic wastewater, and runoff from mines. A more local and seasonal source, particularly important in developed countries in colder climates, is the wash-off of salt used to melt snow on roadways (Anning & Flynn, 2014).

Salinity pollution can have many important negative impacts. One of the most important impacts is that it can hinder the use of a freshwater supply for irrigation. Only water with a relatively low salinity can be used for irrigation. If water applied to crops has a too high salinity concentration, salts accumulate in the root zone of plants and interfere with the plant's extraction of water from the saline solution. A reduced water uptake can lead to wilting of the plant. While some plants are salt-tolerant, the majority of food crops are not. With this in mind, the Food and Agriculture Organization (FAO) has recommended limits to the use of saline water for irrigation (Table 3.12). Restrictions on use for irrigation start at a concentration of TDS of 450 mg/l, a concentration that is not unusual where waste loadings are significant.

Salinity pollution has wide-ranging negative impacts on aquatic ecosystems at the individual, population, community, and ecosystem levels (Cañedo-Argüelles et al., 2013). Freshwater organisms have a limited tolerance to salinity and usually cannot adapt to salinity concentrations significantly higher than natural background levels.

Salinity pollution is also of concern to certain industries, such as food processing and pharmaceutical manufacturing because they require intake water with very low salinity. High salinity levels also contribute to scaling of pipes and boilers in factories (Salvato et al., 2003).

Salinity pollution is a global problem but tends to be more severe in arid and semi-arid regions where the dilution capacity of rivers and lakes is lower and the use of irrigation higher (Vengosh, 2003).

In this report, the FAO recommendations for irrigation given in Table 3.12 are used as benchmarks for the level of pollution.

Table 3.12: Classes of salinity water pollution according to river concentrations of TDS used in this report. These classes correspond to the restrictions on use for irrigation from FAO (1985) shown in the third column.

Water pollution class	TDS (mg/l)	Restrictions on use for irrigation FAO (1985)
Low pollution	< 450	No restrictions
Moderate pollution	450–2,000	Increasing restrictions
Severe pollution	> 2,000	Severe restrictions

[10] Total dissolved solids include both dissolved salts as well as dissolved organic materials. According to the US EPA: "In stream water, dissolved solids consist of calcium, chlorides, nitrate, phosphorus, iron, sulfur, and other ions particles that will pass through a filter with pores of around 2 microns (0.002 cm) in size." US EPA http://water.epa.gov/type/rsl/monitoring/vms58.cfm. Retrieved May, 2015.

3.4.2 What is salinity pollution and how does it impair water use?

GEMSTAT analysis

As for the analysis of faecal coliform pollution and organic pollution (see Sections 3.1.2 and 3.2.2), there are insufficient measurements on the continental scale for Latin America, Africa, and Asia to gain a continental overview of salinity pollution based only on data. Furthermore, the data distribution is geographically biased because of the limited number of countries providing information to the system. Therefore, as in previous sections, all TDS data from 2000 to 2010 were consolidated in individual statistical distributions for each of the three continents (Figure 3.18 and Table 3.13).

While the medians are in the low pollution class, the 90th percentiles for Africa and Asia are above or near 450 mg/l. This indicates that 10 per cent or more of the measurements from these continents have salinity levels that would restrict their use for irrigation to some degree. While Latin America has lower overall measured levels of total dissolved solids, Figure 3.18 (left panel) shows that some measurements do exceed the 450 mg/l guideline value.

Modelling analysis

Figure 3.19 shows an example of the level of TDS for February 2008–2010 according to the classes of TDS in Table 3.12. Areas of severe salinity pollution exist in the upper and lower Nile and Indus basins. Areas of moderate pollution (where use of river water for irrigation is partially restricted according to Table 3.12) include river stretches of the Euphrates, Ganges, and Aral Sea basin.

As was noted previously, faecal coliform bacteria and BOD river concentrations vary from month to month because of the variability of river conditions. River salinity also varies in this way. Table 3.14 shows the length of rivers affected by salinity pollution taking into account the month-to-month variation of river pollution. Around 4,600 to 10,000 km of Latin America's rivers, or about 0.7 per cent of all river stretches, are in the severe pollution class. For Africa, the estimate is around 32,000 to 83,000 km, or around 4 per cent of its river stretches, and for Asia around 28,000 to 65,000 km, amounting to about 3 per cent of its entire river stretches.

Figure 3.20 shows the frequency of months in a year in which river stretches are in the severe pollution category for TDS. In this context, it is assumed that river stretches with severe or moderate pollution six months or more in a year are an indication of hot spot areas.

Figure 3.21 shows the trend in TDS river concentrations between the early 1990s and late 2000s. TDS concentrations have increased in 21 per cent of the river stretches in Latin America, 33 per cent of the river stretches in Africa, and 37 per cent of the river stretches in Asia. In total, 31 per cent of the river stretches on these three continents have an increased TDS concentration.

The areas where salinity pollution has increased to a severe level of total dissolved solids or started at a severe level and became worse are of particular concern. These stretches are shown in Figure 3.21 and can be considered another estimate of hot spot areas.

Table 3.13: Overview of data availability and statistical values for TDS in the period 2000–2010. Data source: GEMSStat. SD = Standard deviation. Units: [mg/l]

Continent	No. of stations/ 10,000 km²	No. of measurements	Median	10th percentile	90th percentile	SD
Latin America	0.04	2,901	52	19	223	119
Africa	0.012	1,687	333	118	1,014	1,820
Asia	0.045	7,441	70	8	445	2,936

Table 3.14: Length and percentage of river stretches (km) in various salinity pollution classes. The minimum and maximum monthly stretches are indicated for the period of 2008 to 2010.

Water pollution class	TDS concentration (mg/l)	Latin America (min, max)	Africa (min, max)	Asia (min, max)
Low pollution	x ≤ 450	1,146,000–1,163,000 95–96%	1,330,000–1,410,000 87–93%	1,367,000–1,473,000 86–93%
Moderate pollution	450 < x ≤ 2,000	39,000–50,000 3–4%	82,000–112,000 5–7%	81,000–150,000 5–10%
Severe pollution	x > 2,000	4,600–10,400 0.4–0.9%	32,000 – 83,000 2–5%	28,000–65,000 2–4%

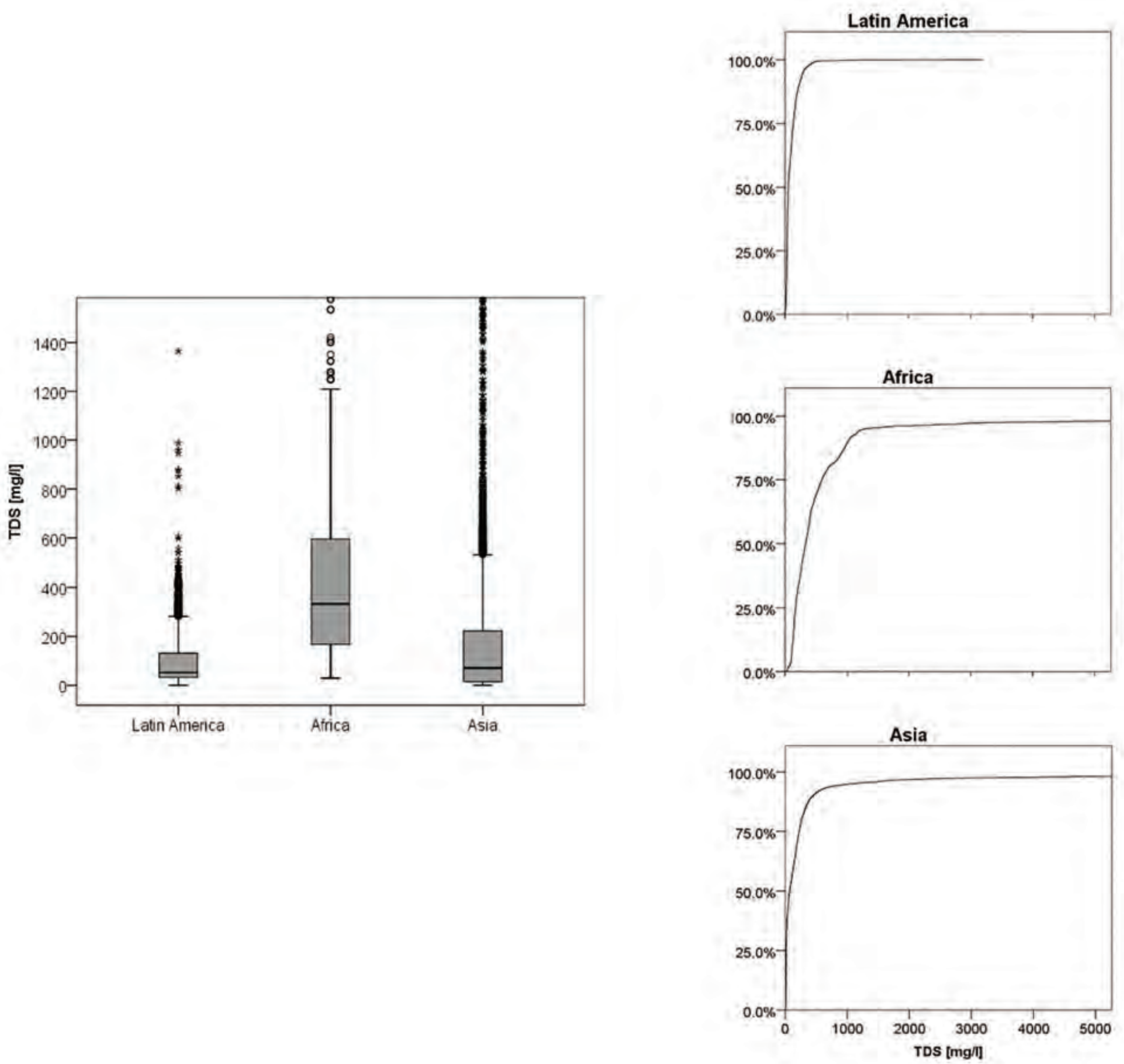


Figure 3.18: Box-and-whisker plots (left) of the distribution and cumulative frequencies (right) of TDS in Africa, Latin America, and Asia in the time period 2000–2010. Boxes show 25th to 75th percentile and median (black line). Data source: GEMStat.

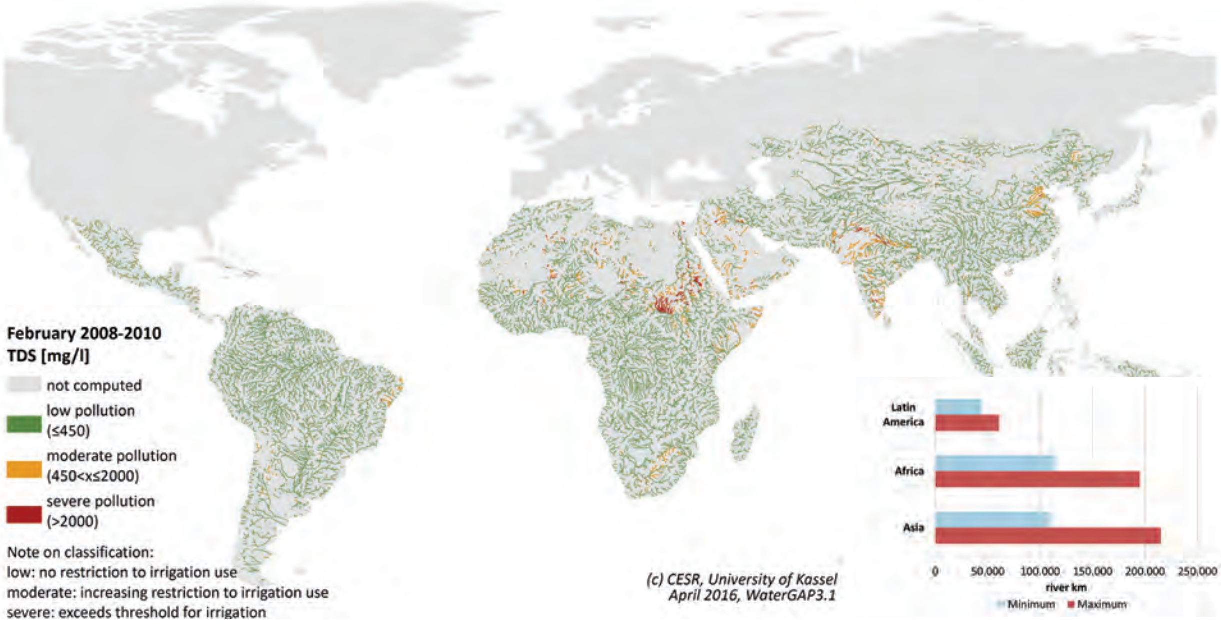


Figure 3.19: Estimated in-stream concentrations of total dissolved solids (TDS) for Latin America, Africa, and Asia for February 2008–2010. Bar charts show minimum and maximum monthly estimates of river stretches in the severe pollution class per continent in the 36-month period from 2008–2010 corresponding to data in Table 3.14.

Figure 3.20: Frequency (months/year) in which "moderate or severe pollution" levels of total dissolved solids occur in different river stretches over the period 2008–2010.

Table 3.15: Hot spot areas of salinity pollution (from Figure 3.20 and Figure 3.21).

- Lower Nile river basin
- Euphrates river basin
- Indus river basin
- Ganges river basin
- Aral Sea basin

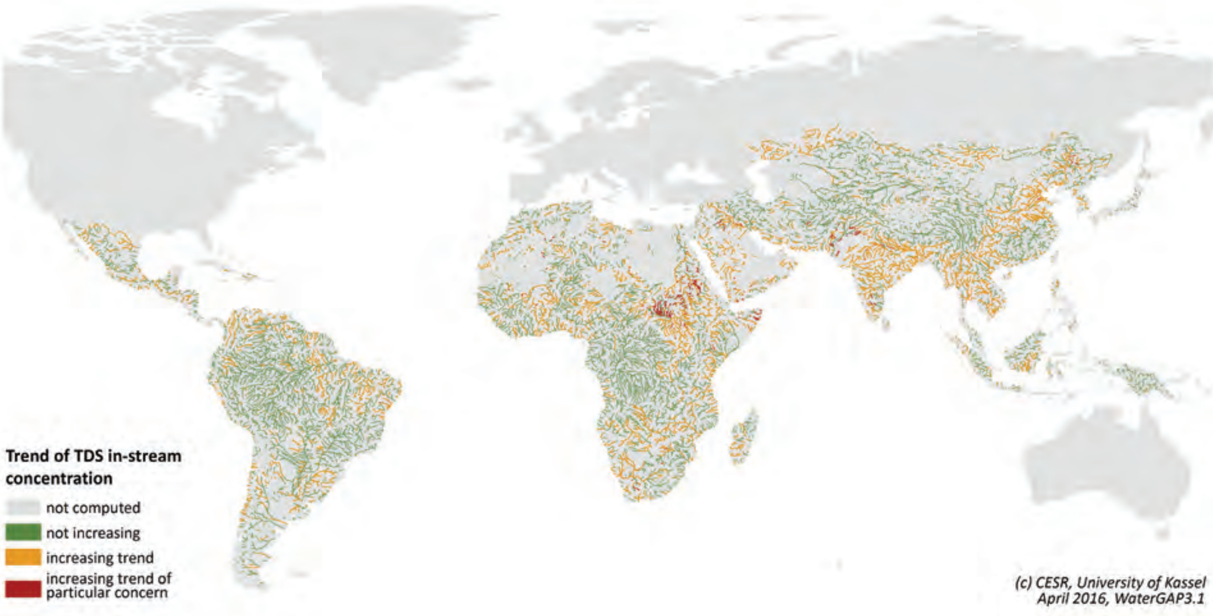


Figure 3.21: Trend of TDS levels in rivers between 1990–1992 and 2008–2010. River stretches marked with orange or red have increasing concentrations between these two periods. River stretches marked with red have an "increasing trend of particular concern" meaning that in these stretches the pollution level increased into the severe pollution category in 2008–2010, or that they were already in the severe pollution category in 1990–1992 and further increased in concentration by 2008–2010.

3.4.3 Sources of salinity pollution

Most of the salinity loading to rivers, including in Latin America, Africa, and Asia, comes from natural background sources (Figure 3.23, upper diagram). In this study, background concentrations of TDS are estimated to range from around 5 to 832 mg/l (Appendix B). However, about 10 per cent of river stretches have a natural TDS concentration of > 450 mg/l (defined here as "moderate" salinity pollution). Exceptions are some arid and semi-arid drainage basins with high weathering rates. But the high salinity areas indicated in Figure 3.19, Figure 3.20, and Figure 3.21 are almost all caused by anthropogenic loadings of total dissolved solids (Table 3.16).

In both Africa and Asia, the main anthropogenic source is return flow from irrigated areas which transfers large amounts of salts from cropping areas to surface waters (Figure 3.22 and Figure 3.23). The second most important category is manufacturing. In Latin America the most important source is manufacturing, followed by irrigation return flows (Figure 3.23). This is because the fraction of continental area devoted to irrigation in Latin America is small compared to Asia. Although the fraction of irrigated area is small in Africa, TDS loadings from irrigation are much larger compared to the other sources, e.g. manufacturing. Loadings from irrigation return flows may be underestimated for the year 2010 because the extent of irrigated area in that year has not been estimated (Siebert et al., 2015), and the coverage of irrigated area for these calculations is assumed to be constant between 2005 and 2010. On all continents, the third most important source was domestic wastewater conveyed by sewers.

Runoff from mining activities is an important source of salinity in some rivers. An example is given in Chapter 4 for the River Vaal. However, it is not included here because of the lack of comprehensive data from the three continents being studied. Therefore, in some river stretches the loadings of total dissolved solids are underestimated. TDS loadings from mining will be included in future studies. Road salt is an important source of total dissolved solids in North American rivers (Anning & Flynn, 2014), but is not expected to be of major importance for the three continents studied here.

Table 3.16: Categories of salinity pollution loadings accounting for total TDS loadings.

- Domestic sewered (point sources)
- Domestic non-sewered – hanging latrines (point sources); domestic septic tanks, pit toilets, open defecation (diffuse sources)
- Manufacturing (point sources)
- Urban surface runoff (diffuse sources)
- Agriculture – irrigation return flows (diffuse sources)
- Agriculture – animal wastes (diffuse sources)
- Background soil/rock (diffuse sources)

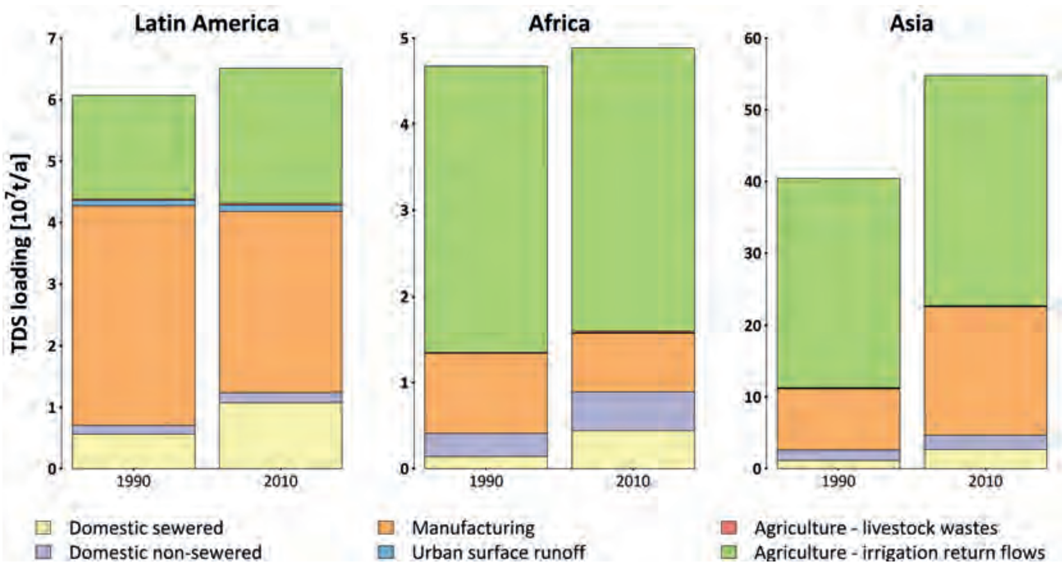


Figure 3.22: Anthropogenic sources of TDS loadings for Latin America, Africa, and Asia for 1990 and 2010. Units: tons/year.

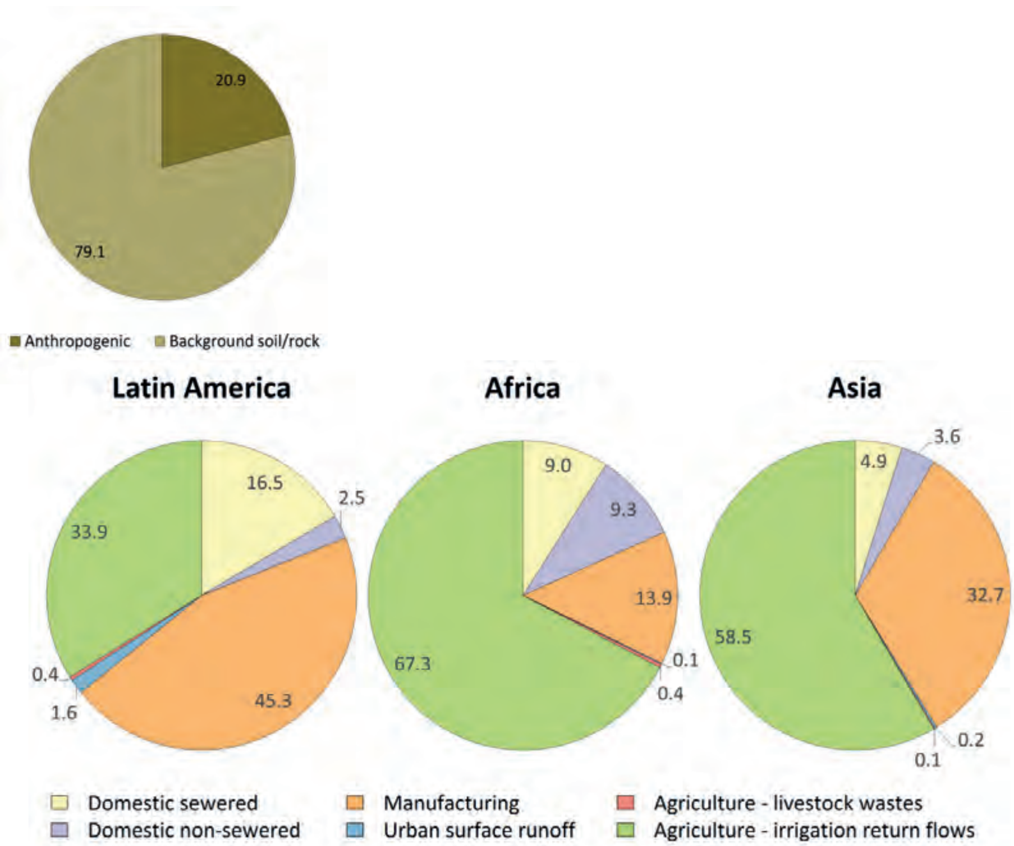


Figure 3.23: Upper diagram: Distribution of total anthropogenic versus background input of TDS to rivers in Latin America, Africa, and Asia. Lower diagrams: Distribution of TDS loadings according to anthropogenic sources for 2010. Units: percentage.

3.5 Eutrophication and nutrient loadings to large lakes

3.5.1 What are eutrophication and other water quality problems in lakes?

Lakes contain around 90 per cent of the liquid freshwater on the earth's surface (ILEC, 2011) and they are an important source of water and food. However, the ability of lakes to provide these and other ecosystem services is threatened by infrastructure development, overfishing, invasive species, and in particular by water pollution. Water quality degradation in lakes takes different forms including eutrophication, pathogen contamination, organic pollution, and chemical pollution. In this study, the focus is on eutrophication because of its negative impacts on lakes, its worldwide scale, and because it may be expanding in scope (e.g. Jin et al., 2005). A few of the many examples of lakes affected by eutrophication now or in the past are shown in Table 3.17.

Eutrophication in lakes is part of a natural process of nutrient accumulation that leads to gradually increasing the plant productivity of a lake. In this case, nutrients originate from natural sources such as the decomposition of organic material, or rock and soil weathering. But in many lakes, anthropogenic inputs of nutrients greatly accelerate the natural process. This is sometimes called "cultural eutrophication". If temperature, light, and other conditions are sufficient, loadings of nutrients stimulate the rapid growth of algae and other aquatic plants. When these large algae populations die off, they are decomposed by bacteria, which deplete the oxygen resources of the lake, threatening the survival of fish and other aquatic organisms. Other impacts of eutrophication in lakes are listed in Box 3.5.

There is a lively discussion in the scientific community about the importance of phosphorus and nitrogen loadings as causes of lake-eutrophication.[11] In this report only the total phosphorus loadings to lakes are taken into account. These loadings were examined in 25 "major lakes" in the world selected because they are of special interest to human society due to their size.[12] Some of these lakes are subject to eutrophication as noted in Table 3.17.

Table 3.17: A selection of past and present eutrophication problems reported for large lakes.

Lake	Main source of nutrient pollution	Selected effects of pollution	Reference
Taihu (China)	Chemical and manufacturing plants, agriculture, domestic waste water	Phytoplankton changed from diatom flora to one dominated by cyanobacteria; algae blooms; Macrophytes disappeared	Stone (2011)
Erie (Canada, USA)	Agriculture, industrial waste water, domestic waste water; reduced phosphorus inputs by mid 1980s	Increase in phytoplankton biomass, algae blooms, eutrophic and hypereutrophic species, fish kills due to anoxia; water quality has been improving since the 1980s.	Allinger and Reavie (2013)
Constance (Germany, Austria, Switzerland)	Agriculture, domestic	Low oxygen concentrations, algae blooms (re-oligotrophication since the 1980s due to massive reduction of nutrient pollution)	IGKB (2002)
Peipsi (Estonia, Russia)	Agriculture, domestic, manufacturing	Low oxygen concentrations, algae blooms	Kangur et al. (2005)
Laguna de Bay (Philippines)	Domestic, agricultural, industrial effluents	Algae blooms (lake wide algae bloom in 1979), low oxygen concentrations which endanger aquaculture	ILEC (2005)
Victoria (Tansania, Uganda, Kenia)	Growth of the predominantly rural human population; agriculture	Phytoplankton changed from diatom flora to one dominated by cyanobacteria; increase of algal biomass; fish kills; more prevalent deep water anoxia; superposition effects by Nile perch introduction	Sitoki et al. (2010)

[11] On the one hand, most scientists agree that under pristine circumstances phosphorus limits the growth of algae. This implies that excess phosphorus causes eutrophication and that its removal from lakes would in turn reduce eutrophication. On the other hand, others believe that in addition to phosphorus, nitrogen also plays a significant role depending on the type of lake, its trophic status, and the season (Kolzau et al., 2014). Still others believe that nitrogen rarely contributes to lake eutrophication (Schindler, 2012).

[12] The "major lakes" sample is made up of 5 of the largest lakes in each of five UNEP "Global Environment Outlook" regions (Africa, Asia, Europe, Latin America, and North America), excluding the Caspian Sea, Aral Sea, and Lake Chad because of their special characteristics. The 25 major lakes are displayed in Figure 3.24 to Figure 3.26.

Box 3.5: Effects of eutrophication on lakes and reservoirs (from Smith et al., 1999)

- Increased biomass of freshwater phytoplankton and periphyton
- Shifts in phytoplankton species composition to taxa that may be toxic or inedible (e.g. bloom-forming cyanobacteria)
- Changes in vascular plant production, biomass, and species composition
- Reduced water clarity
- Decreases in the perceived aesthetic value of the water body
- Taste, odour, and water supply filtration problems
- Possible health risks in water supplies
- Elevated pH and dissolved oxygen depletion in the water column
- Increased fish production and harvest
- Shifts in fish species composition towards less desirable species
- Increased probability of fish kills

3.5.2 What are the phosphorus loadings to major world lakes?

Anthropogenic loadings of phosphorus into lakes originate from domestic sewered wastewater, domestic non-sewered sources, manufacturing, inorganic fertiliser from cropland, animal wastes, and atmospheric deposition. Estimates for the time period 1990–2010 are provided by the WorldQual model, which was also used earlier in this chapter for estimating faecal coliform bacteria, BOD and TDS in rivers (see Appendix B). A fraction of these loadings is assumed to be retained in the watershed of the lake and not enter the lake proper. Loadings of total phosphorus computed by the model have been tested against independent estimates of various lakes and large river basins (Appendix B).

The anthropogenic total phosphorus loads to Qinghai Lake in China (514 kg P/km^2/yr) and to Issyk-Kul Lake in Kyrgyzstan (211 kg P/km^2/yr) are the highest loadings to the selected major world lakes (Figure 3.24). The loads to Great Bear Lake and Great Slave Lake in North America are very small. The phosphorus loads to African lakes range widely, as do the loads to Asian lakes. It is important to note that the size of the phosphorus load is not necessarily proportional to the degree of eutrophication because other factors have an important influence on eutrophication including temperature and light conditions, the physical attributes of a lake, and average residence time of lake water.

The natural long-term processes of eutrophication are accelerated by anthropogenic inputs of phosphorus. Therefore, it is of concern that in 23 out of the 25 major lakes more than 50 per cent of the total phosphorus loads are from anthropogenic sources (yellow and red circles in Figure 3.24).

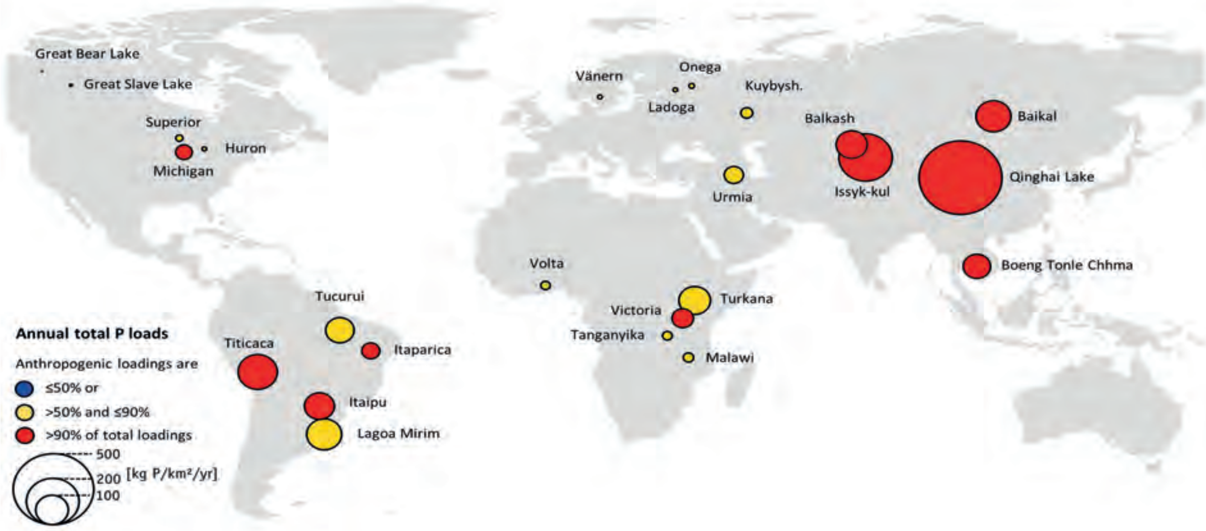


Figure 3.24: Average total phosphorus loads per unit lake basin area and an indication of the anthropogenic versus background loadings for the selection of 25 largest lakes for the period 2008–2010. The size of a circle represents the annual total phosphorus load per unit lake basin area. The colour indicates whether the proportion of anthropogenic loadings exceeds 50 per cent (yellow circles) or even 90 per cent (red circles) of total loadings or falls below 50 per cent of total loadings (blue).

3.5.3 What are the sources of phosphorus?

To avoid or reduce eutrophication in these lakes it is necessary to know what sources of anthropogenic phosphorus are most significant (Figure 3.25). The dominant source in almost all lakes examined here is inorganic fertiliser. Livestock wastes are the second largest source in Africa. Domestic wastewater is an important source of total phosphorus loadings in Europe and North America.

The changes in estimated loadings between the periods 1990–1992 and 2008–2010 are shown in Figure 3.26. Most of the major lakes in Latin America, Africa and Asia have increasing anthropogenic loadings. By contrast, loadings decreased in North America and Europe. Reductions in Western Europe and North America were achieved through reduced usage of phosphorus containing products (e.g. detergents), a higher level of wastewater treatment and reduced fertiliser application. However, fertiliser application is still increasing in South America, in Africa, and in the Asia-Pacific region.

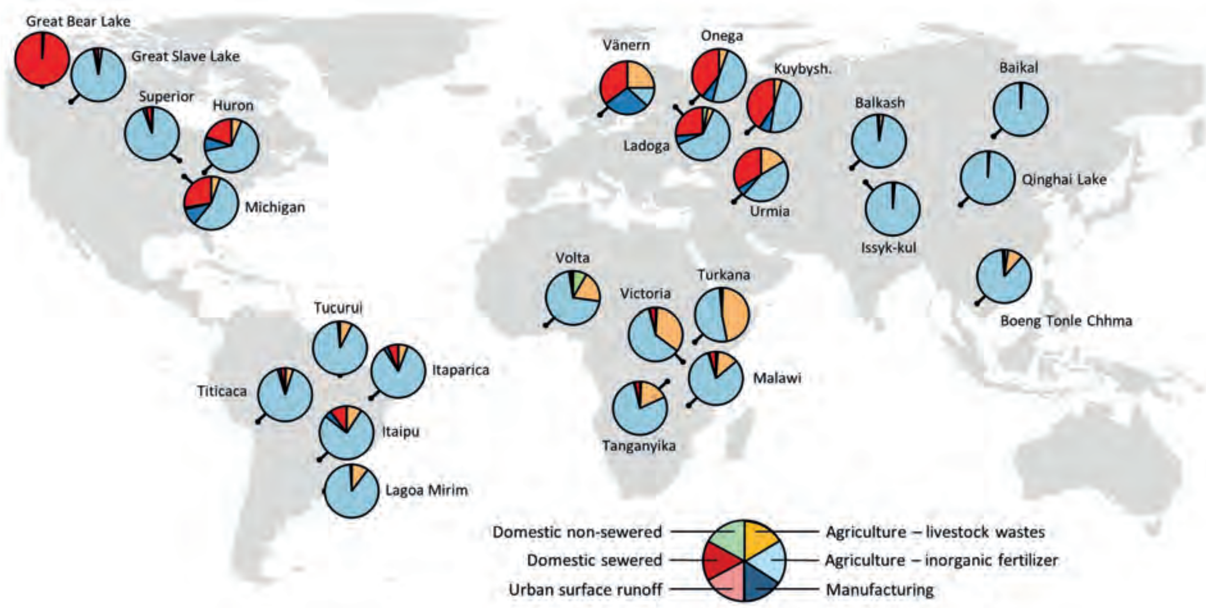


Figure 3.25: Sources of anthropogenic total phosphorus loadings to major lakes. The average percentage contributions to the annual loading for the period 2008–2010 are shown.

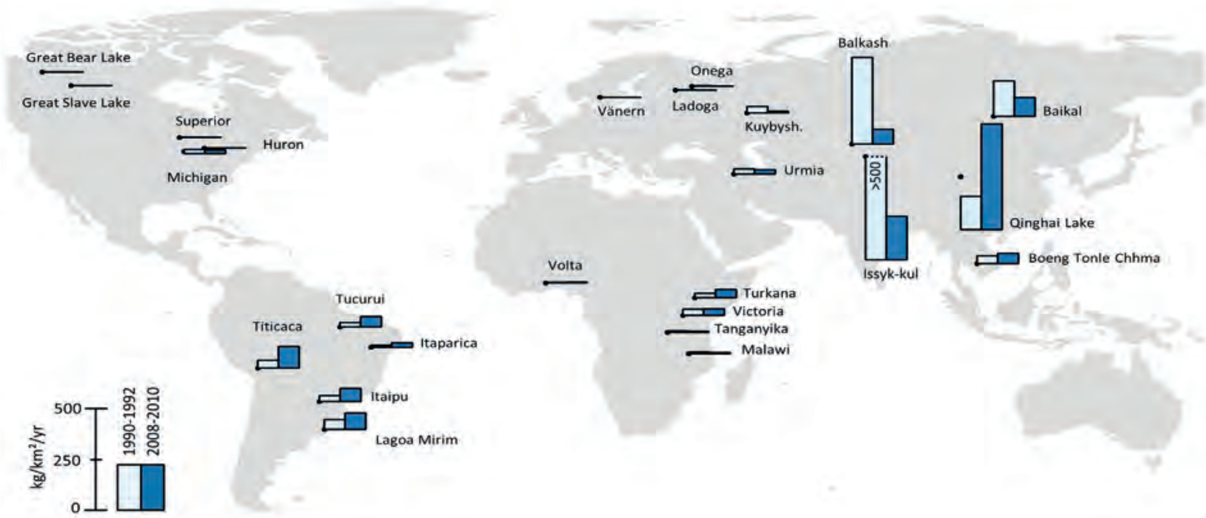


Figure 3.26: Total phosphorus loadings from anthropogenic sources per unit lake basin area for 1990–1992 and 2008–2010. Units: kg/km²/year.

These trends in phosphorus loadings may change the trophic state of a lake (the state of a lake according to the availability of nutrients for aquatic flora). How quickly a lake responds to an increase or decrease in phosphorus inputs will depend, among other factors, on the residence time of a lake (the time it takes the water in a lake to renew itself). Small lakes will respond fairly quickly because they have relatively small volumes and therefore shorter residence times. Larger lakes, as in the 25 lakes examined here, have much longer residence times (e.g. 330 years for Lake Baikal and 23 years for Lake Victoria), and therefore it might take decades or centuries for a lake to respond to changes in phosphorus inputs. Box 3.6 below illustrates a feasible method for estimating the response of small to medium sized lakes to phosphorus inputs.

Box 3.6: Estimating the changes in the trophic state of lakes

The predicted total phosphorus (TP) loads from a lake's basin can be used to classify the corresponding trophic state of the water body by calculating the average equilibrium TP concentration in relation to threshold levels for trophic states according to Vollenweider (1976) (see Figure 3.27). For this plot, small to medium-sized lakes in different continents of the world with coherent data on P loading, lake surface area, and hydrology were selected, which allowed for the calculation of the equilibrium P concentration in the lake as the primary determinant of the trophic state (vertical axis). The horizontal axis represents the hydraulic load (calculated by dividing the annual inflow to the lake surface area) of the system and, therefore, characterises the hydrological setting of the system.

Furthermore, the two time series periods from 1990–1992 and 2008–2010 were compared to identify trends. Most systems showed similar hydraulic loads, except of Lake Taihu and Kariba Reservoir, but marked differences in lake phosphorus concentrations. While European lake systems were predominantly characterised by decreasing P concentrations, most non-European systems showed increasing trends in P concentrations. In case of Lake Constance, Lake Como, and Lake Peipsi even a transition from eutrophic to mesotrophic conditions could be seen indicating the efficiency of water management programs.

Thus, this method can be used for analysing the trajectories of changes in the trophic states of lakes and estimating the relevance of hydrological or water quality related drivers. The plot also illustrates that a large change in TP load does not necessarily need to be associated with a changing trophic state since certain threshold P concentrations have to be reached. The plot also allows for the estimation of a "distance to target". The reduction in TP loadings required to reach mesotrophic conditions for Lake Taihu, for example, would be much larger than for Kariba Reservoir.

A prerequisite for a wider application of this method is an objective survey of lakes of different sizes in a geographic area and requires further hydrological and limnological information including reference trophic states. It must also be stressed that a thorough testing of the phosphorus loading concept is required since this methodology was predominantly developed on temperate lakes and its application to tropical systems needs to be carefully assessed. These aspects are proposed to be part of the full scale World Water Quality Assessment to test the usability of this approach for a global assessment of lake eutrophication.

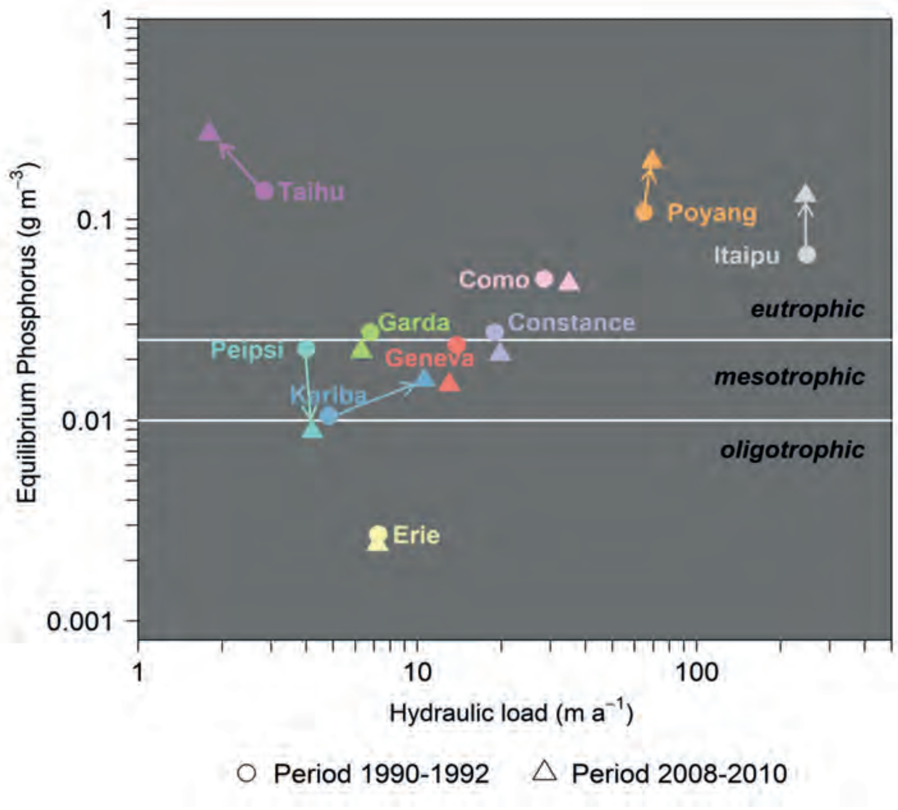


Figure 3.27: Trophic classification of 10 large lakes based on the phosphorus loading model by Vollenweider (1976). Two different periods were used (1990–1992 and 2008–2010) and the simulated TP loadings converted to the corresponding equilibrium phosphorus concentration (y-axis). Critical P concentrations of 10 and 25 mg/m^3 for the transition between oligo-/mesotrophic and meso-/eutrophic systems, respectively, were used. Note the log-log plot.

4 Water Pollution in River Basins

Aim of this chapter

Identifying transferable messages about the world water quality situation with the help of eight river basin case studies.

Main messages

- Similar kinds of water quality challenges are occurring around the world even if the locations and situations are very different. But these challenges sometimes have different immediate and ultimate causes, all linked to unsustainable growth or practices.
- A key to managing water quality is good governance and effective institutions. Barriers to good governance are the fragmentation of authority, lack of technical capacity, and lack of public awareness. These and other barriers can be overcome with action plans, collaborative authorities, and other instruments.
- Coping with the global water quality challenge is closely connected to many other priorities of society such as food security and health. Therefore, actions to protect water quality should be part of efforts to achieve the new Sustainable Development Goals.

4.1 Introduction

After reviewing the water quality situation on three continents in the previous chapter, the water quality situation in eight river basin case studies from around the world (Figure 4.1) is examined in more detail in this chapter. These cases emphasise the diversity of water quality issues (Table 4.1), management actions, and lessons learnt from experience in different river basins. Examples from the Hudson and Elbe rivers show the complete trajectory from articulating a water pollution problem through to its solution. Most of the examples, however, show that much still needs to be done either to restore water quality or to avoid further water quality degradation. The Upper Tietê case, for example, demonstrates how much time it takes from realizing the problem exists to the first signs of water quality improvement.

Each case study first presents an overview of the river basin's physical and governance characteristics. It then reviews the nature of its water quality problems and the current solutions being planned or tried out. Finally, it describes the lessons to be learned from the case study that are relevant to other river basins.

Chapter 4.2 River Basin 1 – Upper Tietê | Confluence of Tietê and Pinheiros Rivers in São Paulo, Brazil
Source: Ricardo Zig Koch Cavalcanti / Banco de Imagens ANA

Chapter 4.3 River Basin 2 – Godavari | Sunset at Godavari
Source: *https://commons.wikimedia.org/wiki/File:Sunset_at_Godavri.JPG*

Chapter 4.4 River Basin 3 – Volta | Transporting sand upstream the Volta for construction
Source: Adelina Mensah

Chapter 4.5 River Basin 4 – Chao Phraya
Source: Dr. Pinida Leelapanang

Chapter 4.6 River Basin 5 – Vaal River | Vaal Barrage
Source: Gordon_O'Brien

Chapter 4.7 River Basin 6 – Medjerda River
Source: Seifeddine Jomaa

Chapter 4.8 River Basin 7 – Elbe River | Valley of Elbe near Děčín.
Source: *https://commons.wikimedia.org/wiki/File:Labe_udoli.jpg*

Chapter 4.9 River Basin 8 – Hudson River
Source: Matthias Manske | *https://de.wikipedia.org/wiki/Hudson_River#/media/File:Hudson_South.jpg*

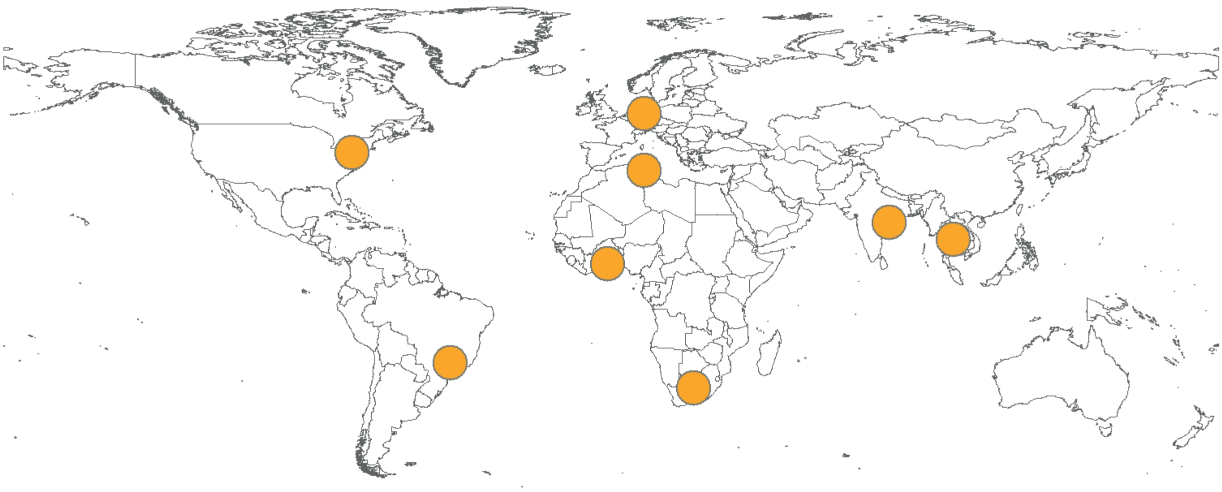


Figure 4.1: Case study locations.

Table 4.1: Case study overview (BOD = biochemical oxygen demand, FC = faecal coliform bacteria, TDS = total dissolved solids, N = nitrogen, P = phosphorus, PCBs = polychlorinated biphenyls).

Continent	River Basin	Typical water quality issue
Latin America	Upper Tietê	Organic pollution (BOD)
Asia	Godavari	Organic pollution (BOD)
Africa	Volta	Pathogen pollution (FC)
Asia	Chao Phraya	Pathogen pollution (FC)
Africa	Vaal	Salinity pollution (TDS)
Africa	Medjerda	Erosion and leaching of salts (TDS) and nutrients
Europe	Elbe	Nutrients (N and P)
North America	Hudson	Synthetic organic chemical pollution (PCBs)

4.2 River Basin 1 – Upper Tietê

The Upper Tietê River flows through the São Paulo Metropolitan Region, south-eastern Brazil, the largest urban and industrial agglomeration of South America. Since the 1950s, the growth of the population and the industrial activities led to a severe deterioration of the Tietê River water quality. In 1991, a Cleanup Programme was launched, and since then, the treatment level of domestic and industrial sewage has significantly increased. The river stretch impacted by severe pollution downstream of the São Paulo Metropolitan Region has decreased from 260 km to 100 km. This is the largest river cleanup project in Brazil and shows the importance of public participation, continuous investments, and the creation of governance and financing mechanisms.

4.2.1 Brief overview of Upper Tietê Basin characteristics and governance

The Tietê River has a total length of 1,136 km and is a tributary of the Paraná River, which is part of the Plata Basin, the second largest basin in South America. It is located entirely within São Paulo State, south-eastern Brazil. The Upper Tietê River flows through the São Paulo Metropolitan Region, the largest urban and industrial agglomeration of South America which includes the city of São Paulo and 38 adjacent municipalities, together responsible for 19 per cent of Brazilian GDP.

The hydrology of the basin is very complex because of many structures for flood control, water supply and flow management that have changed the natural regime of water flow. Human water consumption is larger than the water available in the basin, and a large portion of water (31 m^3/s) has to be imported from neighbouring basins.

Upper Tietê River Basin
River Length: 243 km
Drainage area: 5,720 km² (37% urban)
Population: 20 million (2010)
Precipitation: 1,400 mm

Figure 4.2: Location of the Upper Tietê River Basin.

Water quality management in the basin is the responsibility of several agencies. Water quality is monitored by São Paulo Environment Agency (CETESB), which also has the mandate for water pollution control. The São Paulo State Sanitation Company (SABESP) is in charge of domestic water supply and wastewater treatment in most of the municipalities of the basin. The Upper Tietê River Basin Committee was established in 1991 and has, among other responsibilities, the task to approve the River Basin Plan and water quality targets. Civil society, NGOs, and the media have played an important role in the creation and implementation of the Tietê River Cleanup Program, described later.

4.2.2 Typical water pollution problem, causes and impacts

Over the last 50 years, an intense urbanisation process has taken place in Brazil. The population of the São Paulo Metropolitan Region has increased sevenfold since 1950 and its growth was not followed by a proportionate increase in domestic wastewater treatment levels. The intense industrialisation process that occurred during that period also contributed to the increase of water pollution. The location of the São Paulo Metropolitan Region on the upstream reaches of the Tietê River is also an important factor, since the relatively low river discharge here affords only a low dilution capacity for pollutants.

In the 1950s, fishing, rowing, and swimming were important activities at the Tietê River and many clubs were created along the river, some of which still exist. However, since 1972 the high pollution levels in the river have discouraged these activities.

High concentrations of BOD, phosphorus, ammonia-nitrogen, pathogenic microorganisms, and toxic chemicals are observed in the Upper Tietê River, indicating the high contribution of domestic and industrial wastewater (CETESB, 2014). The total domestic organic load in the river is 635 ton BOD/day. The industrial organic load is 26.4 ton BOD/day and the industrial inorganic load is 307 kg BOD/day (FUSP, 2009).

Because of the high BOD loads, the section of the Tietê River that runs through the São Paulo Metropolitan Region frequently has dissolved oxygen concentrations below 2 mg/l, and many tributaries have values close to 0 mg/l. Fish surveys carried out in the river showed a significant reduction of fish diversity as the river flows into the urban areas, and a complete absence of fish when it flows through the city of São Paulo (Barrella & Petrere, 2003).

The uncontrolled growth of the São Paulo Metropolitan Region around two major reservoirs (Billings and Guarapiranga) has degraded water quality because of the release of sewage, garbage, and diffuse pollution. The eutrophication of these reservoirs is a concern for public water supply, requiring the use of algicides to control the high levels of algae, and increasing the costs of water treatment.

Irrigation with polluted water is also a concern on farms because of the contamination of farm produce. Pinheiros River, a tributary of Tietê River, is a large urban breeding ground of mosquitoes. Insecticides are applied in the river margins to eliminate mosquitoes and other vectors, and traces of these insecticides were found on the waters of Pinheiros River (Cunha et al. 2011).

The São Paulo Metropolitan Region is affected by the heat island effect that contributes to the formation of convective storms of high intensity, causing floods in small urban watersheds and extensive runoff that contributes to a significant pollution load. Downstream of the São Paulo Metropolitan Region water pollution causes the formation of excessive foams from detergents, the accumulation of debris, and unpleasant odours.

4.2.3 Solutions and transferable lessons

In the late 1980s, NGOs and the media organized several actions against the Tietê River degradation and a campaign to clean up the river. In 1991, a petition calling on the State government to clean-up the Tietê River was signed by 1.2 million people and in 1992 the São Paulo State Government launched the Tietê River Cleanup Program. The programme is funded through loans from the InterAmerican Development Bank and Brazilian Development Bank, and from resources of the SABESP. The programme includes the construction of new wastewater treatment plants, expansion of existing plants, construction of sewer collection networks, and the control of industrial pollution.

The programme was divided into three phases with a total investment of US$ 3.6 billion. The programme is currently in its third phase, and will finish in 2016. A fourth phase is planned with a total investment of US$ 1.9 billion and the goal to universalise the collection and treatment of sewage in areas attended by the SABESP.

Since 1992, the level of sewage treatment of domestic wastewater has increased significantly from 24 to 84 per cent (Figure 4.3). Sewage collection has increased from 70 to 87 per cent. The expansion of sewage collection networks in poor regions has been a challenge, as some households were unconnected to sewers because people were unable to pay. In these cases, the State government decided to pay for these connections.

With regards to industrial pollution, the CETESB identified 1,250 companies in 1992 that were responsible for 90 per cent of the industrial pollution of the Tietê River. These companies were asked to submit plans for constructing treatment systems and were supported through loans from the World Bank and the Brazilian Development Bank (BNDES). The financing of these plans and imposing of fines between 1992 and 2008 led to a 93 per cent reduction of the industrial organic load and a 94 per cent reduction of its inorganic load (CETESB, 2008).

The main result of the increase in the treatment of domestic sewage and industrial effluents was a decrease of the downstream river reach impacted by pollution. In 1992, a total length of 260 km was affected downstream of the São Paulo Metropolitan Region. In 2014, this was reduced to 100 km. These improvements contributed to the return of fish at some locations and the reduction of unpleasant odours.

Despite the improvement in water quality downstream, the river in the São Paulo Metropolitan Region is still highly polluted. The recovery of the Tietê River is a long process that will need continuous investments over the next years. The Tietê River Cleanup Programme is the largest river cleanup project in the country and shows the importance of public participation and the provision of financing mechanisms.

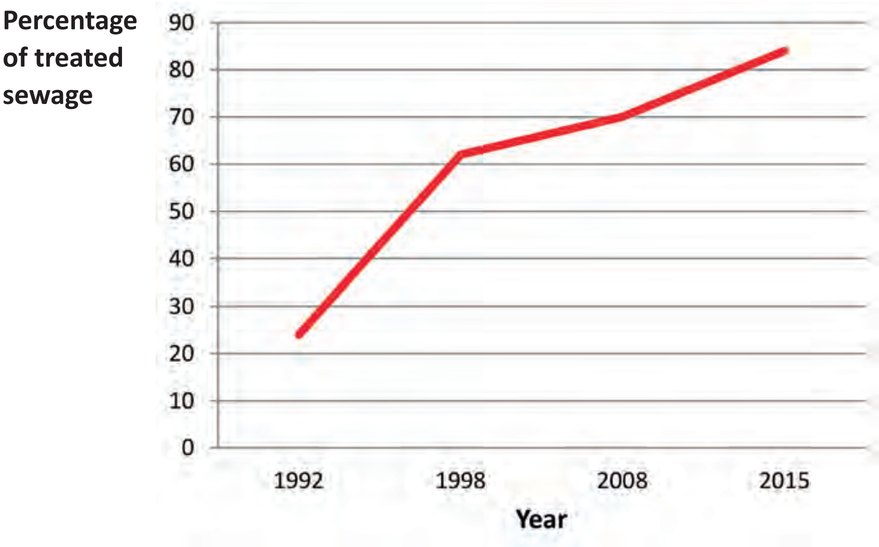


Figure 4.3: Trend in percentage of domestic sewage treated in the Upper Tietê River Basin (SABESP, 2014).

4.3 River Basin 2 – Godavari

In the Godavari river basin, discharge of untreated and partially treated sewage from cities is one of the principal reasons for the river's non-compliance with Indian water quality criteria. A Location Importance Index (LII) has been developed to assess the extent and severity of violations of water quality standards. A High LII indicates frequent pollution stress and thus a need for conducting a detailed pollution inventory and expanding water quality monitoring.

4.3.1 Brief overview of Godavari Basin characteristics and governance

The Godavari River is the second longest river in India and it has the third largest river basin in the country. Godavari originates from Trayambakeshwar in Maharashtra and then flows for about 1,465 km in a generally south-eastern direction before emptying into the Bay of Bengal. The catchment basin area of the river is 312,812 km^2 with agricultural land and forest as the main land use categories in 2005-06 (60 per cent and 30 per cent of the catchment area, respectively) (CPCB India, 2011). Despite its massive catchment area, the river's discharge is not substantial because of the low average annual rainfall in the basin. Its four important tributaries are the Manjira, the Pranhita, the Indravati and the Sabari.

Water is a State subject in India, i.e. the State is responsible for the management of water resources. Responsibilities for water management are shared between the State Pollution Control Boards (responsible for surface and groundwater quality and industrial discharges), the State Groundwater Boards (responsible for ground water estimation, qualitative and quantitative studying and approval of groundwater abstraction), the State Water Resources/Irrigation Departments (responsible for the approval of surface water withdrawal from river systems), and the Urban Local Bodies (responsible for water withdrawal from surface/groundwater bodies, treatment and supply, and treatment of sewage). There is only a modest amount of information sharing and/or cooperation between these agencies (Central Water Commission, 2012).

4.3.2 Typical water pollution problems, causes and impacts

At several locations, the water quality of the Godavari River does not meet the required criteria for Class A ("Drinking Water Source without conventional treatment but after disinfection") including for the parameter biochemical oxygen demand (BOD). Figure 4.5 summarizes the long term trend of BOD from several monitoring stations in the river. While there is a variation in the peaks, mean BOD levels are more or less constant.

Figure 4.4: The Godavari Basin extends across the States of Maharashtra, Karnakata, and Andhra Pradesh.

Discharge of untreated and partially treated sewage from cities is one of the principal reasons for the non-compliance. The sources of water pollution include (a) domestic sewage, (b) industrial effluent, and (c) agricultural non-point sources. The population density in the basin ranges from 25–50 persons/km^2 to 500–1,000 persons/km^2. More than 441 towns, 58,072 settlements and 33 cities are located in the basin area. The population of the basin, based on a 2001 census, was 60.57 million, out of which about 75 per cent live in rural and the other 25 per cent in urban areas. Nearly 40 per cent of the workforce is engaged in cultivation, 30 per cent as agriculture labourers, and 30 per cent in mining and manufacturing and other industries (Central Water Commission, 2012). In the absence of a detailed effluent inventory, the sewage load entering the Godavari is calculated based on certain assumptions. Assuming approximately 80 litres of sewage generation per person in urban areas and approximately 50 litres sewage in rural regions, the volume of raw sewage entering Godavari will be approximately 3,000 million litres per day. Further assuming an average BOD concentration of 200 mg/l and an average treatment capacity of 40 per cent, the total BOD load can be estimated at 219,000 t/yr. This would correspond to an average BOD intensity of 409 kg/km/day of river length.

No direct estimate of effluent generation in the Godavari basin or effluent entering the Godavari has been made or is available in literature. In Andhra Pradesh (situated in the lower Godavari basin), sugar and distillery units are large in number in addition to pulp & paper and fertiliser companies. These industries are likely to be massive water consumers and contributors to the deterioration in water quality in the river particularly from Nashik to Nanded in Maharashtra and at Baster in Chhattisgarh and Burgampahad in Andhra Pradesh (CPCB India, 2011).

Pollution due to the runoff of chemical fertilisers is also likely to be a problem. The average annual use of chemical fertilisers in the basin area is 49.34 kg/ha which is more than twice the national average. The total consumption of pesticides is 21,586 t/yr.

4.3.3 Solutions and transferable lessons

In the Godavari basin, there are 34 water quality monitoring stations spread across the States of Maharashtra and Andhra Pradesh. The Water Quality Index (WQI, Abbasi & Abbasi, 2012) is used as a single parameter to (a) communicate water quality to stakeholders and (b) compare water quality across locations over time. CPCB in India has adopted the WQI from the index developed by National Sanitation Foundation (NSF) USA. CPCB's WQI uses parameters such as BOD, DO, faecal coliform bacteria (FC), and pH. The WQI used so far is based on concentrations and does not account for the adequacy of river flow for diluting wastes and supporting the aquatic ecosystem. It would be useful, therefore, to introduce minimum "environmental flows" as an additional benchmark for tracking the health of the Godavari.

As assessment of compliance is one of the key objectives of the water quality monitoring program, it is useful to develop metrics to prioritise the monitoring

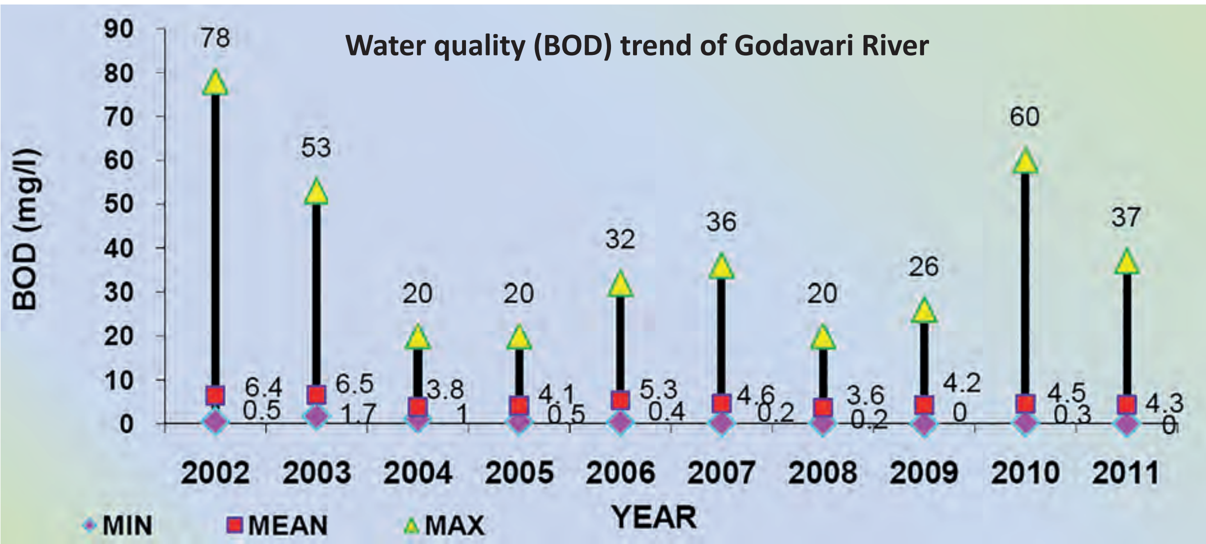


Figure 4.5: Water quality (BOD) trend between 2002 to 2011 in the Godavari River (CPCB India, 2011).

locations. To achieve this objective, a new Index called Location Importance Index (LII) was developed. The LII is a measure to assess the extent (frequency), severity (magnitude) of violations and how contiguous the violations are in relation to standards. To calculate LII, monthly BOD and DO observations from 18 water quality monitoring stations in the State of Maharashtra are used. High LII values, e.g. in the stretch downstream of the city of Nasik, indicate frequent pollution stress and thus a need for conducting a detailed pollution inventory and initiating water quality control measures. Further, these stretches are ideal for the placement of automated water quality monitoring stations. These measures have been recommended to the Maharashtra Pollution Control Board.

There is a need for conducting comprehensive impact assessment going beyond the assessment of in-stream water quality. Such an assessment should cover the entire river basin ecosystem. For a holistic impact assessment, parameters such as water use (domestic, industrial agricultural) non-point pollution loads, agricultural yield, public health indicators, groundwater quality, ground water levels, biodiversity, and top soil contamination should be considered including climate change related vulnerability.

4.4 River Basin 3 – Volta

The resources of the Volta River basin of West Africa are essential to the livelihoods of the predominantly rural communities that inhabit it. Due to limited sanitation infrastructure, faecal coliform contamination has already deteriorated water quality in parts of the basin and this will continue to escalate with increasing population and urbanisation. Transboundary management structures, participatory processes and other innovative solutions are suggested as short and medium term remedies.

4.4.1 Brief overview of Volta Basin characteristics and governance

The Volta River basin has a rich network of diverse ecosystems that provide a wide range of natural resources for its six riparian countries. These resources directly and indirectly support the livelihoods and economic development of its current population of over 20 million. With populations projected to reach 33 million by 2025 and with increasing variability and changes in weather patterns in the basin (Oyebande and Odunuga, 2010), the sustainability of basin resources, especially water (McCartney et al., 2012), is under severe and increasing threat.

The creation of the Volta Basin Authority (VBA) in 2006 and the Convention on the Status of the Volta River and the Establishment of the Volta Basin Authority (signed in 2007, ratified by the six countries in the period 2008-2009) is a transboundary approach towards coordinated management of the basin's resources. The VBA has overall responsibility for implementing an international cooperation for the sustainable management of water resources and promoting better sub-regional economic integration (VBA, 2010). In addition to the VBA mandate, the management of the Volta Basin is characterised by a number of international, regional and national bureaucratic structures, such as ratification of various international conventions, membership in the Economic Community Of West African States ECOWAS, as well as the West African Economic and Monetary Union (Ghana excepted). Traditional management systems are also important, even though the complexities between modern and customary systems can sometimes lead to conflicts (UNEP-GEF Volta Project, 2013).

Brief facts about the Volta River Basin (Source: UNEP-GEF Volta Project, 2013):

- *Situated in the sub-humid to semi-arid West African Savannah Zone and covering 28% (400,000 km^2) of West Africa;*
- *Shared by: Benin (4.1%), Burkina Faso (46%), Ghana (39%), Côte d'Ivoire (1.8%), Mali (2.4%), and Togo (6.4%);*
- *Drained by 4 sub-basins: the Black and White Voltas (from Burkina Faso), Oti River (Benin), the Lower Volta (Ghana), and emptying into the Gulf of Guinea;*
- *The Volta Lake in the Lower Volta, created in 1965 by the construction of the Akosombo Dam for hydropower is the 2nd largest man-made lake by surface area (8,500 km^2) in the world;*
- *Precipitation varies between 1,600 mm (south) and 360 mm (north);*

- *Annual runoff is 56.4 billion m^3;*
- *Population density: 72/km^2 in 2010; 83/km^2 in 2015; >100 inhabitants per km^2 by 2025;*
- *Main livelihoods: agriculture (extensive and mostly rainfed), livestock production, fisheries, forestry, and hunting and gathering.*

4.4.2 Typical water pollution problem, causes and impacts

Available data indicates that severe water quality deterioration is not widespread in the Volta Basin. Significant localised problems are more prevalent in the densely populated northern towns which have lower hydrological flows than the south, where the higher flows dilute pollutants (UNEP-GEF Volta Project, 2013). Although requiring more extensive and long-term datasets to be conclusive, reports of surface water quality in the basin indicate generally good water quality (e.g., Andah et al, 2003; Goes, 2005; WRC, 2008) with low average nutrient levels, especially in the Volta Lake (van Zweiten et al., 2011). High nutrient loads from agricultural sources occur in specific locations such as cotton, sugar cane, or commercial oil palm plantations (Programme GIRE Burkina Faso, 2001; Samah, 2012) or from markets (Ofori, 2012), and, to a lesser extent, localised industrial pollution from beverage and textile production (Gampson et al., 2014). Faecal coliform levels are, however, consistently above WHO guidelines for drinking water (e.g., Kankam-Yeboah & Opoku-Duah, 2000; UNEP-GEF Volta Project, 2013). Samah (2012) reports levels between 121±32 cfu/100 ml and 425±181 cfu/100 ml in the Asukawkaw River for March-June 2012 that contributes about 40 per cent to the total volume of the Volta Lake.

The presence of faecal coliform bacteria in the basin have been attributed to increasing domestic inputs from discharge of waste, untreated sewage, and open defecation along the banks of the Volta River by both humans and grazing animals, including in some areas, large flocks of migratory birds (Abdul-Razak et al., 2009). In most parts of the basin, a major economic activity is the extensive production of livestock at high densities (although this tends to decrease from the north at 10 to 20 animals per km^2 to the south at 1 to 5 animals per km^2), which has impacts on water quality (UNEP-GEF Volta Project, 2013). In Mali and Burkina Faso, surface water quality is poor with numerous coliform and bacillus bacteria. In the Sourou Valley of Burkina Faso, shallow wells that are a preferred source of drinking water are highly polluted with coliforms exceeding 1x103 cfu/100 ml for E. coli and 1x104 cfu/100 ml for faecal coliforms (Boubacar et al., 2013). In Burkina Faso and northern Ghana, run-off from inland port communities and urban settlements near river banks and reservoirs also significantly affect water quality.

Rural households in the basin mainly depend on individual or communal latrines or defecate openly in nearby bushes or river banks. In urban areas, the sewerage systems are only able to service a small portion of the population and, as a result, untreated sewage is discharged directly into the environment in a number of larger cities such as Ouagadougou, Bobo Dioulasso, and Abidjan. In Ghana, national assessments identified 70 decentralised wastewater and faecal sludge treatment plants serving less than 10 per cent of the urban wastewater volume, and of these, only 13 per cent were still operating (Murray & Dreschel, 2011). In studies assessing the quality of effluent into the Volta River, an effective reduction of BOD concentrations and total removal of coliform (99.99 per cent) was shown in one study (Hodgson, 2007), whilst another showed that, although the treatment performance of two treatment facilities significantly reduced coliform by 95 per cent, the final effluent still did not meet the Ghana EPA standards and required final disinfection (Kagya, 2011).

The concentration of FC can be influenced by seasonal changes, with high contamination levels at the onset of heavy rains where runoff carries raw sewage and leachate from waste dumping sites into the water bodies. The construction of small, medium and large reservoirs in the basin, primarily used for irrigation, the anticipated rainfall variability and the decrease in average annual basin flow of approximately 24 per cent and 45 per cent by 2050 and 2100, respectively (McCartney et al., 2012; Sood et al., 2013), will have serious hydrological and health implications due to lower dilution flows and increased pollutant concentrations.

The faecal contamination of water in the Volta basin has important implications for urban and rural water supply. The Volta Lake, for example, is a water reservoir for large cities such as Akosombo; and rural communities depend directly on the surface water as they tend to have less access than urban communities to potable water from boreholes, pumps, or piped water taps. Burkina Faso and Ghana have a largely rural population. So, only 37 per cent (in Burkina Faso) to 62 per cent (Ghana) of households have access to safe drinking water (Rodgers et al., 2007). Even where there is access, a large number of people still prefer and continue to use untreated water from the river due to quality perceptions and opportunity costs (Engel et al., 2005).

As a result, waterborne diseases are a threat to the rural communities, with a significant contribution to the 2012 mortality rates of children aged less than 5 years in Benin (10 per cent), Burkina Faso (11 per cent), Ghana (7 per cent), Côte d'Ivoire (10 per cent), Mali (12 per cent), and Togo (9 per cent) (WHO, 2014a). Contaminated water also has implications for aquatic organisms such as clams, a common and inexpensive source of protein and livelihood for the communities at the Volta estuary. Adjei-Boateng et al. (2009) and Amoah et al. (2011) found that the clam *Galatea paradoxa* in these areas was highly contaminated with FCs, due to its capacity to accumulate up to five times the bacterial load in the surrounding water, through its filter feeding activities. The evidence of high microbial contamination of fish caught in polluted waters (Kombat et al., 2013), making it unsafe or undesirable to eat, shows that there are potential impacts to the health and livelihoods of the local communities.

Water contamination by FCs is compounded by poor awareness and education about public health, inappropriate technologies for sanitation, both in urban and rural areas, lack of effective and coordinated legal systems for controlling the discharge of effluents and lack of financial resources. The capacity to address such issues is challenged both at the regional and national levels by (i) limited research and technical capacity, (ii) inadequate implementation of regulations, (iii) complexities of ecosystems and poverty, (iv) the language barrier between Anglophone and Francophone countries, and (v) lack of effective and operational institutional and legislative mechanisms to ensure basin wide action, as well as other factors. However, there are still a number of opportunities and transferable lessons in terms of governance, information flow and technological solutions, which can be used for integrated water quality improvements.

4.4.3 Solutions and transferable lessons

The advantage of having the VBA as a management structure is the regional recognition and respect that it has, which allows for access and collaboration with reputable international and national institutions, projects and programmes. Existing networks of institutions can be enhanced, or new networks created, to enable the development and implementation of both regional and national management solutions. The independent development of national strategies by individual countries is less efficient than a comprehensive regional strategy. However, as this will require time and funds, the sharing of best practices by the countries is needed at this time. A database of related information generated through regional, cross-basin, and national research can support this process. A harmonised method of water quality monitoring techniques, including faecal source tracking, can also provide important information required for evidence-based decision making.

The VBA also encourages countries to financially support improved sanitation and water pollution control. This includes increasing the technical and institutional capacity to collect and interpret relevant data, formulate policy, and implement strategies. Integrated water resources management requires participatory frameworks and processes at all levels to succeed. Institutions from government, civil society (including traditional authorities), academia, and the private sector need multi-stakeholder platforms to communicate, support each other, and coordinate activities. At the local level, community engagement, especially by beneficiaries, and the use of indigenous knowledge, where appropriate, will lead to acceptance and success. The appreciation of gendered roles in water use and sanitation is also essential in the development of management strategies (e.g., Peter, 2006; Figueiredo and Perkins, 2013).

Currently, solutions for effective water management in the Volta Basin tend to focus on strategies for improving sanitation and the provision of safe drinking water. These strategies are applied in addition to traditional wastewater treatment systems at community and household levels for reducing pathogen loading into the environment. Potential innovative on-site technologies, such as anaerobic digestion and biogas generation (Avery et al., 2014), the application of low-tech options using locally available biomaterials, or ecosanitation, where urine and faecal matter are separated to recover nutrients (Mihelcic et al., 2011); could also be explored.

A range of small scale water treatment technologies, from low cost chlorine disinfection systems to more expensive reverse osmosis systems, appropriate storage of water and improved hygiene are required to minimise the potential health impacts of drinking contaminated water. Local ingenuity and simple mechanisms also improve access to safe drinking water; for example, the SODIS method of placing clear bottles filled with water on a piece of metal in full sunlight for a number of hours kills off all microbes (McGuigan et al., 2012). However, local ownership of both the technology development and the treatment system used is an essential element of its success. Demand-driven water treatment systems are far more sustainable than those which are eventually abandoned because community members were not aware of the full capital and operational costs from the start (Rossiter et al., 2010).

In addition to the numerous opportunities for addressing water quality issues of the Volta Basin, promoting community and household level solutions has far-reaching impacts in protecting the health of humans and the ecosystem. Education and awareness creation processes are, therefore, required to build knowledge and gain support, place pressure on local governments to change policy, and enhance enforcement practices in order to support larger scale basin management planning (Palaniappan et al., 2010).

Figure 4.6: Map of Volta basin

4.5 River Basin 4 – Chao Phraya

The Chao Phraya River is considered the lifeblood of Thailand. The river supports 13 million people and is used in a variety of ways, including for drinking water, irrigation, and as the primary water source for the Tha Chin River. Under low to average water conditions, domestic, agricultural, and industrial discharges are greater than the river's capacity for self-purification. The main source of water pollution is untreated wastewater from domestic sources. Existing wastewater treatment plants service only limited areas. Therefore, the construction of new wastewater treatment plants is suggested in order to improve water quality. Moreover, community involvement, through means such as water conservation and waste minimisation programs in Pathum Thani and Nonthaburi, are essential to the success of water quality programmes.

4.5.1 Brief overview of Chao Phraya Basin characteristics and governance

The Chao Phraya River basin is located between latitude 12 01' to 19 45'N and longitude 98 10' to 101 30'E. It covers ca. 160,000 km^2, representing 30 per cent of the country's total area, and 57 per cent of its population. The upper region of Chao Phraya basin is mountainous with agriculturally productive valleys and the lower region contains alluvial plains that are highly productive for agriculture.

The Chao Phraya River basin consists of the upper four tributaries of Ping, Wang, Yom, and Nan; the lower two tributaries of Pasak and Sakae Krang; and the delta of Chao Phraya and Tha Chin (Paramee, 2003). The region is dominated by the monsoon, with a rainy season lasting from May to October and supplementary rain from occasional westward storm depressions originating in the Pacific. The annual precipitation is 1,179 mm with an annual discharge of 196 m3/s. There are two large dams in the Chao Phraya River basin: Bumiphol and Sirikit which control the runoff from 22 per cent of the basin. The whole basin is rich in biodiversity and contains extensive areas of rainforest. The lower part of the basin has extensive irrigation networks, enhancing intensive rice paddy cultivation. However, in recent years, human intervention has been increasing in forest areas resulting in the conversion of forest to agricultural land.

About half of the population of the Chao Phraya River basin is living in the Bangkok Metropolitan Area (BMA) and parts of Samut Prakan, Nonthaburi and Pathumthani. Bangkok and its vicinity has the highest population density with 1,497 inhabitants/km^2. Similarly, the upper Ping River Basin also consists of areas with a highly concentrated population. Increasing human settlement and changes in land cover have caused degradation of water quality, increased frequency of flash floods, erosion and landslides.

Various agencies are responsible for water governance in the Chao Phraya River basin. The Electricity Generating Authority, Thailand (EGAT) controls the water release from the two main reservoirs in the basin and the Royal Irrigation Department (RID) regularly monitors the water level at the lower reach of Chao Phraya at the Chainat diversion dam. The Pollution Control Department (PCD) monitors the water quality of the Chao Phraya Delta. In the Thachin river basin, several environmental agencies and provincial and local governments have been developing policies and action plans to manage and improve water quality.

4.5.2 Typical water pollution problem, causes and impacts

The lower reaches of Chao Phraya River basin are considered to be the most polluted of the basin, and the Tha Chin River one of the most polluted rivers in Thailand. According to the routine water quality monitoring by the PCD, the lower reaches of Chao Phraya and Tha Chin have not met National Surface Water Quality Standards since the 1990s. Based on the 2009 Annual Report on Water Quality Management by PCD, the overall water quality in Thailand has declined significantly during the past 10 years. According to the 2009–2013 water quality index (WQI) data, Bangkok (the Chao Phraya River) has the poorest water quality as shown in Figure 4.8.

Figure 4.7: Map of Chao Phraya basin.

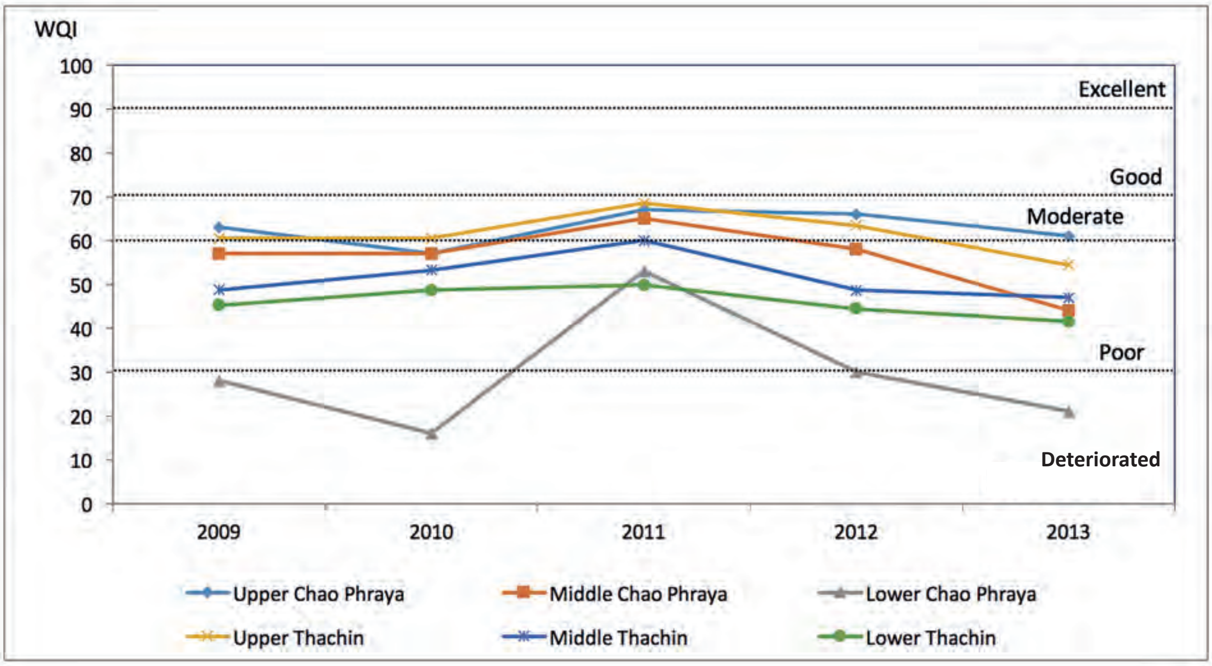


Figure 4.8: Trends of water quality in the Chao Phraya and Tha chin Rivers from 2009 to 2013 (PCD, 2013).

The concentrations of selected water quality parameters in the Upper, Central, and Lower Chao Phraya River and Tha Chin River for the year 2013 illustrate this gradient (Table C.1, Annex C). The parameters indicating poor water quality in the dry season are faecal and total coliform bacteria (FC and TC), NH_3-N, and BOD, whereas those in the rainy season are FC, TC, and NH_3-N. Municipal waste and industrial effluents result in low DO levels and high BOD levels in the lower Chao Phraya and Tha Chin River basins. Industrial wastes contribute to low DO levels below the water quality standard (Kunacheva et al., 2011). The surrounding agricultural areas also contribute to a high amount of NH_3-N and derivatives in the basins. The levels of TC and FC, which reflect the sanitary quality of the river, are degrading because of the discharge of human and animal wastes into the river (Campos & Cachola, 2007).

The major issues of water quality are low levels of DO, frequently below 3 mg/l, high organic matter (BOD), and high FC (Simachaya 2003). Land-based BOD loading into the Upper Gulf of Thailand has increased from 207 t/day in the 1990s to 1144 t/day in the 2000s (PCD, 1997). Total nitrogen loading from the Delta, Chao Phraya and Tha Chin River contributes up to 116,000 t/yr to the Upper Gulf of Thailand (Leelapanang, 2010). As a result, the estuary in the Upper Gulf of Thailand has frequently experienced algal blooms; red tides occurred 18 times at the river mouth during the year 2008 (MCRC, 2009). The Chao Phraya River exhibits serious organic pollution which threatens many species of aquatic life. Similarly, water quality in the Tha Chin River is heavily degraded, due to the combined discharges of industrial, domestic and rural effluents.

In general, the basin is entering a critical period in which small changes in hydrologic conditions can create large socio-economic disturbances. In recent years, land use in the Chao Phraya and Tha Chin River basins has been changing from agricultural to urban and industrial. Due to the increase in population, it is unavoidable that new settlements will be built in areas where water management is difficult. Human impact on water resources, and vice versa, is visible throughout the basin. Native plants acting as surface cover on native land are being destroyed at a rapid pace, causing flash floods, erosion, and landslides. The construction of dams and diversions requires the resettlement of people, usually to unclaimed and infertile areas. In the lower part of the basin where intensive irrigation networks exist, rice is cultivated year-round. Thirty years ago, the same area had a single annual rice harvest. Since then, the number has doubled, then tripled, and today there is continuous cultivation. Clearly, the land is heavily used, with no time for revitalisation.

4.5.3 Solutions and transferable lessons

The National Policy regarding water quality is stipulated in both the National Economic and Social Development Plan and in the National Policy and Plan for Natural

Resources and Environment Management, which set long-term (twenty-year) goals, standards and strategies. In the Eighth Plan, the national goal was to maintain the quality of surface water at the 1996 level (UNESCO, 2003).

The maintenance of river integrity is based on maintaining minimum stream discharges to repel salt-water intrusion in the lower reaches of rivers, dilute pollutants and maintain minimum dissolved oxygen levels to ensure that the quality of the aquatic environment does not fall below acceptable levels. A minimum flow of 16 m^3/s is currently considered sufficient in the lower reaches of the Chao Phraya River to repel salinity intrusion. Pollution control is more problematic. Most of the wastewater discharges of domestic and industrial origin have increasingly been controlled and mitigated through the enforcement of separate effluent standards by various regulating governmental agencies. In addition, the regulation of streamflow in the Chao Phraya River by releases from upstream reservoirs operated by EGAT (Electricity Generating Authority of Thailand) and RID (Royal Irrigation Department) can to some extent improve the poor downstream water quality during the dry season. Allocation of basin water supplies must take into account these needs (Pattanee, 2005).

Thailand has developed master plans of water quality management for major river basins including the Chao Phraya. Construction of wastewater treatment facilities in municipalities is prioritised and recommended as well as a control of wastewater from industrial and agricultural sources. The government has "mobile land doctor units" helping farmers to diagnose and remedy land degradation problems. Charging fees for waste discharges is also being studied and will be applied to many sites in the near future. Four municipalities apply the Polluter-Pays-Principle for wastewater treatment plants and a few more are working towards this policy. Water quality models and geographic information system (GIS) have also been developed and used as tools to help decision-makers in water quality management (Pattanee, 2005).

4.6 River Basin 5 – Setting resource quality objectives for the Vaal River

The Vaal River drains what is effectively the economic hub of Africa, the city of Johannesburg in South Africa. This city was built in the late 1800s and 1900s as a mining city and has innumerable mines dotted around the city, with thousands of kilometres of tunnels beneath the city streets. As mines have been depleted and closed across the Upper Vaal basin, groundwater has risen bringing with it toxic acid mine water which decants onto the surface and into the rivers. Operational mines also pump to void mine water, which also enters the surface water resource. Despite many initiatives to mitigate this issue, even by treatment of the mine water and an active programme to dilute the salinity using inter-basin transfers of cleaner water, the net result is a salinity problem in the rivers downstream. Recent management interventions include the setting of Resource Quality Objectives (RQOs) for the river downstream that are codified in law and become objectives for management action. This study provides an example of how water quality monitoring can be translated into management objectives.

4.6.1 Brief overview of Vaal Basin characteristics and governance

The Vaal River runs through four of South Africa's provinces (Gauteng, Free State, North West, and Mpumalanga), and eventually joins the Orange River which runs into the Atlantic Ocean. This water management area is of major national strategic and economic importance because it hosts economic activity amounting to 20 per cent of South Africa's Gross Domestic Product. It has a catchment area of 197,000 km^2 providing habitation for some 5.6 million people. Water resources in the area have been fully allocated for over three decades, and 54 per cent of water requirements are met through inter-basin transfer schemes primarily from Lesotho via the Lesotho Highlands Water Project, and the Thukela catchment. Owing to such interdependencies between catchments, water infrastructure (numerous dams and inter-basin transfer schemes) is considerable and its management is increasingly key to water supply.

4.6.2 Salinity pollution in the Vaal River, causes and impacts

Poor water quality of surface and groundwater resources is a major issue in the Upper Vaal, both through direct impacts from mining and industry (return flows from mine dewatering) and indirectly from air pollution (coal power stations). The Vaal River Reconciliation study (DWAF, 2009b) identified that salinity (as represented by Total Dissolved Solids, TDS), eutrophication and microbiological water quality are the major water quality issues in the river.

Levels of salinity, as indicated by TDS concentration, are shown in Figure 4.9. The impact of effluent discharges and diffuse sources in the Vaal Barrage catchment is apparent from the substantial increase in TDS concentration between Vaal Dam (VS7) and Vaal Barrage (VS8), where the TDS concentration is 7.3 times greater than natural concentrations (DWAF, 2009a).

The increase in the TDS concentrations from the point VS7 to VS8 is attributable to the highly saline tributaries that drain into the Vaal Barrage but also includes diffuse pollution (DWAF 2009a). The Vaal Barrage sub-catchment is one of the most complex catchments in South Africa. It is highly developed with industries, urban areas and mining activities. In excess of 90 per cent of the dry weather flow is made up of return flow emanating from the respective tributaries. The TDS concentration in the Vaal River levels off at approximately 600 mg/l due to the dilution management rule practiced in the Vaal Barrage, where water from the upstream Vaal Dam is used to dilute and manage the salinity.

4.6.3 Solutions and transferable lessons

The Water Act of 1998 (of South Africa) requires that Resource Quality Objectives (RQOs) be set for all water resources in South Africa, including rivers, wetlands, estuaries, lakes, and groundwater and a procedure was drafted to regulate this process (DWA, 2011). The selection of objectives takes into consideration both, the quantity and quality of water resources, as well as the habitats and biota associated with these water resources. The objectives are selected after the water body is assigned a "management class"; this class is based on the socio-economic and ecological drivers and requirements of the water resource (DWA, 2012). During 2014, the RQO procedure was implemented for the Vaal River, but only the Upper Vaal is described here.

The main steps for determining RQOs are:

1. Delineate resource units (RUs).
2. Prioritise those resource units that have water "issues" (see Figure 4.10).
3. Prioritise those components that would best illustrate these "issues". Components should include quantity, quality, habitat and/or biota.

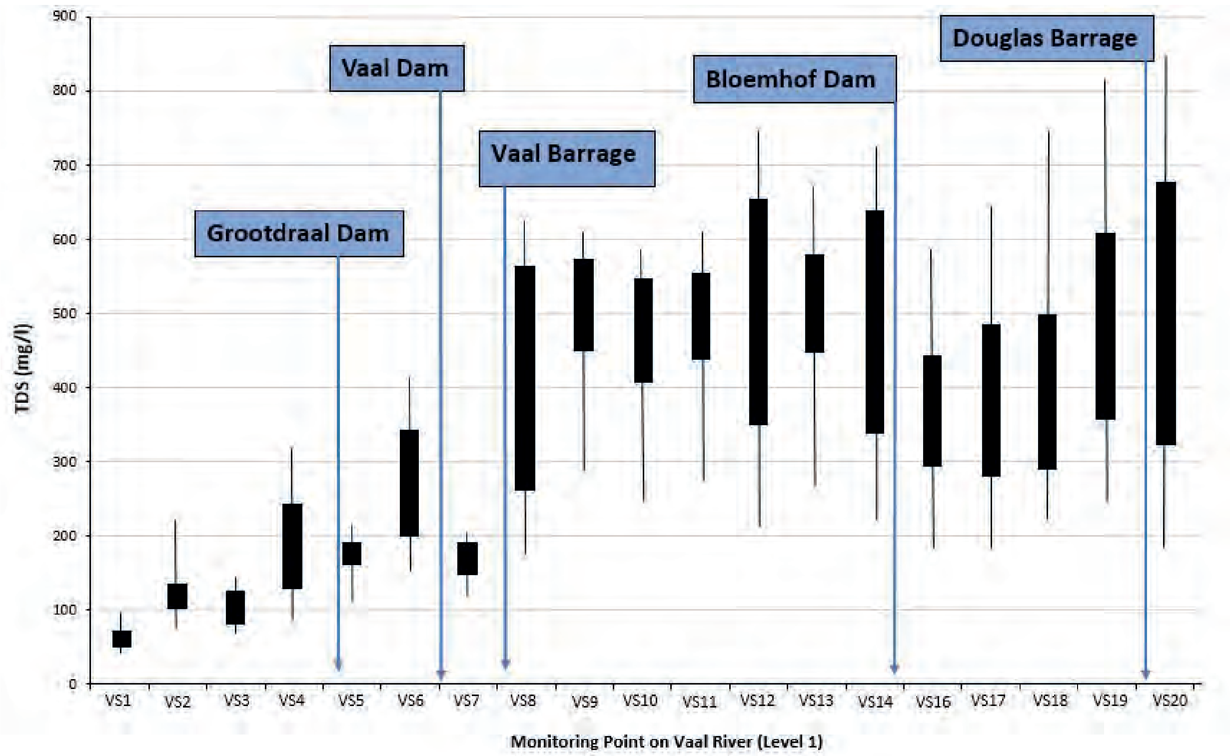


Figure 4.9: TDS concentrations (mg/l) in the Vaal River showing the 5th, 25th, 75th and 95th TDS concentration percentiles (figure redrawn from DWAF 2008).

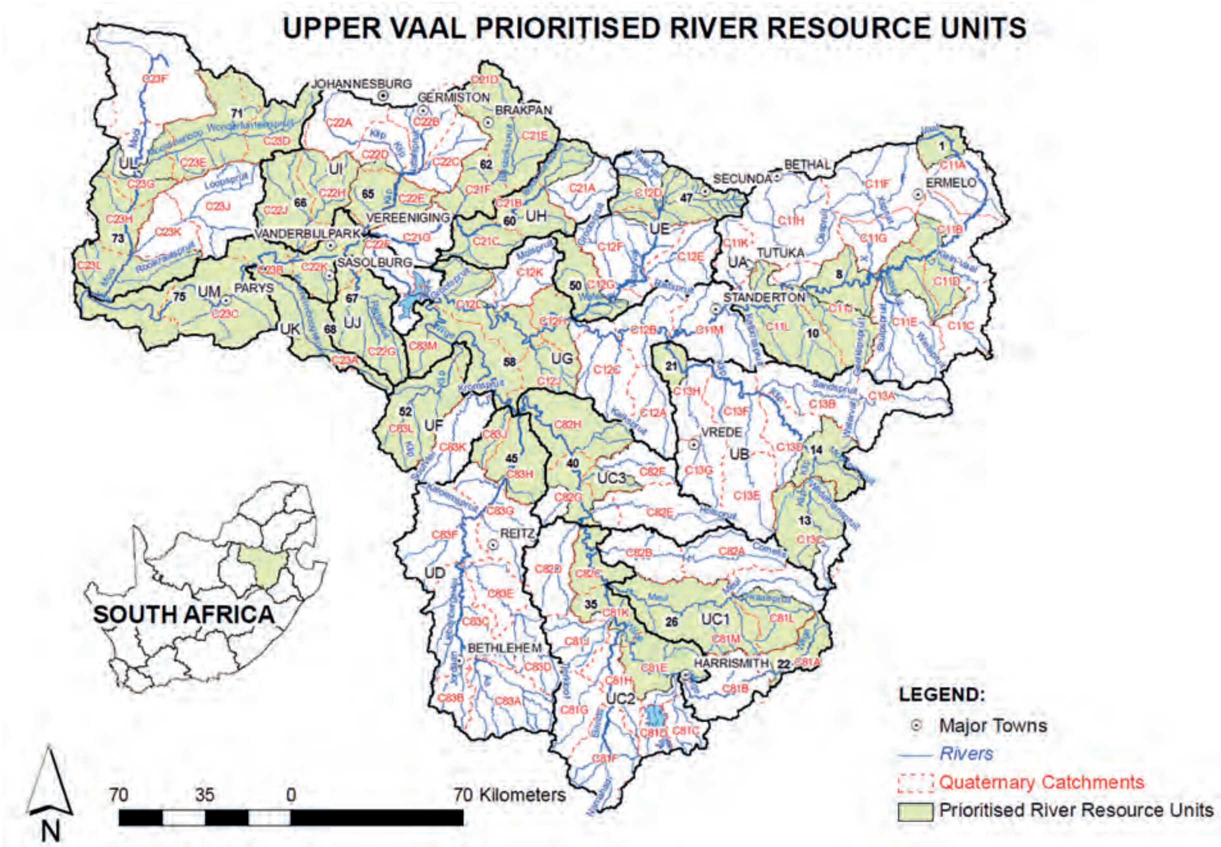


Figure 4.10: Prioritised Resource Units for the Upper Vaal catchment demonstrating the extent of coverage of the legally binding Resource Quality Objectives (DWS, 2014). RQOs are set for each of the indicated Resource Units.

For example, in some areas nutrients may be the driving issue, in others an indicator fish species may be the best indicator of what is happening with the resource, etc.

4. Determine RQOs for each resource unit that would serve to maintain the water resource (quantity, quality, habitat and biota) in a condition that meets the desired Management Class. A key characteristic of the RQO procedure is that the RQOs themselves are essentially narrative and describe the objective in terms that can be accepted by stakeholders. These are then supported by Numerical Limits which are subject to change as knowledge and science improves.

This procedure was implemented for the Upper Vaal (DWS, 2014). While this report documents all of the many issues and the resulting RQOs for the quantity, quality, habitat, and biota for the Upper Vaal (Table C.2, Appendix C), only selected salinity results are illustrated here.

Key features of these RQOs are:

- The RQOs respond to the classification of the water management area (basin) into management classes which addresses both biophysical and socioeconomic needs and influences.
- The RQOs are generally narrative as this allows greater certainty and concordance with stakeholder requirements.
- The RQOs are supported by numerical limits which may be subject to improvement as information and data is added following both monitoring and also developments in understanding.

The RQOs and the numerical limits are gazetted in the Government Gazette and thus become legally binding on all authorities. The Department of Water and Sanitation is required to control sources of pollution and impact so that the RQOs can be met. It does this through a system of Source Directed Controls (licenses).

4.7 River Basin 6 – Medjerda

The Medjerda river basin is the only permanent stream in Tunisia. It originates in the Atlas Mountains of eastern Algeria, crosses Tunisia's Northern region and discharges into the Golf of Utica in the Mediterranean Sea. The continuous increase of pressures on water use in the region for agriculture, industry and urbanisation deteriorate the in-stream and nearshore water quality of the Medjerda significantly. A strategy for joint soil and water conservation measures is needed to identify hot spot and vulnerable areas to reduce sediment loads and their associated impacts. Participative actions for awareness-raising are especially targeting "the new generation" and local population.

4.7.1 Brief overview of Medjerda Basin characteristics and governance

The Medjerda River has an average discharge of 1 billion m^3/yr representing 37 per cent of the total surface water of Tunisia and 22 per cent of the renewable water resources in the country; it provides drinking water, completely or partially, to 60 per cent of the Tunisian population (Jaouadi et al., 2012). The length of the main river basin is about 484 km covering an area of 23,700 km^2, 32 per cent of which is located in Algeria (Figure 4.11). Mean precipitation in the Medjerda river basin ranges from 600–1,000 mm/yr in the north sub-humid region to 300–400 mm/yr in the south semi-arid to arid part of the basin, resulting in an average of about 480 mm/yr. The main economic activity in the basin is agriculture which produces a large fraction of the total national cereal production (70 per cent of the cultivated area). This gives the basin a central role in national food security. As a result, most of the available water in the Medjerda catchment is used for irrigation (80 per cent). Meanwhile, the household and tourist sectors account for 16 per cent of water use, and industry 4 per cent. Several wastewater treatment plants have been serving municipalities near the river since 1994.

A large dam was constructed in 1981 on the main river tributary of the Medjerda following the severe flood of 1973 which saw river discharge reach 3,500 m^3/s. Although the main goal of the Sidi Salem dam is to provide flood protection to downstream inhabitants and agricultural areas, it also makes more irrigation water available to the northern and central parts of the country. In addition, electricity is produced at several hydropower plants using water stored behind the dam. Even though the Sidi Salem reservoir has contributed to the development of the Northern regions (for example, by providing water for expanding irrigated areas), it has also had significant adverse impacts on the natural environment, especially related to the silting of its reservoir. Zahar et al. (2008) reported that the Sidi Salem reservoir has substantially reduced the discharge of the Medjerda, altering the morphology of its cross section, but also reducing the frequency of floods at the downstream part. However, the impact of climate change in the region is thought to have increased the complexity of flood management. Although new guidelines for flood protection have been adopted for the management of the Sidi Salem reservoir, the frequency of flooding remains high and perhaps is even increasing, as indicated by high water events in 2003, 2004, 2005, 2012, and 2015.

Water monitoring in the basin is provided mainly by two agencies: the "Direction Générale des ressources en Eau" (DGRE) for water resources and the Agence Nationale de Protection de l'Environnement" (ANPE) for water quality.

4.7.2 Typical water pollution problem, causes and impacts

Jdid et al. (1999) have reported that water quality in the north-western part of the Medjerda basin is characterised by high heavy metal concentrations, especially arsenic and zinc. The concentration of total dissolved solids (TDS) of surface water is in the range of 0.14–4.2 g/l in most parts of the catchment, except the southwestern part (the Mellègue sub-catchment). Here TDS concentrations reach up to 9.68 g/l during the dry season. Also, an analysis of physico-chemical and bacteriological parameters revealed degradation of water quality: Faecal coliform bacteria reach a concentration of 1,100 cfu/100 ml below the largest cities (such as Jendouba and Beja, Figure 4.11). Also, at some stations nitrogen and phosphorus loads reach values of 330 and 315 kg/day, respectively. From the ecological perspective, measurements of the free-flowing part of the river (Riahi & Ben Thayer, 2008) and the Sidi Salem reservoir (Koumaiti et al. 2010) indicate that the river is mesotrophic.

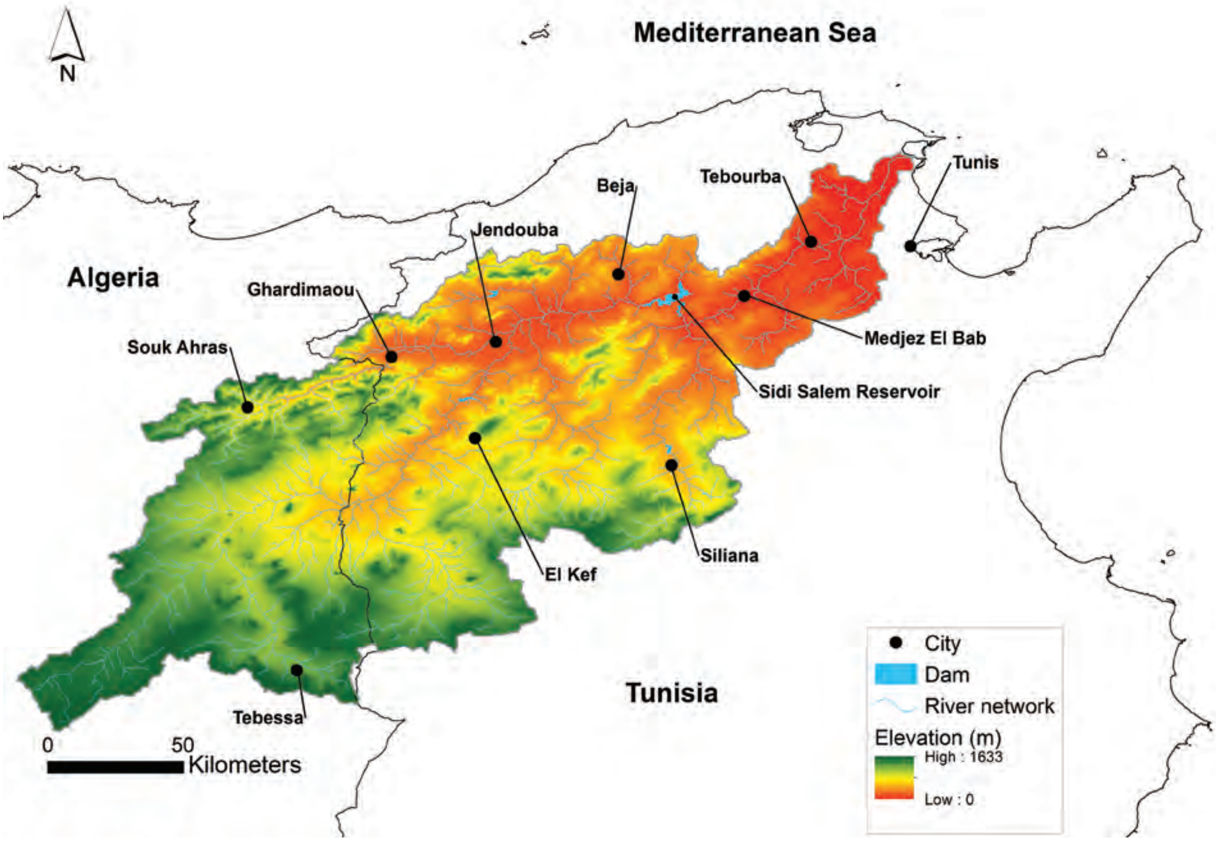


Figure 4.11: The geographical location of the Medjerda catchment and its digital elevation model.

High heavy metal concentrations are caused by leaching from closed mining activities and by the intrinsic geochemistry of the sub-soil, which has high natural concentrations of heavy metals. Bouraoui et al. (2005) have reported that the Medjerda River basin is experiencing an intensification of agriculture and irrigated area is increasing rapidly. In addition to diffuse sources, point sources (e.g., sewage plants) have significantly increased during the last decade. It is estimated that the Medjerda River basin receives 1.27 million m^3/yr of untreated and 12 million m^3/yr of treated wastewater from the sewage systems (DGRE, 2006). The increased use of fertilisers in agriculture during the last decade has also affected shallow aquifers, where nitrate concentrations reach about 300 mg/l near irrigated areas. The catchment is also subject to soil erosion episodes due to heavy rainfall events characteristic of the Mediterranean region. Moreover, it was found that the most severe soil erosion episodes occurred particularly at the beginning of the rainy period (September-October) after a long dry period (hot summer) following the crop harvesting and soil tillage season (Mosbahi et al., 2013).

Agriculture is suspected of being the largest contributor to non-point source pollution. However, its contributions have not been quantified because of the lack of monitoring of in-stream water quality. Also, food industries produce large volumes of wastewater containing high levels of organic pollutants, which affect the aquatic ecosystem of the Medjerda River. Even though many industries have their proper wastewater pre-treatment plant, the lack of maintenance and experienced staff to run these plants means that they do not always operate effectively. An additional threat to the water quality of the river comes from the possible leaching of lead, zinc and other compounds from mine tailings at abandoned mining sites especially in the north-western part of the basin (Mlayah et al. 2009).

Accelerated soil erosion occurred during the last decade due to the increased frequency of flooding and led to siltation in the river. Economic impacts occurred because of losses in soil productivity due to decreases in fertile soil volume, losses of nutrients and organic matter, the need for greater quantities of fertilisers to make up for diminished soil fertility as well as the reduction in the life span of dams and reservoir capacities. Environmental impacts arise from the siltation and increased turbidity of waterways. Environmental impacts are not always restricted to those regions where erosion occurs; high levels of nutrients, associated with erosion of agricultural soils, may be transported to the mouth of the Medjerda River and contribute to coastal eutrophication and possibly hypoxic conditions.

4.7.3 Solutions and transferable lessons

In order to protect the limited resources in the Medjerda catchment, various Tunisian agencies are working together on an ambitious sustainability project. For this, an interdisciplinary framework was established covering environmental, socio-economical and institutional aspects.

Faced with ever-increasing challenges of water resource management in the country, a coherent national water policy is essential. In Tunisia, soils are under serious risk due to long dry periods followed by heavy bursts of intensive rainfall, falling on steep slopes with fragile soils and low vegetation cover. The dams in the Medjerda basin are threatened by siltation. Thus, a strategy for soil and water conservation measures is needed to identify hot spot and vulnerable areas to reduce sediment loads and their associated impacts. Also, for better water quality assessment in the Medjerda catchment, an innovative high resolution monitoring approach is recommended for the future.

Recently, action has been taken in Tunisia to increase public awareness for water resources management and environmental preservation. The association "Research in Action" (REACT) encourages sustainable development by encouraging an easier transfer of scientific results related to water resources management and environmental preservation to different target groups. REACT has aimed to raise awareness about water issues among the youth of the country through lectures, videos and events focused on sustainable water management, and games related to water sharing.

4.8 River Basin 7 – Elbe

The transboundary Elbe River basin is under pressure from point and diffuse sources that cause increased concentrations of nutrients and other water pollutants. Although nitrogen and phosphorus loads have been steadily decreasing, further measures are needed to achieve a range of environmental objectives. Catchment wide management options are planned in the Elbe River Basin Community, which is an association of ten German federal states.

4.8.1 Brief overview of Elbe characteristics and governance

The Elbe River has its source in Krkonoše Mountains in the Czech Republic and discharges after more than 1,000 km into the North Sea via an estuary that widens up to 15 km. Two-thirds of the catchment area of around 150,000 km² are part of Germany. One-third of the catchment is part of the Czech Republic. Minor areas belong to Austria and Poland. Main confluents are the Vltava in the Czech Republic and the Saale as well the Spree/Havel system in Germany (Figure 4.12). This case study will mainly focus on the water management issues in the German part of the catchment. Within Germany, ten federal states cover areas of between 0.9 per cent (Berlin) and 24.4 per cent (Brandenburg) of the catchment area.

The catchment is characterised by a transitional climate from the humid-oceanic climate of Western Europe to the dry-continental climate of Central and East Europe. Average annual rainfall varies from less than 500 mm in the regions of Thuringia and Saxony-Anhalt to 1,800 mm in the Harz Mountains. The catchment wide average rainfall is 628 mm, which is balanced by an average annual evaporation of 445 mm. Typically, the discharge into the Elbe River is high in late winter and spring due to snow storage and snow melt. However, infrequent flooding may also occur in summer. The average annual discharge at the German-Czech border is 311 m³/s which increases at the catchment outlet to 861 m³/s. Approximately 60 per cent of the German catchment is used for agriculture, nearly 30 per cent is forest land and less than 10 per cent is covered with settlements. The transboundary catchment has about 25 million inhabitants, 75 per cent of them live in the German part. In addition to Berlin and Hamburg, major cities are Leipzig and Dresden (Figure 4.12).

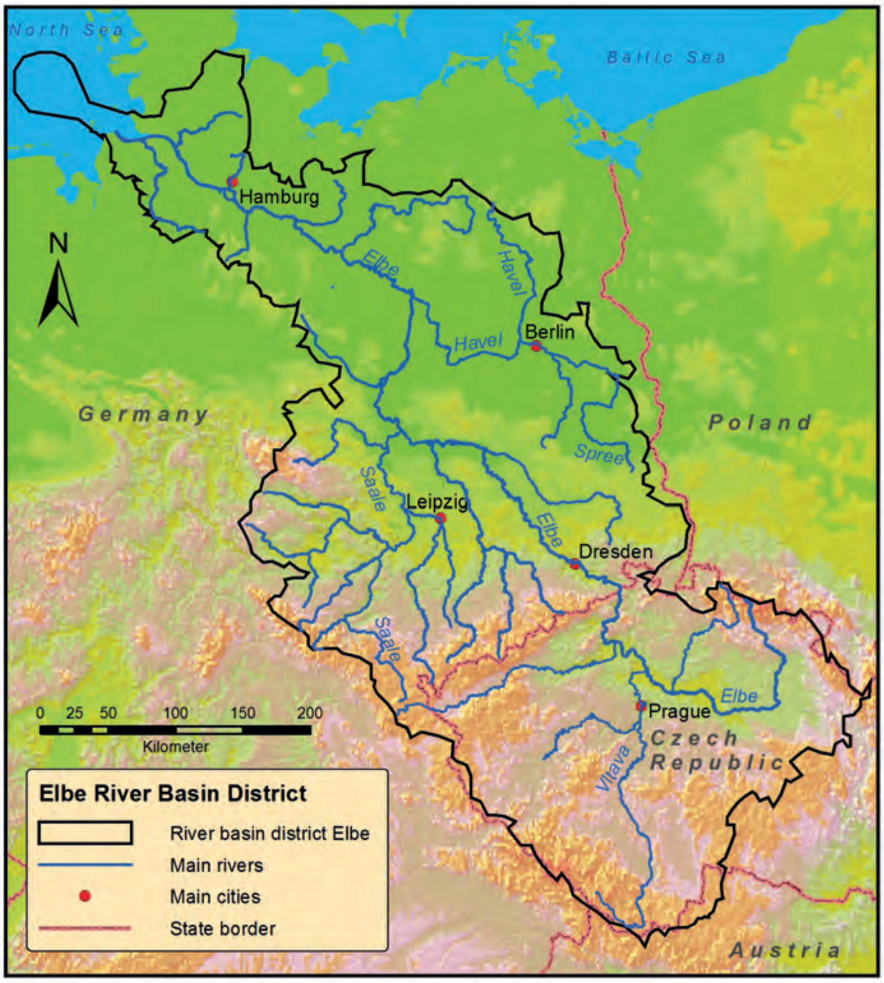


Figure 4.12: Topography of the Elbe River Basin, with its major cities, and the main tributaries of the river.

In 1990, an International Commission for the Protection of the Elbe River was founded. The main objectives of this transboundary organisation are to promote the fair use of river water, especially for municipal users via river bank water extraction and for agricultural water users, while maintaining the health of its aquatic and riparian ecosystems and healthy flora and fauna. The Commission also aims to develop a strategy to decrease the burden imposed on the North Sea ecosystem by the Elbe River basin (IKSE, 1990).

Germany, one of the main riparian nations of the Elbe, has established the Elbe River Basin Community for managing the part of the river basin that crosses German state borders. Members of the Community are the federal government and the ten federal states which share a part of the catchment. The Community mainly focuses on the implementation of the European Water Framework Directive (WFD) and the Floods Directive (FD) (FGG Elbe, 2009). With the exception of Berlin and Hamburg, water management administration in the German states is hierarchically structured on two or three levels. Generally, the supreme authority is a state ministry.

4.8.2 Typical water pollution problems, causes and impacts

In the German part of the Elbe River basin five important management issues are discussed from a catchment wide perspective

- Hydromorphological deterioration and longitudinal continuity
- Contamination with pollutants and nutrients
- Sustainable management of water quantity
- Local impact of mining activities
- Adaption to climate change.

Recent activities mainly focus on the enhancement of hydromorphological conditions and the improvement of fish migration as well as the reduction of contamination by pollutants and nutrients. The latter is also important because of side effects on coastal and marine water bodies. With respect to marine environment protection, a total nitrogen (TN) concentration limit of 2.8 mg/l has been defined for marine and coastal water bodies. This can be compared to a TN concentration of 3.4 mg/l averaged for the years 2009 to 2012 at the monitoring station

Seemannshöft which is located at the catchment outlet. The non-binding target value of total phosphorus (TP) concentration for this monitoring station is 0.1 mg/l, which is exceeded in samples by up to 100 per cent. Figure 4.13 illustrates the general downward trend of TN and TP over a longer period of time. The decrease of nutrient concentration values is typical also for the vast majority of monitoring stations in the German Elbe River basin, which shows a long term trend starting in the 1990s with an initially rapid decrease of nutrient concentrations. However, a slowing of the decreasing trend can be observed in recent years. And, compared to the average, the inter-annual variability is increasing. For TN, an influence of hydrological and meteorological conditions in the winter period is considered to be the main trigger for the observed variations. Also intensification of land use may have caused these changes. In 2013, 29 per cent of the groundwater bodies showed an unsatisfactory chemical status because of accelerated nutrient concentrations.

Measurements in coastal water bodies show that high nutrient concentrations cause chlorophyll concentrations that are up to 400 per cent beyond the target value. Also in the Elbe River and main tributaries, elevated concentrations of chlorophyll and corresponding oxygen concentration depressions are found. In the Elbe estuary, summer oxygen concentrations often are close to a critical value because of nutrient enrichment and eutrophication.

Pressures on single water bodies or on micro/mesoscale catchments can be reduced on the local level with consideration for specific management demands. However, the nutrient concentrations and loads in macro-scale catchments such as the Elbe River and the associated coastal and marine water bodies can only be reduced by coordinated measures to reduce emissions and to increase the retention of nutrients by all responsible upstream authorities. With the implementation of the WFD, the ten riparian states have set up an approach which combines measures for point sources, diffuse sources and nutrient retention. Additionally, synergies with measures to improve structures, e.g., of habitats, are expected. Major options to reduce the nutrient input from agricultural diffuse sources are i) amendment of the Fertilisation Ordinance (Düngeverordnung, DÜV), ii) improvement of crop rotation including intertillage and undersown crops, reduction in intensity of farming practices, iii) fertiliser management, iv) modification of land use including establishment of buffer strips or “living fences” v) tile drain management and vi) mentoring and transfer of knowledge. In detail, these measures are adapted to regional and local requirements. Point source management includes both the improvement of wastewater treatment efficiency, and the management of urban stormwater runoff.

The effect of the measures is estimated on the one hand by expert judgment and on the other hand by nutrient balance modelling and scenario calculations. The combination of these methods increases the reliability of assessments and planning. Nutrient balance modelling with MONERIS 3.0 has identified the main sources and pathways of nitrogen as: groundwater and interflow (40 per cent), tile drains (25 per cent) and waste water treatment (20 per cent). Tile drains are more important as pathways in the northern lowland part of the catchment and urban waste water prevails in cities e.g. of Berlin or Hamburg. For phosphorus, the main sources and pathways are: groundwater and interflow (20–25 per cent), waste water treatment (20–25 per cent), erosion (13 per cent) and tile drains (10 per cent). Erosion is more important in the southern part of the catchment due to its relief. By expert judgment, a significant reduction of nitrate input into surface and groundwater of 10-15 per cent in the German part of the catchment is expected because of the amendments of the Fertilisation Ordinance. Agri-environmental measures to control inputs from drains and improved efficiency in waste water treatment have a high potential for reduction of nitrogen loads. Wastewater treatment is also the main option for reducing phosphorus loads.

Strategies are also developed for the other above-mentioned important management issues that include a status description and options for measures. These strategies are the basis for public discussions. For example, a detailed plan was set up to improve fish migration in the main tributaries at 171 dams, locks and weirs up to 2021. A sediment management concept was compiled that sets up a framework for the evaluation and management of sediment and particle bound contaminants. Such contamination problems are often caused by emissions from contaminated sites but also by reworking of old sediment structures.

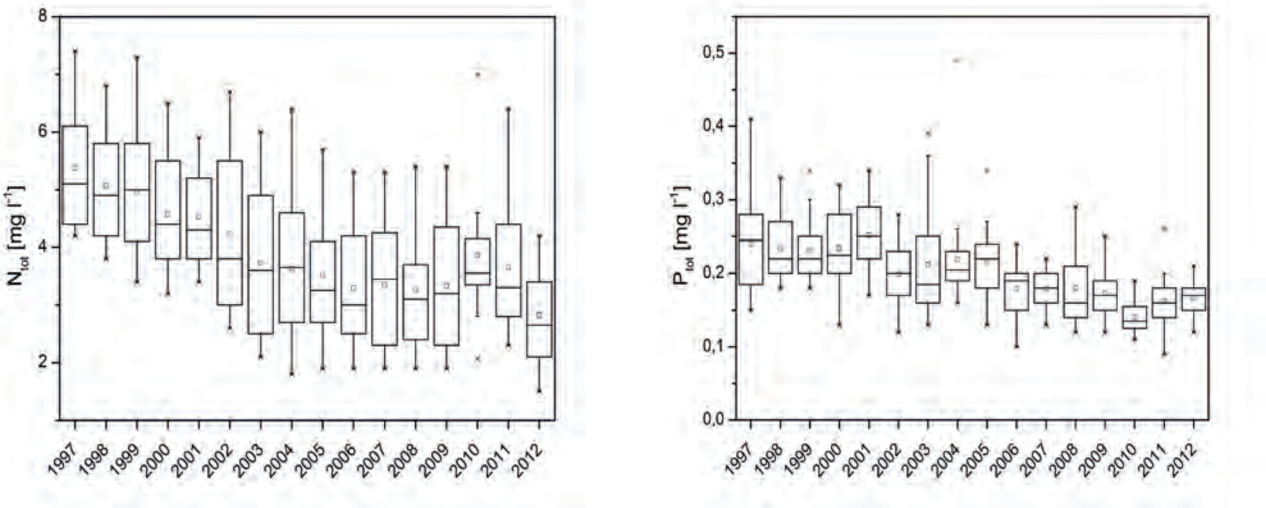


Figure 4.13: Long-term trends of nutrient (Ntot = total nitrogen TN, Ptot = total phosphorus TP) concentrations at the monitoring station Seemannshöft at the mouth of Elbe. Box-and-whisker plot: central bar =median; tops and bottoms of rectangles = 25th and 75th percentile; asterisks = minimum and maximum values.

4.8.3 Solutions and transferable lessons

The nutrient management problem under discussion is at the intersection of different stakeholders and drivers, i.e. agriculture, water pricing, water authorities, and nature conservation, to name but a few. However, the WFD, national laws and regulations, and other international conventions define the target frame. The consideration and acceptance of target values for nutrient reduction in coastal water bodies in inland states is an important step in the achievement of objectives. Modelling results support the identification of nutrient sources as well as pathways and a catchment-wide strategy that includes regional characteristics. Modelling also provides a basis for defining regional (inland) measures that focus on the effective reduction of nutrient input in coastal water bodies. Local pressures are also included at a small scale. On the negative side, modelling results are sometimes not accepted in public discussions about water pollution because models are difficult to understand, and because they sometimes lack adequate input data. The integration of expert knowledge in the discussions can partly compensate for these shortcomings.

After a period with a significant decrease in nutrient loads, the rate of decrease has diminished in recent years both for N and P, despite continuing mitigation measures. This may be caused by inertial effects after the initial strong reduction of nutrient loads, or because the measures are ineffective, or perhaps because the positive impact of the measures is being delayed for unknown reasons. The situation in the Elbe River basin is comparable to that of other rivers with high concentrations of pollutants despite control of pollutant loadings to the river (Dorioz and Tadonléké 2009).

The administrative structure of the Elbe River Basin Community, which coordinates the efforts of the federal states in the German part of the Elbe River catchment, established the basis for an integrated and coordinated plan of action. The Elbe River Basin Community works on the principles of voluntary and consensus decision making, and in this way reflects the federal structure of Germany. The joint identification of management problems at the catchment scale is the prerequisite for a common understanding and defining environmental targets and management options.

4.9 River Basin 8 – Hudson

The Hudson River basin is a typical example of a mixed-use watershed in the developed world. Historically, the trajectory of water quality issues has followed the transition from settlement, deforestation and resource extraction, through agricultural expansion, industrialisation, and urbanisation. Today, the dominant water quality issues reflect the local history of development and its regional variation.

4.9.1 Brief overview of Hudson Basin characteristics and governance

The Hudson River basin, including its major tributary, the Mohawk River, is situated primarily in New York State, with small portions lying in the neighbouring states of Connecticut, Massachusetts, New Jersey, and Vermont. There is a strong gradient of land use/land cover, with the northern Upper Hudson dominated by forest, the Central Hudson/Mohawk by forest, agricultural and suburban lands, and the southernmost portion being heavily urbanised. Two large park areas, the Adirondack Park in the north and the Catskill Forest Preserve in the southwest, help protect a significant portion of the watershed from development and associated potential water quality impacts. The New York City water supply system provides drinking water for the New York City metropolitan area and other towns in the region, but its catchment (within the Hudson and Delaware basins) is protected from excessive development.

Pollution: From the 1800s to the 1960s, the Hudson River was grossly polluted by effluent from river cities and industry, but with programs such as the Pure Waters Bond Act in 1965 and passage of the Clean Water Act in 1972, funding became available for improved sewage treatment, ultimately resulting in the return of sensitive indicator species in the 1990s. Today, while phosphorus loading has diminished largely due to the removal of phosphorus from detergents, the Hudson still remains the most heavily loaded US estuary in terms of nitrogen, the source of which varies from the forested north (atmospheric deposition), through the agricultural centre (farm runoff) to the urban south (wastewater discharge).

Hudson River Facts

- *Hudson/Mohawk basin area: 34,680 km^2;*
- *Hudson River length: 507 km from its primary source in Lake Tear of the Clouds to the tip of Manhattan Island;*
- *Average precipitation: 1000–1275 mm/yr over a significant north/south gradient;*
- *Major regional water supply system: the NYC reservoir system (17 reservoirs, with watersheds straddling the Hudson and Delaware basins) supplies NY City and other cities of the region, and represents an interbasin transfer of water;*
- *Canal system: the New York State barge canal system connects the river to the Great Lakes and Lake Champlain, providing an opportunity for invasive aquatic species.*

Invasives: The Hudson River exchanges biota with neighbouring basins through canals and aqueducts. Among these biota, Eurasian water chestnut (Trapa natans) and water milfoil (Myriophyllum spicatum) became established and invasive. In particular, thick water chestnut beds choke backwaters and embayments. In 1991, zebra mussel (Dreissena polymorpha), which had invaded the Great Lakes in the 1980s via ship ballast, was discovered in the Hudson River, most likely transported on boats. By 1992, zebra mussels represented > 50 per cent of the heterotrophic biomass (Strayer et al. 2014).

Climate change: Effects are already evident in the Hudson River watershed: sea level has risen ~30 cm since 1940, freshwater discharges have increased, and temperatures have been rising since 1930 (Strayer et al. 2014). Although phenological responses in organisms have been moderate, timing/duration of spawning runs of anadromous (sea-run) fishes has been changing, moving toward earlier runs that may not match up well with in-river primary and secondary production. Regional climate projections indicate more concentrated precipitation events, including major storms which result in severe flooding as in 2011 Hurricane Irene and Tropical Storm Lee and in 2012 Hurricane Sandy.

There is no single governance system for the watershed; a number of different agencies and programs from federal to local hold responsibility for water quality regulation. The Hudson River Estuary Program (HREP), funded by New York State and managed by the state's Department of Environmental Conservation (DEC), has a watershed management programme in place to help mitigate impacts from urbanisation, development,

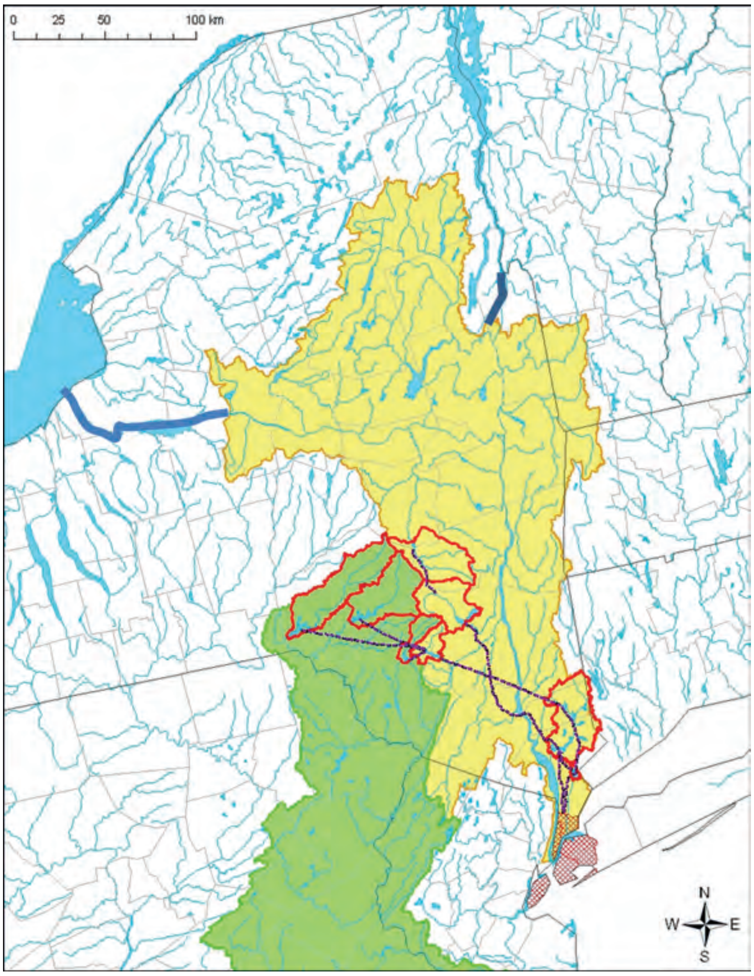


Figure 4.13: Regional map showing the Hudson River watershed (yellow) and other major features of the region including the Delaware watershed (green), the five boroughs (counties) comprising New York city (hatched), the New York City water supply watersheds (red outline) and aqueduct/tunnel system (purple). Counties of New York and surrounding states are outlined in grey. Inter-basin transfers occur through the Champlain and Erie Barge canals (dark blue).

agriculture, and climate change. The Estuary Program has an active stakeholder advisory board that helps to guide action plans. The New York City Department of Environmental Protection (DEP), a city-level agency, is responsible for monitoring and securing the integrity of the City's water supply system, including its watershed, and its sewage and waste treatment system. As most of the City's sewage is treated and discharged to the Hudson and other waters around Manhattan, the DEP also monitors water quality in the harbour and nearby waters. Non-governmental organisations also play a significant role in monitoring water quality and pollution.

4.9.2 PCBs: causes and impacts

In addition to the above concerns, the largest single toxic contaminant issue in the freshwater portion of the Hudson is that of polychlorinated biphenyls (PCBs). From 1946–1977, the General Electric Corporation (GE) discharged hundreds of tons of Arochlor, a mixture of PCB congeners used in manufacturing electrical capacitors. Although a portion of the discharged PCB mass was removed during maintenance dredging, volatilised off, or transported by the river downstream to the Atlantic, significant portions remained in floodplain soils and river sediment, becoming bio-available and taken up in terrestrial, riverine and estuarine food chains. In 1976, New York State banned all fishing from the source region to the Federal Dam at Troy, NY, and closed commercial fisheries for striped bass in the 250 km of tidal estuary downstream of Troy. Eight years of study later, the US Environmental Protection Agency (EPA) designated the entire stretch from Hudson Falls (320 km from the mouth) to New York Harbor as a Superfund site. Despite that, the complexity of the problem, compounded by a bitter battle between GE and the EPA, led to inaction for decades. In the meantime, a consortium of academics and state agencies monitored the ecosystem, documenting the bioaccumulation of persistent congeners and impacts on fish and wildlife.

The primary impacts of the PCBs in the Hudson River were unacceptable risks to human health and the environment. Since the loadings have stopped, there has been a very slow process of natural recovery of the river ecosystem. Concentrations of PCBs in sport fish and in fish commonly taken by the commercial fishery exceeded both the tolerances set by the United States Food and Drug Administration (FDA) and the concentrations used by the New York State Department of Health (DOH) in advising the public on consumption of wildlife. As a result, the State of New York banned the taking of fish from the 70 km reach between Hudson Falls and the estuary (referred to in project documents as the "upper Hudson"), closed the commercial fishery, and issued an "eat none" advisory for the entire Hudson River from Hudson Falls downstream to the mouth of the river at the Battery in New York.

Following a halt in discharges in 1977, PCBs in water and fish dropped fairly quickly, but levels stabilised in many species by the mid-1980s, particularly in the upper Hudson. PCB concentrations in most species remained well above the FDA tolerance and/or the DOH consumption advisory guidelines. At the request of the DEC in 1989, EPA began a major reassessment of conditions in the Hudson related to GE's PCB discharges, including extensive monitoring of PCBs in the water column at different flows and times of the year, sampling of known PCB "hot spots" (areas mapped by DEC as containing deposits of concentrated sediment-bound PCBs in discrete locations) to look at changes over time, and annual monitoring of fish at various trophic levels in several locations river wide. EPA also developed a set of predictive tools to inform decisions about various remedial alternatives and conducted quantitative human health and environmental risk assessments. Human health risks identified included both excess cancer risk and risk of non-cancer health hazards associated with consumption of contaminated fish. Ecological risks identified by EPA included population-level effects on piscivorous wildlife, including bald eagle, belted kingfisher, great blue heron, mink, and river otter. Piscivorous mammals were at greatest risk.

EPA's assessment of river conditions in their 2001 Record of Decision (U.S. EPA, 2001) concluded that trends in PCB concentrations in the water column and fish tissue showed a levelling off with little if any reduction in the last decade. In the Record of Decision, EPA, following the process set in the Federal "Superfund" law, ruled that GE should conduct targeted environmental dredging to remove the highly contaminated sediments from the upper Hudson between the discharge points (in Fort Edward and Hudson Falls) and the Mohawk River confluence at the head of the estuary. This dredging and removal began in 2009 and was completed in 2015.

While EPA was assessing what was necessary to support development of the remedial dredging program, the State of New York, the US Department of the Interior (DOI) and the National Oceanographic and Atmospheric Administration (NOAA), acting as Trustees of natural resources, conducted assessments of potential injuries to a variety of these natural resources. These assessments include measuring impacts of PCBs in the Hudson River ecosystem on American mink (severe reproductive impairment), birds such as tree swallows (growth and development; nesting behaviour), and shortnose and Atlantic sturgeon (survival; growth and development). This assessment work is ongoing

4.9.3 Solution(s) and transferable lessons

EPA's selection of targeted environmental dredging was intended to accelerate the natural recovery rate of the river ecosystem. EPA concluded in the Record of Decision that two active remedial approaches would be necessary to promote this: control of ongoing sources and removal of the most highly contaminated portions of the river bottom (including the "hot spots") which acted as ongoing sources to the rest of the river system. Source control at the two capacitor plant sites was achieved before the start of the dredging project in 2009 through implementing a series of remedial actions by GE under State regulatory authority. Actions undertaken at these sites included removal of contaminated sediments near major wastewater outfalls at the sites and groundwater and PCB oil recovery programs designed to limit offsite contaminant migration to the river.

The most significant problems to address in the river were risks to people who consume fish and piscivorous wildlife. To reduce these risks, the PCB body burdens of Hudson River fishes needed to be reduced. Through geochemical evaluations and modelling, EPA determined that fish received their PCB body burdens from both the water column and the food web, from PCBs in surficial and near-surface sediments. To address these pathways, EPA decided to remove the most highly contaminated sediments from areas where significant PCB mass was present and potentially bioavailable or where significantly elevated PCB concentrations occurred at or near the sediment surface. PCB congeners containing three or more chlorines ("tri plus PCBs") were targeted due to their greater propensity for bioaccumulation, environmental persistence, and potential impacts on human health and ecological risk.

Removing targeted sediments and controlling remaining upstream sources of PCB at GE capacitor plants in Hudson Falls and Fort Edward is expected to reduce PCB concentrations in surficial sediments and thus reduce PCB body burden in fish, ultimately decreasing human health risks posed by consuming contaminated fish and ecological risks posed by fish consumption by wildlife. (The routes of exposure to humans and wildlife via floodplain soils will not be abated by the river bottom sediment remediation. To address the ecological and human health risks posed by disposal of PCBs to the Hudson River, a robust investigatory and remedial program, potentially approaching the scale of the sediment remedy, may be required.)

To determine specifically where to remove contaminated sediment, a sediment sampling and analysis programme was undertaken. After using side-scan sonar to map the river bottom by surficial sediment type, a core sampling programme of approximately 8,000 cores, on a triangular grid of 24 m spacing, was undertaken to map the distribution of PCBs in river sediments.

EPA also set three primary "performance standards", for resuspension (impacts on the water column caused by contaminant release during dredging), residuals (the ability of the contractor to meet the project cleanup concentration where dredging was done) and productivity (the rate of sediment removal on a monthly and annual basis). The resuspension standard was set at the drinking water standard for total PCBs of 500 ng/l (http://www.epa.gov/safewater/pdfs/factsheets/soc/tech/pcbs.pdf). The residuals standard was set at 1.5 mg/kg tri plus PCBs.

Once GE's project design team completed the process of delineating the sediments to be removed, and the necessary infrastructure was developed for the project (sediment dewatering and transfer facility, work marinas), the contractor hired by GE performed the first year of sediment removal. This first year ("Phase 1") was planned to be an opportunity for both EPA and GE to better understand project operations in the context of meeting the three performance standards and also in improving the quality of project operations.

Difficulties encountered during Phase 1 included resuspension of PCBs due to several technical issues (e.g. need for repeated dredge passes to meet the residuals standard, inefficiencies in loading/unloading of scows causing delays, presence of debris preventing bucket closures, etc.) and underestimating the areas required to be capped due to underestimation of contaminant depth. After the first year of dredging, a peer-review panel of national experts in remedial dredging was convened to evaluate the project and provide recommendations on project revisions, including revisions to the three performance standards.

During Phase 2, the project has been successful in meeting resuspension standards; the drinking water standard has been consistently met downstream of dredging operations, and the rate of PCB losses has been < 1 per cent of the PCB mass dredged. Sediment removal has significantly increased, with the annual production rate exceeding goals in every year of Phase 2 until 2015. The capping rate has also been low, with less than 8 per cent of dredged areas being capped due to inability to meet the residuals standard.

The primary lesson learned from the dredging programme in the upper Hudson is that a large remedial dredging project can be successfully performed with low resuspension losses, even without controls such as silt curtains or sheet piles, assuming accurate characterisation of site conditions (especially depth of contamination), a sufficiently conservative design approach in setting depth of cut which limits the need for multiple dredging attempts, and properly operated dredge equipment, selected to match site conditions.

4.10 General conclusions from the case studies

Common problems occur around the world

The analysis in Chapter 3 identified the scale of water quality challenges in Latin America, Africa, and Asia from a "top down" perspective. In this chapter, water quality situations were reviewed in eight case studies of river basins from around the world that illustrated in a practical way the realities of these challenges.

The global analysis in Chapter 3 identified that about one-third of all river stretches in Latin America, Africa, and Asia have severe pathogenic pollution. Two rivers in two different locations in the world – the ***Volta*** in West Africa and the ***Chao Phraya*** in Thailand – are different in character, but both have high levels of pathogen pollution linked to the occurrence of waterborne diseases.

About one-seventh of all river stretches on the three continents were identified to have severe organic pollution. The ***Upper Tietê*** River in Brazil and the ***Godavari*** River in India are both affected by organic pollution with high BOD loadings, high BOD river concentrations, and frequent episodes of very low dissolved oxygen. Large stretches of both rivers have few fish and very low diversity.

Tens of thousands of river kilometres on each of the three continents have severe levels of salinity pollution. The ***Vaal*** River in South Africa and the ***Medjerda*** River in Tunisia are both examples for severe salinity pollution. High levels of salinity impede the use of the river for water supply, irrigation water and industrial use.

The ***Elbe*** is an example of a river that has overcome its earlier problems with pathogen and organic pollution but now confronts another type of water quality challenge – high loads of nutrients that lead to eutrophication in its estuary reaches. The ***Hudson*** has also mastered its earlier problems with pathogen and organic pollution while continuing to have high nitrogen loads, but now suffers from the legacy of toxic pollution related to sediment deposits of PCB which have found their way into the aquatic food web.

As can be seen from these examples, similar water quality challenges are occurring around the world even if the locations and situations are very different. Developing countries are experiencing problems that developed countries have overcome, but new problems also persist in developed countries. It is clear that major efforts are needed to achieve sufficient water quality and the ecosystem services it provides.

Similar problems can have different immediate causes

While above it was shown that similar water quality problems occur at very different places around the world, the case studies also showed that similar problems can sometimes have different immediate causes:

- A principal cause of the pathogen pollution in the ***Chao Phraya*** River is the discharge of domestic wastewater from sewers, whereas in the ***Volta*** basin, the main source is not sewers but runoff from inadequate sanitation facilities.
- The salinity pollution in the ***Medjerda*** River is caused largely by return flows from irrigation whereas in the ***Vaal*** River it is mainly from wastewater from industrial sources and runoff from mining activity.

A range of underlying drivers, some common, some specific

The case studies also illustrated that the immediate causes of water quality degradation, such as untreated wastewater discharges, are in turn driven by many different underlying factors, which may vary from river basin to river basin:

- Important underlying drivers of the water pollution of the ***Upper Tietê***, ***Godavari***, and ***Chao Phraya,*** are urbanisation and economic activity which lead to discharges of concentrated, untreated wastewater.
- For the ***Vaal***, the main driver is also economic activity, especially industrial production. As noted above, this leads to the discharge of untreated wastewater and runoff from mining activities.
- For the ***Volta***, the drivers are population growth and inadequate sanitation facilities. At the onset of the rainy season, there is a large wash-off of pollution from inadequate sanitation facilities from the land into the river.
- The water pollution of the ***Medjerda*** and the ***Elbe*** share a common driver: the demand for food. This demand stimulates the irrigation of cropland in the Medjerda basin and this in turn leads to irrigation return flows to the river containing salts

and nutrients. In the Elbe basin, food demand is satisfied mostly by rainfed crops, which are applied with excess amounts of fertilisers, some of which are washed off into the Elbe river.

- For the ***Hudson*** River, the driver of its current PCB pollution has been the demand for industrial products, which may contain dangerous materials that are unsafely disposed of. Another driver of water quality changes in the Hudson River is climate change, which has raised the level of the sea at the river's mouth, increased freshwater runoff, and raised river temperatures, all with potential ecological consequences.

Coping with the water quality challenge

Finally, many valuable lessons about how to cope with the water quality challenge can be derived from the case studies:

- As seen in the ***Godavari***, it is important to avoid fragmentation of authority as this affects the management of river water quality.
- As seen in the ***Elbe*** and ***Volta,*** consolidating authority in an overarching international "commission" can provide an indispensable instrument to deal with international aspects of water quality management. In the case of the Elbe, it was also shown that a wide-reaching national institution (the Elbe River Basin Community) can also provide a valuable platform for gaining the cooperation of all critical actors within a river basin.
- As seen in the ***Medjerda*** and the ***Elbe***, in order to manage water quality, it is essential, under some circumstances, to first manage the *land*. In the case of the Medjerda, management of run-off from agriculture is key to reducing salinity loadings to the river. In the case of the Elbe, an ambitious basin-wide programme is successfully intervening in agriculture in the basin to reduce nutrient wash-off from agricultural land.
- In cases where water quality problems are worsening, sometimes a first important step is to educate the public about the situation. This was the successful approach used in the ***Medjerda*** and ***Upper Tietê*** basins.
- Another effective tool to promote water quality management are basin-wide action plans and targets as in the case of the cleanup programme of the ***Upper Tietê***, the Resource Quality Objectives used in the ***Vaal*** basin, and the water quality master plans developed for the ***Chao Phraya*** basin.
- The ***Volta*** basin also shows that actions to control water pollution require the strengthening of the technical capacity for water quality management in the basin.

The case studies also show that the challenge of protecting water quality is closely link with other important goals of society – providing food, developing the economy, providing safe sanitation. Therefore, over the coming years it will be very important to link goals for water quality with other goals of the Post 2015 Agenda and the new Sustainable Development Goals. This topic is taken up again in Chapter 5.

5 Solutions to the Water Quality Challenge: A Preliminary Review

Aim of this chapter

- To review technical and management options available as solutions to the global water quality challenge.
- To give examples about the practical implementation of solutions.

Main messages

- There are many options available to developing countries for avoiding the water quality deterioration of their rivers and lakes. Among the main technical options are: (i) pollution prevention, (ii) treatment of polluted water, (iii) the safe use of wastewater and (iv) the restoration and protection of ecosystems.
- Apart from established strategies, there are innovative new ideas which were not available or used by developed countries when confronted with similarly deteriorating water quality decades ago. Examples are: pollution prevention in industry, constructed wetlands, and conservation and maintenance of forested headwaters.
- A "one size fits all" option will not work to solve the global water quality challenge. Instead, regionally adapted clusters of measures will be needed to control the diverse types of water pollution and sources of pollution. Some of these packages might be applicable to many different river basins.

Previous chapters have shown that water pollution is prevalent and increasing in rivers in many countries in Latin America, Africa, and Asia. The situation is not completely different from what prevailed several decades ago in North America and Europe when increasing population and economic activity propelled a substantial increase in water pollution. At that time, the accent was on economic development at the expense of environmental quality. After several decades, the intensity of water pollution peaked, and developed countries managed to substantially scale-down the levels of organic pollution, nutrient loading and pathogen contamination in their rivers and lakes (as indicated by sinking river concentrations of BOD, phosphorus, and faecal coliform bacteria) (EEA, 2014; Hogan, 2014; OECD, 2008). Although some types of water pollution persist in developed countries (see Chapters 1 and 4), the water quality of many of their freshwater ecosystems has improved significantly.

Now, as noted above, several countries in Latin America, Africa and Asia are following a similar trend. Yet the majority of river stretches on these continents are still in good condition and countries still have the chance to avoid further pollution and restore already-polluted rivers. The case studies in Chapter 4 give some examples about how this can be put into practice through various management approaches and technical options (Table 5.1). As we see later, these are only a subset of many other technical options available to countries for reducing water pollution. (Many case studies in Chapter 4 mention monitoring as part of solving their pollution problems. Although monitoring is not a technical option in the sense of Tables 5.1 and 5.2 in this chapter, it is a very important step in tackling pollution control, as emphasized in Chapter 2.)

Table 5.1: Technical options mentioned for the specific water quality issues in the case studies (Chapter 4).

River Basin	Upper Tietê	Godavari	Volta	Chao Phraya	Vaal	Medjerda	Elbe	Hudson
Type of pollution	Organic pollution	Organic pollution	Pathogen pollution	Pathogen pollution	Salinity	Erosion, salinity, nutrients	Eutrophi-cation	Organic chemical pollution
Technical options employed								
Pollution prevention							X	X
Treatment of wastewater treatment	X		X	X	X	X		
Safe reuse of wastewater			X				X	X
Protection & restoration of ecosystems				X	X		X	X

Among the most established options is to lay out a network of sewers for collecting wastewater from different sources and delivering the wastewater to a conventional wastewater treatment facility, as developed countries began to do decades ago. This has only been a partly successful strategy in developing countries because of the high energy costs of conventional treatment facilities, the lack of technical capacity to run these plants, and other drawbacks. Moreover, pollutants from diffuse sources such as urban surface runoff and irrigation return flows are difficult to collect and treat, both in developing and developed countries. In other cases, specific types of pollutants, e.g. pharmaceutical residuals and some trace metals, are not effectively removed by conventional treatment. Despite all these drawbacks, gravity driven sewerage and conventional wastewater treatment is often still a favourable option for bringing a water pollution problem under control.

New options have arisen over the last few decades and are worth considering. They complement (rather than replace) conventional wastewater treatment. If wastewater treatment is included, the major options now available for reducing water pollution loads are:

- Pollution prevention
- Wastewater treatment (conventional and unconventional)
- The safe reuse of wastewater
- Ecosystem protection and rehabilitation

Section 5.1 briefly reviews the specific measures that fall under these major categories and how these measures can be used to reduce sources of water pollution. An overview of these measures and how they apply to the different types of water pollution sources is given in Table 5.2. The options are diverse and their feasibility depends on the type, intensity, and quantity of specific water pollutants as well as many other technical factors, which are discussed in the text.

But selecting the right technical option is only one aspect of water pollution control. It is also important to develop effective management and governance strategies. Some of these aspects are discussed in Section 5.2.

Table 5.2: Selected technical options relevant for different sources of pollution. Technical options marked with "+" are relevant to reducing the indicated source of pollution. This is not an exhaustive list of options.

	Source of pollution				
Technical option	Domestic sewered	Domestic non-sewered	Urban surface runoff	Industry	Agriculture and sediment pollution
1. Pollution prevention					
Increasing water use efficiency	+	+		+	+
Reduction of wastes produced	+	+		+	+
Urban green infrastructures			+		+
2. Treatment of wastewater					
Mechanical/primary treatment	+		+		
Biological/secondary treatment	+			+	
Chemical/tertiary treatment	+			+	
Advanced treatment	+			+	
Constructed wetlands & natural treatment systems	+		+		+
3. Safe reuse of wastewater					
Use of stormwater			+		
Reuse of domestic wastewater and sludge	+				
Household greywater recycling systems	+				
Reuse of wastewater in industries				+	
4. Protection and restoration of ecosystems					
Forest conservation / reforestation of river basins			+		+
Using natural wetlands for treatment of wastes	+		+		+
River dilution	+	+	+	+	+
Flow regime restoration	+	+	+	+	+
Targeted environmental dredging				+	+

5.1 Technical Options

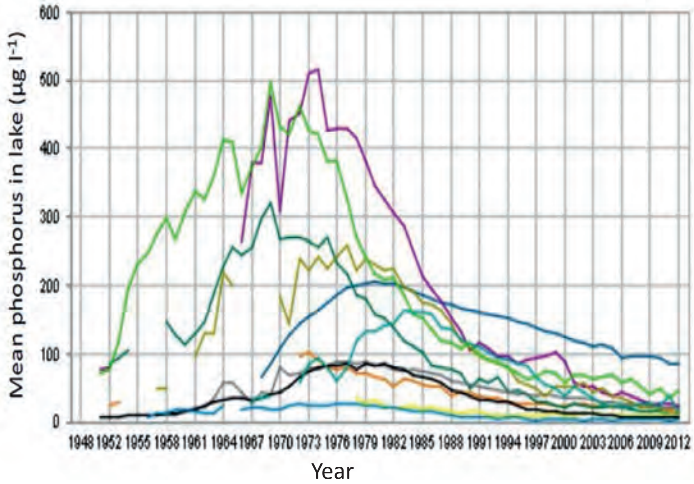
5.1.1 Pollution prevention

"Pollution prevention", or "source control of pollutants", is the banning, avoidance, reduction, or elimination of a contamination at the source. In many circumstances, pollution prevention has been shown to be as effective as conventional wastewater treatment in reducing water pollution loadings.

Best practice example

'Source control of phosphorus'

Prior to 1980, polyphosphates were used in detergents in large quantities because of their ability to bind calcium and magnesium ions and thus soften water. The phosphorus loading of many lakes and rivers, especially in OECD countries, increased dramatically with increasing detergent use after World War II. As a response, the use of phosphate in detergents was regulated in Central Europe beginning in the late 1970s. Consequently, phosphates were replaced by other water-compatible chemicals such as sodium aluminium silicate, and average phosphorus concentrations in wastewater were halved. This action, along with the upgrading of wastewater treatment plants, led to a decline in the phosphorus loading of many Central European lakes to their pre-1950 levels.



Trend of mean phosphorus concentrations in 11 alpine lakes from 1940 through 2012. Data from EEA (2015).

Pollution prevention is achieved in various ways, as explained in the following paragraphs.

Increasing water use efficiency

One way to prevent water pollution is to use water as efficiently as possible so that less wastewater is produced.

- *Households.* Water use can be made more efficient in the household by fixing leaky taps and toilets, using water saving devices in toilet cisterns, taking showers rather than baths, and using water-saving washing machines and dishwashers.
- *Manufacting and industries.* Measures here include the introduction of water efficient production processes, water recycling and wastewater reuse.
- *Agriculture.* This includes water efficient irrigation, and tailwater return systems.

Reduction of wastes produced

Another pollution prevention strategy is to reduce the amount of wastes produced and thereby reduce the amount of wastes in wastewater. (See box "Best practice example 'Source control of phosphorus'").

- *Households.* One option here is to use compost toilets which do not require water and produce compost (such as the Ecosan systems). Another option is to employ a greywater system which recycles household water used for washing purposes. Technically speaking, it is more practical to include these systems in new buildings than retrofit them into existing buildings. There are many other alternatives, which differ in sophistication and costs. Some options are very feasible and affordable for low income households.
- *Manufacting and industries.* This includes "Green chemistry" which aims to avoid the release of hazardous substances into the water cycle. One example here is to add equipment at an industrial facility to reduce or recover waste. Another is to modify the production of chemicals so that less waste is produced.
- *Agriculture.* The main options here are nutrient and pesticide management which include minimising fertilizer and pesticide surpluses, changing crop rotation, and reducing surface run-off through tile-drain management.

Urban green infrastructures

Controlling stormwater runoff from city surfaces is an old problem, but new ways are being developed to deal with it. Traditionally, stormwater runoff is collected in large conduits and either delivered to a treatment plant or discharged directly to surface waters. An alternative approach, which is increasing in popularity, is "rainwater harvesting" through which water is stored on the urban landscape in natural depressions or in artificial cisterns and then sometimes used for watering parks and for other non-potable purposes.

Constructing "green roofs" made up of plants that absorb and retain rainwater has become a simple and popular way of lessening the immediate runoff of stormwater. In addition, green roofs make houses cooler in the summer and warmer in the winter and the roofs act as small habitats for a wide range of flora and fauna.

Urban "green infrastructures" also include pavement that enhances stormwater infiltration, and structures that reduce the infiltration of storm runoff into sewers.

5.1.2 Treatment of wastewater

A wide range of different options are available for conventional and non-conventional treatment. Some are single-stage systems; others, such as mechanical-biological-chemical treatment, are a combination of different stages. Some include tailor-made pre-treatment systems. (See box "Fuheis demonstration site as best practice example of 'Treatment of polluted water'").

Fuheis demonstration site as best practice example of **'Treatment of polluted water'**

As part of the project IWRM-SMART (Sustainable Management of Available Water Resources with Innovative Technologies), the Fuheis demonstration site near Amman (Jordan) started operation in the autumn of 2009. Different technologies are operated at the site, including sequencing batch reactors, extended aeration systems, constructed wetlands, a sludge humification system and a sludge screening and anaerobic stabilization reactor. The facilities are used for identifying the combinations of technology that can successfully treat different wastewaters. The facilities are also used for the training of technicians, and to inform managers and decision makers about technical options for dealing with water pollution.

Source: Manfred van Afferden (UFZ)

Mechanical/primary treatment

Primary treatment is used to remove larger particles and some of the finer particles as well, depending on the set-up of the system. The key function of a mechanical system is to settle out particles in the wastewater by gravity. As a stand-alone solution it must be considered outdated but in combination with more advanced treatment it is still very useful. This is because pre-removal of larger particles makes the next steps in the treatment process much more efficient. On average, well run mechanical treatment systems may reduce the amount of organic matter by 30–50 per cent, and nutrients by 10–20 per cent.

Biological/secondary treatment

This type of treatment involves the decomposition of wastes by a wide variety of microorganisms. Secondary treatment helps in removing most of the organic matter and only part of the nutrient load. Hence the effluent from this stage of treatment often still contains substantial amounts of nutrients and other chemicals which require further treatment to be removed. However, the microbiological processes in this stage of treatment can be optimized to boost the removal of nitrogen compounds such as nitrate and ammonia, but only if the processes are controlled correctly, e.g. with alternating periods or zones of high and low oxygen concentrations. One consequence of secondary treatment is that it produces a large amount of sludge which must be disposed of safely.

Chemical/tertiary treatment

This treatment stage typically includes the use of specific additives, such as iron-sulphate, to remove phosphorus and other chemicals. Precipitation of heavy metals is a common method to take the metals out of the water phase and into the sludge phase. Since tertiary treatment targets substances that are not removed by more affordable primary and secondary treatment, it tends to be the most expensive stage of treatment.

Advanced treatment

Research is constantly advancing the state of wastewater treatment. For example, conventional treatment systems require large amounts of land which may not be available in cities; this lack of land has stimulated the development of very compact systems for specific types of wastewater. The principles used in these new types of technology are based on well-known but optimised mechanical/biological methods. Typical clients for new treatment methods are hospitals, industries, and cruise ships. A limitation of such systems is that they are adapted to a particular kind of wastewater having a narrow range of characteristics. Wastewater outside this range could destroy the microorganisms that play an essential role in the treatment system.

Some advanced treatment facilities recover methane, a useful fuel, from the gasification of sludge and other treatment processes. Often this fuel is used for the internal fuel needs of the treatment facility. Some advanced treatment produce an excess of fuel which is sold or utilised in other public facilities.

Constructed wetlands and natural treatment systems

"Constructed wetlands", usually consisting of reeds, are fabricated to mimic the purifying capacity of natural wetlands. Before passing through the wetland, wastewater is usually pre-treated to remove sand and grit. Well-dimensioned and -maintained wetlands can provide the same pollutant removal rates as traditional mechanical/biological treatment systems. Constructed wetlands are mainly used for treating domestic wastewater low in chemicals because a high concentration of chemicals can destroy the biological processes of the wetland. They are particularly suited for rural areas land is available for the wetland. One drawback of constructed wetlands is that they store large quantities of phosphorus, organic material, and heavy metals in their soils and sediments, and this necessitates a periodic renewal of the treatment system.

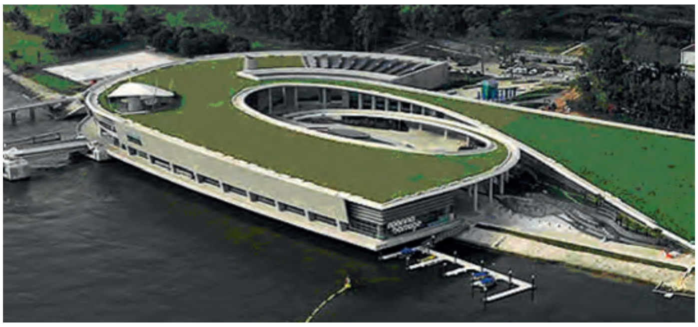
5.1.3 Safe reuse of wastewater

Use of stormwater

There are a number of ways in which the harvesting and subsequent use of stormwater helps to reduce water pollution. First it prevents polluted stormwater runoff from directly entering surface waters. Second, it helps reduce the frequency of stormwater overflows from sewer systems. Third, it replaces some water withdrawals from surface waters and therefore helps maintain more consistent flows in the river system. (See box "Singapore as a best practice example on 'Safe reuse of wastewater'")

Singapore as a best practice example on
'Safe reuse of wastewater'

No other city in the world is harvesting stormwater at the scale of Singapore. As a small island lacking natural aquifers and lakes, and with little land to collect rainwater, the city needs to maximize what it can harvest. With a network of drains, canals and 17 reservoirs of various sizes, two-thirds of the Singapore land area has been turned into a giant water cistern. The harvested water is used for recreational purposes and many other uses.



Source: http://www.anmc21.org/english/bestpractice/images/img/env_wat02_2.jpg

Reuse of domestic wastewater and sludge

The reuse of wastewater, excreta and greywater for irrigating or fertilising crops is widespread and can reduce or avoid water pollution by preventing these substances from directly entering surface waters. But for reuse to be successful it must be carried out in a safe and socially acceptable way, and this depends on how the wastewater and waste is managed and on various ethical, cultural and educational factors. The main task for managers is to ensure that wastewater, and its by-products such as composts and sewage sludge, are treated to a hygienically safe state before further use. Treatment options include long term storage, exposure to very high temperatures, and exposure to UV light.

Another safe way to reuse wastewater from the domestic sector is to use it for cooling or other purposes in closed production cycles in the industrial sector; this minimizes the risk that people will be exposed to unsafe substances or organisms in the wastewater. Depending on the type of wastewater, it may also be safe to use it for watering ornamental plants and fruit-growing bushes and trees, although not for irrigating food crops such as leafy vegetables and root plants.

A continuing problem is that not all dangerous chemical substances in wastewater are removed by conventional treatment. Therefore, the reuse of treated wastewater and sewage sludge may inadvertently convey dangerous substances to soils and groundwater. One solution is for these substances to be removed at the source, through "pollution prevention" actions as described above, before they enter the wastewater stream.

Most treatment systems produce sludge which has to be managed carefully to avoid public health hazards. One safe option is to use sludge as the feedstock for a biogas generator which produces methane-rich gases that can be used for heating, cooking, and other energy uses. The stabilized sludge can afterwards be used as a fertiliser or soil amendment once it is confirmed to be free of dangerous substances. (See box "Best practice example on 'Anaerobic Digestion System (ADS) biogas systems' in Ghana."). As with treated wastewater, a good way to ensure that sludge is free of dangerous chemical substances is to remove these substances at the source through "pollution prevention".

Best practice example on
'Anaerobic Digestion System (ADS) biogas systems' in Ghana

Biogas Technologies Africa Limited (BTAL), located near Accra (Ghana), is providing low tech, innovative solutions to convert faecal matter, biodegradable healthcare waste and solid waste into biogas energy and nitrogen-rich plant fertiliser. Numerous institutions, including hospitals, hotels, educational centres, and food processing industries as well as private homes, have benefited from the low cost and low land requirements of the biogas plants. These plants can also be used in areas with unreliable or limited water supply and do not require electricity to operate. With support from UN-Habitat, UNIDO, and UNEP, BTAL is carrying out similar projects in Senegal, Nigeria, Uganda, Mozambique, Tanzania, South Africa, and Kenya.

Source: John Idan

Household greywater recycling systems

Systems for treating and reusing greywater have become relatively common worldwide (Al-Zu'bi et al. 2015, Ghrair et al. 2015, de Gois et al. 2015, Lam et al. 2015). By definition, "greywater" is wastewater from baths, showers, washing machines, dishwashers, and kitchen sinks; "blackwater" is water from toilets (Birks & Hills 2007). Certain studies further divide greywater into "light greywater" (wastewater from bathrooms, showers, and baths) and "dark greywater" (wastewater from washing machines, dishwashers, and kitchen sinks). Sievers et al. (2014) give the following typical concentration ranges for dark greywater in Europe: chemical oxygen demand 102 to 1,583 mg/L, biochemical oxygen demand 56 to 427 mg/L, total nitrogen 3 to 48 mg/L and total phosphorus 0.5 to 15 mg/L.

The degree of sophistication of the recycling system depends on the intended use of the treated greywater (Ghaitidak & Yadav 2015, Teha et al. 2015). In some cases, comparatively simple processes are used such as sand filters (Ochoa et al. 2015) and helophyte treatment plants (Laaffat et al., 2015, Saumya et al. 2015). In other cases, different components from conventional wastewater treatment are combined, for example, ozonisation units, UV disinfection units, adsorption set-ups, and filtration components (Kneer et al. 2009). In still other cases, biological systems, such as membrane bioreactors and biologically aerated depth filters, are used.

Reuse of wastewater in industries

There are many opportunities for wastewater reuse in industry. For example process water can be re-used for sanitation and other water uses at the industrial sites. Depending on the circumstances, wastewater may also be used as boiler feed water or cooling water. Some authors have proposed using industrial wastewater as input to bioenergy production (Ranade & Bhandari, 2014).

As with the reuse of wastewater in other sectors, a prerequisite for reusing industrial wastewater is to treat it to a safe and acceptable level. A wide spectrum of technologies are relevant including precipitation and sedimentation, biological treatment media filtration, membrane filtration, ion exchange, reverse osmosis, and disinfection. Such treatment is used to reduce or remove priority pollutants, pathogens, biodegradable compounds, and metals and other non-biodegradable compounds. A complicating factor for industrial wastewater treatment is the extreme variation of the quality and quantity of wastewater over time. Both treatment and economic efficiency can be improved by eliminating potentially damaging wastewater compounds at the source, before they enter wastewater streams.

5.1.4 Protection and restoration of ecosystems

River networks, lakes, reservoirs, and groundwater are interconnected compartments of the hydrological cycle and closely linked to the terrestrial environment. They provide many essential ecosystem services such as drinking water, flood protection, nutrient cycling, means of transport, energy production, and self-purification. Here we discuss their role as a controller of water quality.

Forest conservation/reforestation in river basins

The headwaters of streams and rivers are typically much steeper than their lowland parts. Therefore, if they are thinly-vegetated they may have more frequent rapid surface runoff and a higher rate of soil erosion than lowland areas. If they are heavily forested they will have a much lower rate of erosion, and a much smaller amount of sediment and nutrients will be transported from the land surface into freshwater ecosystems. Hence, conserving the forest cover of headwaters, or re-introducing this forest cover, can be a very effective way of controlling downstream water quality. (See 'Catskill/Delaware watershed conservation' box).

Using natural wetlands for treatment of wastes

Floodplains, riparian zones, and wetlands play a key role in the integrity, functioning, and biodiversity of aquatic ecosystems. Because they retain water and have alternating dry and wet conditions with steep bio-geochemical gradients, they act as filters of poor quality water that flows into them. Hence, their protection and restoration is an important element of water quality management at regional or catchment scales. (See box 'Danish Action Plan on the Aquatic Environment')

River dilution

Rivers themselves can effectively dilute small loads of non-persistent pollutants when river discharge is high enough and consistent. However, a river cannot safely dilute persistent pollutants, such as organic chemicals, because these substances accumulate in the food web and in sediments. Also it is obvious that rivers with low flows cannot successfully dilute pollutants that are discharged in large volumes.

Flow regime restoration

Removing dams or artificial channels will restore a more natural flow regime to a river and can sometimes mitigate water quality problems. For example, removing a dam on an otherwise free-flowing river may successfully reduce eutrophication and dissolved oxygen problems occurring behind the dam. This is because these problems are most likely related to the long residence time and accumulation of nutrients in the reservoir behind the dam. In this case, removing the dam and restoring the unrestricted flow of the river may remove the water quality problem.

Targeted environmental dredging

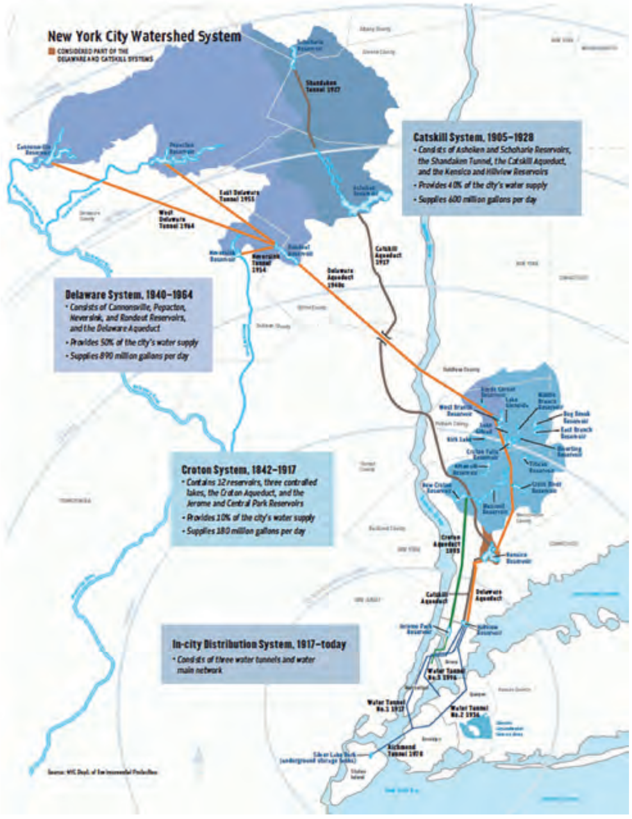
Environmental dredging is used to remove contamination from targeted areas in river beds. This technology is very specific and is designed to minimize resuspension of small sediment particles that may be contaminated with PCBs, heavy metals, or other toxic materials. Resuspension is avoided, for example, with hydraulic dredges or similar machinery which function like large vacuum cleaners to remove contaminated sediments with strong suction pumps.

Best practice example

'Catskill/Delaware watershed conservation'

New York City obtains most of its water from the Catskill/Delaware watershed located upstream from the metropolitan area. Approximately 1.4 billion gallons of water (about 5.3 million cubic meters) are consumed daily by eight million New York City residents and one million upstate customers. At present, all of New York City's drinking water is unfiltered.

In order to maintain the quality of this water supply New York State [annually] spends about 100 million US$ for actively managing the forest catchment areas and compensating the farmers for using less fertiliser and reducing grazing. By comparison, it has been shown that the alternative to these actions – constructing a treatment plant for filtering the raw water to achieve sufficient water quality according to required standards – would require investments of about 7–10 billion US$ with annual operation and maintenance costs of about 110 million US$.



The Catskill watershed and water supply system for New York City (Source: NYC Dep. of Environmental Protection).

Best practice example

'Danish Action Plan on the Aquatic Environment' for controlling nutrient loads

Danish inland and coastal waters deteriorated in the 1970s and 1980s leading to country-wide public and political concern. The cause was the high nutrient loading from point and diffuse sources. Diffuse sources play a major role because more than 60 per cent of the total area of Denmark is cultivated land, and livestock production and density is high. Under the so-called "Action Plan on the Aquatic Environment II", a series of natural wetland rehabilitation projects were carried out to control nutrient losses from agricultural areas to the freshwater and marine environment. These projects included the re-establishment of 16,000 hectares of "wet meadow" to help reduce nitrogen leaching, and 20,000 hectares of formerly removed forests.

It was estimated that nitrogen loads were reduced by 127,000 tonnes N/yr under the action plan, equivalent to a 40 per cent reduction of overall nitrogen discharges into the aquatic environment.

Aerial view of large scale wetland rehabilitation project in the Skjern River watershed under the Danish Action Plan on the Aquatic Environment (Source: Danish Forest and Nature Agency)

5.2 Other issues for protecting water quality

5.2.1 Water quality protection and the Post-2015 Development Agenda

As emphasised throughout this report, water is a key requirement for the sustenance of human life and sustainable development. It is not surprising, then, that water quality issues are strongly linked with other development themes such as poverty, hunger, health, education, gender inequality, and environmental sustainability. In Chapter 3, for example, it was reported that the groups most vulnerable to pathogen water pollution are women and children who still rely on surface waters for their domestic needs. It was also recounted that poor fisher are vulnerable to organic pollution and smallholder farmers to salinity pollution.

The lack of access of poor people to water of adequate quality contributes to socio-economic inequalities. On the positive side, since 1990 more than two billion people have gained access to improved sources of drinking water through programmes associated with the Millennium Development Goals (WHO/UNICEF 2014b). Nevertheless, while access to drinking water has increased, the quality of surface waters used for household water supply in many parts of the developing world continues to deteriorate as articulated in previous chapters. Therefore, it is very significant that the new Sustainable Development Goals (SDGs) under the Post 2015 Development Agenda have ambitious targets not only for access to drinking water, but also for water quality (UN, 2015). A holistic and coherent approach is needed to tackle this and other goals. A concerted global education and awareness-building campaign around water quality issues will be needed, with targeted regional and national campaigns that connect water quality to issues of cultural and historical importance. Explaining the necessity of good water quality to households, the media, policy makers, business owners, and farmers can have a tremendous impact on protecting and restoring water quality.

5.2.2 Precedents for restoration

It is not necessary for developing countries to go through the same cycle of increasing water pollution, widespread degradation of freshwaters, and eventual recovery, that developed countries went through decades ago. The many different technical and management options available for coping with increasing pollution loads are given in Section 5.1 above.

Furthermore, it is possible to begin restoring stretches of rivers and lakes that are already polluted by building on experience from other parts of the world. For example, Chapter 4 presents the example of the restoration of a large segment of the Upper Tietê River in Brazil. Elsewhere in Latin America, the Medellin River in Colombia was restored through the efforts of the Medellin River Sanitation Programme and integrated urban water management (Kraemer et al., 2001). Water quality in the eastern part of Columbia was improved by employing the polluter pays principle which led to an expansion of wastewater treatment (Kraemer et al., 2001). In Africa, the water quality behind the Hartbeespoort Dam in South Africa was restored through biological remediation (Keto, 2013 and Kraemer et al., 2001). Many lakes and rivers have been restored in Europe, including Lakes Norvikken and Mälaren located in Sweden which were revived by reducing phosphorus loadings (Schindler, 2012).

The countries along the Elbe River collaborated successfully in restoring their river through an effective institution called the International Commission for the Protection of the Elbe (see Chapter 4). The Commission championed wastewater treatment in the public sector, conveyed water management reports to the public, and carried out many other activities to promote water quality management in the basin (Dombrowsky, 2008). Meanwhile, the Rhine Action Programme brought together its riparian states in a successful effort to restore the water quality of the Rhine (Raith, 1999; Bernauer, 2002). Similarly, the London River Action Plan was instrumental in restoring the integrity of the Thames River (London Rivers Action Plan, 2009).

One lesson from these and other examples presented in Chapter 4 is that an *action plan*, agreed upon by all the main actors in a river basin, is a key step in restoring rivers and lakes. Another lesson is that it is useful to set up a *collaborative institution*, such as an international commission, for developing and carrying out the action plan.

5.2.3 Financing and governance for protecting and restoring freshwaters

It is generally accepted that the infrastructure for managing water, wastewater and sanitation will require considerable additional investments. Because of the high costs of conventional wastewater collection and treatment, pollution control agencies usually combine financing with cost recovery measures. These might include, for example: direct cost recovery from the user/polluter (also known as "beneficiary charges"), indirect local taxation (typically using property tax as a vehicle), and subsidies from other government departments. Cost recovery also requires sound regulatory frameworks and policies. Without this enabling environment, the investments needed to support water pollution control will be inaccessible to most developing countries.

Financing of wastewater infrastructure in developing countries comes from various sources including overseas development assistance programmes of donor countries, multinational financial institutions, or international commercial lending and credit agencies.

One way to achieve sustainable financing for water pollution control is to adopt a mix of economic policy instruments that foster an efficient allocation and use of water and protect and reduce the pollution of water resources. As highlighted by the fourth principle of the Dublin statement on sustainable water management adopted by the UN in 1992, all uses of water have an economic value. Managing water as an economic good is an important way of achieving efficient and equitable water use and of encouraging conservation and protection of water resources. The use of economic instruments in water resources management is often more cost effective than other instruments, because it helps internalise the costs of water pollution (Klarer et al., 1999).

Over the years, it appears that the barriers to controlling water pollution have stubbornly remained in place (Camdessus, 2003; UN-Water, 2015a). For example, many governments and institutions from the river basin to country level still have not adopted a strategic approach to wastewater management based on sound planning and evidence. Another important barrier, especially in developing countries, has been the fragmentation of institutional responsibilities for wastewater management which prevents efficient coordination of actions. This was brought up in Chapter 4 in the discussion of water quality management in the Godavari River Basin (Table 5.3). In addition, several case studies in this chapter highlighted the importance of participatory processes, such as "Research in Action" REACT in Tunisia, including community involvement and inclusion of indigenous knowledge.

But there are signs that some developing countries are giving higher priority to wastewater and water resources management. Two examples are the newly adopted Africa Water Vision for 2025 and the establishment of the African Ministerial Council on Water (AMCOW) (Meena, et al, 2010). These steps contribute to the good governance needed to tackle water quality degradation. Good governance, including evidenced-based policymaking and the effective application and enforcement of legal and institutional restrictions on water pollution, will be a prerequisite to meeting the global water quality challenge. Many examples of good governance solutions from the case studies in Chapter 4 are given in Table 5.3.

Table 5.3: Summary of governance solutions mentioned in the case studies (Chapter 4).

Case study	Pollution problem	Governance bodies *	Interest organisations	Programmes and policy instruments
Upper Tietê	Organic pollution	São Paulo Environment Agency	Upper Tietê River Basin Committee	Tietê River Cleanup Program
Godavari	Organic pollution	State Pollution Control Boards, State Groundwater Boards, State Water Resources/ Irrigation Department, Urban Local Bodies		
Volta	Pathogen pollution		Volta Basin Authority	Convention on the Status of the Volta River

Table 5.3: cont.

Case study	Pollution problem	Governance bodies *	Interest organisations	Programmes and policy instruments
Chao Phraya	Pathogen pollution	Electricity Generating Authority, Royal Irrigation Department, Pollution Control Department, Regional Environment Office		National Economic and Social Development Plan, Plan for Natural Resources and Environment Management, Wastewater discharge fees (Polluter-Pays-Principle)
Vaal	Salinity	Department of Water and Sanitation		Water Act of South Africa, Law-binding management objectives (Resource Quality Objectives)
Medjerda	Erosion, salinity, nutrients	Direction Générale des Ressources en Eau, Agence Nationale de Proctetion de l'Environnement		
Elbe	Eutrophication		International Commission for the Protection of the Elbe River, River Basin Community Elbe	European Water Framework Directive, Urban Wastewater Treatment Directive, Nitrate Directive, Hazardous Substances Directive, Floods Directive
Hudson	Organic chemical pollution	Department of Environmental Conservation, New York City Department of Environmental Protection		Hudson River Estuary Program

5.3 Some questions for a full assessment

This chapter has clearly shown that many technical and governance solutions are available to meet the water quality challenge. These include new approaches that were not available to the developed countries some decades ago when population growth and increased economic activity led to a substantial increase in water pollution. It was also shown that no single set of solutions will work everywhere. This is because of the great variation in types of water pollution, sources of water pollution, socio-economic conditions, and hydro-ecological boundary conditions. On the other hand, similar water quality challenges are occurring around the world even if the locations and situations are very different. Therefore, it may be possible to develop different packages of technical and governance options that can be used in many different river basins to deal with similar problems. In order to identify these packages, a full global water quality assessment should address the following questions:

- What are the types and sources of water pollution related to various socio-economic and eco-hydrological conditions?
- What is the efficiency and success rate of existing water pollution measures and programs?
- What are the most important drivers of water pollution?
- For a particular location, what is the relationship between pressures, impacts, and responses to water quality degradation?
- What are effective clusters of technical and governance options for particular archetype water quality problems?
- What are the most useful indicators for tracking progress towards the water quality Sustainable Development Goal?

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Appendix

Appendix

Appendix A

A1 Available data from GEMStat (1990–2010)

Table A.1: Overview of data availability in the time period 1990-2010 based on GEMStat. Stations were assigned to global river basins (Source: Major River Basins of the World/Global Runoff Data Centre. Koblenz, Germany: Federal Institute of Hydrology BfG). Maximum number of measured parameters = 26. Number of measurements = all measurements of all parameters of all stations within a river basin.

Subregion	River basin	Data available from–to	No. of stations/ RB	No. of measured parameters	No. of measurements
North-Africa	Nile	1990-2010	2	15	425
	Oum-Er-Rbia River	1994-2010	1	13	2,186
	Sebou	1990-2010	2	14	3,098
South-Africa	Groot Kei	1990-2010	1	9	1,394
	Groot Vis	1990-2010	1	9	1,686
	Incomati	1990-2009	1	9	1,452
	Indian Ocean Coast	1990-2010	3	9	1,730
	Limpopo	1990-2010	7	9	4,877
	Olifant	1990-2010	1	9	972
	Orange	1990-2010	5	10	6,281
	South Atlantic Coast	1990-2010	1	9	1,874
	Tugela	1990-2010	2	10	1,734
West-Africa	Niger	1992-1996	7	12	463
	Pra	1991-1994	1	11	283
	Senegal	1991-2000	5	11	129
	Volta	1991-1995	1	12	331
Central-America	Colorado (Caribbean Sea)	1990-1996	17	14	2,790
	Grijalva-Usumacinta	1990-1996	2	15	1,366
	Panama Canal	2003-2010	51	14	16,296
	Panuco	1990-1996	1	15	369
	Papaloadan	1990-1996	1	16	622
	Rio Boqueron	2003-2010	1	14	1,075
	Bravo	1990-1996	2	16	1,134
	Santiago-Lerma-Chapala	1990-1996	1	16	257
North-America	Alabama	1990-2001	4	2	307
	Alsek	1992-2004	1	5	172
	Churchill	1990-1997	1	9	181
	Fraser	1990-2004	3	8	1,371
	Hudson	1990-2001	8	9	383
	Mackenzie	1990-2004	4	9	749
	Mississippi	1990-2005	59	11	5,427
	Nelson-Saskatchewan	1990-1997	3	9	600
	Bravo	1990-2005	16	10	2,509
	Sacramento	1990-2002	12	10	694
	Skeena	1990-2004	1	7	561
	St. Croix	1990-1996	1	6	281
	St. John	1992-1994	1	7	69
	St. Lawrence	1990-2005	9	9	891
	Susquehanna	1990-1995	1	10	307
	Yukon	1990-2005	6	9	490

Subregion	River basin	Data available from–to	No. of stations/ RB	No. of measured parameters	No. of measurements
South-America	Amazon	1993–2010	461	17	7,223
	Doce River	1997–2010	3	14	1,578
	Guandu River	2001–2010	1	11	1,198
	Jequitinhonha River	1997–2010	3	14	1'457
	Meia Ponte River	2001–2010	1	11	357
	Oyapock	2004	4	5	20
	Paraguacu River	2008–2010	2	11	240
	Parana	1990–2010	169	19	19,660
	Parnaiba	1992–2010	20	14	500
	Sao Francisco	1990–2010	45	16	2,487
	Tocantins	1996–2010	82	15	1,176
	Uruguay	1990–2010	37	15	1,479
East-Asia	Bei Jiang/His	1990–1996	2	15	1,268
	Chang Jiang	1990–1997	3	17	2,276
	Han	1990–2010	3	13	2,939
	Hwang Ho	1990–1997	2	15	1,306
	Japan*	1990–2010	17	18	31,117
	Liao	1990–1997	1	12	892
	Min	1990–1996	1	12	810
	Qiantang	1990–1996	1	12	655
South-Asia	Cauvery	1990–2008	8	15	12,112
	Chaliyar	1990–2008	2	15	4,124
	Ganges-Brahmaputra-Meghna	1994–2010	5	10	513
	Godavari	1990–2008	6	15	8,273
	Indus	1990–2003	4	15	4,589
	Krishna	1990–2008	7	15	13,664
	Mahandi	2001–2008	5	15	2,960
	Mahi	1990–2008	2	15	3,450
	Narmada	1990–2008	5	15	6,260
	Penner	1990–2008	1	15	991
	Periyar	1990–2008	2	15	4,126
	Sabarmati	1990–2008	3	15	4,082
	Sahyadri	1990–2008	10	15	8,329
	Sri Lanka*	2003–2010	27	12	12,198
	Subarnerekha	1992–2008	4	14	3,915
	Tapti	1990–2008	4	15	6,503
South-East-Asia	Chao Phraya	1990–1993	3	11	308
	Indonesia*	1990–1994	6	15	2,163
	Mekong	1990–2009	72	14	50,107
East Europe	Amur	1990–2010	2	8	822
	Danube	1990–1996	2	9	937
	Don	1990–2010	1	8	347
	Dvina-Pechora	1990–2010	5	8	3,070
	Kolyma	1990–2010	1	7	590
	Lena	1990–2010	2	7	620
	Narva	1990–2010	2	7	391
	Ob	1990–2010	9	7	5,611
	Oder	1992–2003	3	9	3,297
	Vistula	1992–2003	3	8	3,168
	Volga	1990–2010	4	7	2,059
	Yenisey	1990–2010	5	7	3,608

Subregion	River basin	Data available from–to	No. of stations/ RB	No. of measured parameters	No. of measurements
Northern Europe	Dee	1990–2005	1	9	923
	Denmark*	1990–1996	4	5	1,070
	Forth	1990–2005	1	9	1,165
	North West England	1990–2005	1	10	1,213
	Northumbria	1990–1995	3	4	598
	Oulu	1993–1995	1	3	101
	Pasvik	1993–1995	1	3	95
	Severn	1990–2005	1	11	1,154
	South West	1990–2005	1	11	1,247
	Thames	1990–2005	1	11	1,110
	Torne	1990–1998	2	7	304
	Trent	1990–2005	1	11	1,253
	Tweed	1990–1996	1	10	827
Southern Europe	Douro	1990–1995	7	5	1,799
	Ebro	1990–1995	3	5	991
	Guadalquivir	1990–1995	3	5	903
	Guadiana	1990–1995	4	5	1,047
	Italy*	1990–1995	8	6	1,609
	Po	1990–1995	8	6	2,295
	Portugal*	1990–1994	2	5	478
	Tagus	1990–1995	6	10	1,872
	Turkey*	1993–2002	7	4	1,170
Western Europe	Danube	1990–1996	7	9	660
	Elbe	1990–1995	4	9	830
	Garonne	1990–1996	4	8	1,224
	Loire	1990–1996	5	8	2,062
	Meuse	1990–2010	18	12	7,178
	Oder	1993–1995	1	4	138
	Rhine	1990–2003	19	12	10,708
	Rhone	1990–2002	8	9	4,729
	Schelde	1990–2010	49	13	25,045
	Seine	1990–1996	4	9	1,904
	Weser	1990–1995	2	9	666
	Yser	2001–2010	3	11	1,671

*Not all of GEMStat stations could be assigned to a river basin. In this case, the number of stations, measurements, and parameters of a country were listed.

Appendix B

B1 WorldQual – model description

B1.1 The modelling framework

WorldQual is a continental scale water quality model used to increase understanding of large scale water quality patterns, support large scale assessments of water quality degradation, and relate water quality degradation to threats to human health, food security, and aquatic ecosystems.

WorldQual simulates loadings and in-stream concentrations of different water quality parameters on a 5 by 5 arc minute spatial grid (about 9 by 9 km at the equator). It has been tested and applied in several previous studies, e.g. Malve et al. (2012), Punzet at al. (2012), Reder et al. (2013), Reder et al. (2015), Voß et al. (2012), and Williams et al. (2012).

WorldQual calculates loadings to rivers and the resulting in-stream concentrations based on the hydrological information simulated by WaterGAP3 (see below) and based on standard equations of water quality dynamics. It has a monthly temporal resolution. Up to now it has been used to simulate biochemical oxygen demand (BOD5), faecal coliform bacteria (FC), total phosphorus (TP), total nitrogen (TN) and total dissolved solids (TDS) (Malve et al., 2012; Voß et al., 2012; Reder et al., 2013; Reder et al., 2015; Williams et al., 2012).

WorldQual is linked to a global integrated water model "WaterGAP3" within a common modeling framework. WaterGAP3 is made up of two main components: (i) a water balance model to simulate the characteristic macro-scale behavior of the terrestrial water cycle in order to estimate water availability (Alcamo et al., 2003; Müller Schmied et al., 2014; Schneider et al., 2011; Verzano 2009; Verzano et al., 2012), and (ii) a water use model to estimate water withdrawals and consumptive water uses for agriculture, industry, and domestic purposes (aus der Beek et al., 2010; Flörke et al., 2013). WaterGAP3 also operates on a 5 x 5 arc minute spatial resolution (see Figure B.1).

Using a time series of climatic data as input, the hydrological model calculates the daily water balance for each grid cell, taking into account physiographic characteristics such as soil type, vegetation, slope, and aquifer type. Runoff generated on the grid cells is routed to the rier basin outlet on the basis of a global drainage direction map (Lehner et al., 2008), taking into account the extent and hydrological influence of lakes, reservoirs, dams, and wetlands. The climate input for the hydrology model consists of precipitation, air temperature, and solar radiation. These data come from the WATCH data set (Water and Global Change) applied to ERA-Interim data (WFDEI) for the time period 1979–2010 (Weedon et al. 2014). The climate data have a temporal resolution of one day and a spatial resolution of 0.5° by 0.5° (latitude and longitude, respectively) downscaled to the 5 arc minute grid cells.

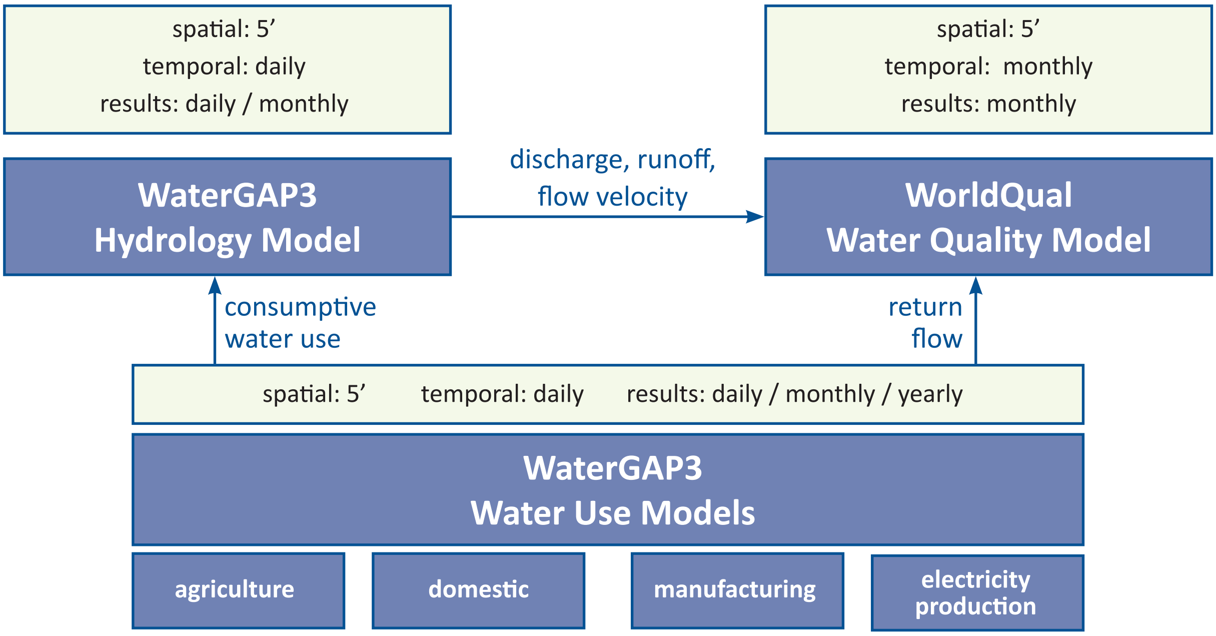

Figure B.1: Overview of the WaterGAP3 modelling framework (Verzano 2009, modified).

B1.2 Pollution loadings

B1.2.1 Sources of pollution

Loadings are calculated for point sources and diffuse sources for the following parameters:

- faecal coliform bacteria (FC; pathogen pollution),
- biological oxygen demand (BOD; organic pollution),
- total dissolved solids (TDS; salinity pollution), and
- total phosphorous (TP; eutrophication).

Figure B.2 illustrates the point and diffuse sources represented in the WorldQual model. Point sources include domestic sewered wastewater, wastewater from manufacturing industries and urban surface runoff. Diffuse sources include agriculture and background. The model also takes into account non-sewered domestic sources, of which some sources are handled as point sources, and some as diffuse sources (See B1.2.3).

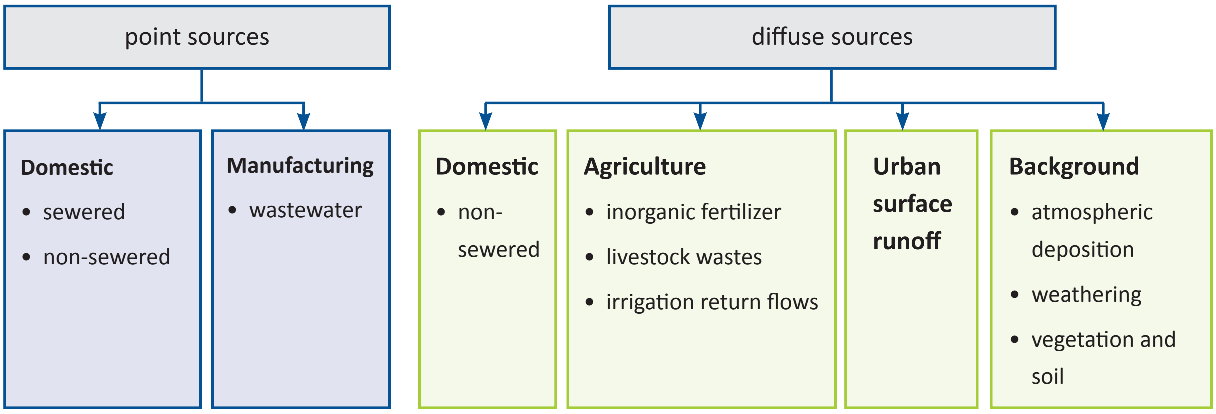

Figure B.2: Pollutant loading sectors in WorldQual categorized as either point sources or diffuse sources.

B1.2.2 Domestic sewered sector

Loadings from the domestic sewered sector are calculated on a grid cell level by multiplying a per capita emission factor (BOD, FC, TDS, and TP) with the urban and rural populations connected to a sewage system (Williams et al., 2012). The resulting domestic sewered loadings are then abated depending on the level of wastewater treatment. National values for percentages of primary, secondary, and tertiary wastewater treatment of sewage treatment plants (STPs) are downscaled to the grid-cell level to define a cell-specific reduction rate. Additionally, reduced treatment efficiency due to deficiencies of STPs is taken into account. Data are available from the WHO/UNICEF Joint Monitoring Programme (2013) for the years 1990, 2000 and 2010. These data are applied to the years 1990–1995, 1996–2004 and 2005–2010, respectively. Further information on efficiencies of STPs were collected for several countries and applied as continental averages (Table B.1).

Gridded population data are available from the History Database of the Global Environment (HYDE) version 3.1 (Klein Goldewijk, 2005; Klein Goldewijk et al., 2010) for the time period 1990–2005. For the remaining period 2006–2010, national data from UNEP (2015) were allocated to grid cells based on the gridded population density of the year 2005.

BOD per capita emission factors were collected from the literature. If no data were available, an average per capita emission factor was calculated per region.

Table B.1: Default sewage treatment plants efficiency.

Region	Regional average [%]	Reference
Africa	58	Murray and Drechsel (2011), UNEP/GEF (2009), FAO and WHO (2003), WHO CEHA (2005), Water Affairs South Africa.(2011)
Asia	59	Tacis (2000), CPCB (2005), CPCB (2009), MoP COSIT (2011), UNECE (2009), Government of Mongolia (2012), Shukla et al. (2012), Murtaza and Zia (2012), UNDESA-DSD (2004), UNECE (2012 a, b)
Latin America	47	UNEP (1998), Ojeda and Uribe (2000), Lopera Gomez et al. (2012)

Table B.2: Default BOD per capita emission factors per GEO region.

Region	Regional average [g/cap/day]	Reference
Africa	37	Metcalf & Eddy et al. (2014), UNEP (2000), Williams et al. (2012)
Asia	40	IPCC (2006), Williams et al. (2012)
Latin America	56	Metcalf & Eddy et al. (2014), Williams et al. (2012)

Regional numbers (Table B.3) have been derived from the concentration of FC in human excreta taking into account differences in diet, climate, and state of health (Feachem et al., 1983). Assumed reduction rates for primary, secondary, and tertiary treatment are intermediate values from Dorner (2004); Endale et al. (2012); George et al. (2002), Hwang (2012), Qureshi and Qureshi (1990), Saleem et al. (2000), Samhan et al. (2007). Several values within the range given by the different references for the human per capita FC excretion were tested with the model. During this testing all parameters except the human per capita excretion were kept constant. Best results of simulated FC in-stream concentrations compared to measured FC in-stream concentrations were achieved with the numbers provided in Table B3 (see Reder et al., 2015).

Table B.3: Default FC per capita emission factors per GEO region. Regional differences arise from diet, climate, and state of health.

Region	Regional average [cfu*/cap/year]	Reference
Africa	$170*10^{10}$	Feachem et al. (1983), Finegold (1969), Maier et al. (2009), Moore and Holdeman (1974); Reder et al. (2015), Schueler and Holland (2000), van Houte and Gibbons (1966), Zubrzychi and Spaulding (1962).
Asia	$700*10^{10}$	
Latin America	$500*10^{10}$	

* cfu: colony forming unit

Based on UNEP (2000) and Mesdaghinia et al. (2015) a TDS emission factor of 100 g/cap/day was assigned to all three continents.

The TP per capita emission factors were calculated as follows. First, the protein per capita consumption per country and year was used from FAOSTAT (FAO, 2014). It is assumed that about 16 per cent of the protein is nitrogen whereof, on average, 36.5 per cent is excreted by the human digestive tract (van Drecht et al., 2009). Second, the TP per capita emission is about one-sixth of the nitrogen emission (van Drecht et al. 2004). Continent-specific averages of protein consumption were taken in case country-specific protein consumption data were not available.

B1.2.3 Domestic non-sewered sector

For the human waste produced where sewers are not used, three types of sanitation practices are accounted for: (i) waste produced with some type of private on-site disposal, such as septic tanks, pit toilets, bucket latrines etc. (diffuse source), (ii) waste produced where people practice open defecation (diffuse source), and (iii) waste produced where people use hanging latrines (point source).

Waste loadings from onsite disposal (e.g. septic tanks) are calculated by multiplying a per capita emission factor with the population connected to these disposal types. A release factor is applied to estimate the final loading which enters the stream.

Waste loadings from open defecation are calculated by multiplying the emissions per capita per year times a release rate of 0.1 per cent (from Section B1.2.7). This annual loading is then transported to a stream on a monthly basis proportional to monthly runoff from WaterGAP3. The emissions per capita for BOD, FC, TDS, and TP follow the assumptions in Section B1.2.2.

Waste loadings from hanging latrines are calculated by multiplying the emissions per capita per year times the population using this sanitation practice. No reduction takes place as the feces are directly disposed into the surface waters.

Data on different sanitation practices are derived from the WHO/UNICEF Joint Monitoring Programme (JMP) for Water Supply and Sanitation country files between 1980 and 2011 (JMP, 2013), national databases, reports, and a literature search. As for the domestic sewered sector, data are only available for the years

1990, 2000, and 2010, and assumed to be unchanged over 5 year periods.

B1.2.4 Manufacturing sector

Loadings from the manufacturing sector are calculated by multiplying the average raw effluent concentration times the return flow from manufacturing industries (Williams et al., 2012). The manufacturing load is reduced by a reduction factor depending on the treatment level following the assumptions made for the domestic sector. Treatment rates and deficiencies of sewage treatment plants are assumed to be the same as in the domestic sewered sector. Manufacturing wastewater volumes are calculated by the water use model of WaterGAP3.

A representative value of 400 mg/l was assigned to the effluent concentration of BOD from industrial sources based on literature (Al-Kdasi et al., 2004; Azmi and Yunos, 2014; EEAA, 2002; Haydar et al., 2014; Mortula and Shabani, 2012; UNEP, 1998; UNEP, 2000; Williams et al., 2012).

For TDS, the effluent concentration was assumed to be 3000 mg/l according to Al-Kdasi et al., 2004; Azmi and Junos, 2014; EEAA, 2002; Haydar et al., 2014; Jain et al., 2003; Kang and Choo, 2003; Metcalf & Eddy, 2014; Mortula and Shabani, 2012; Tas et al., 2009; Williams et al., 2012).

For FC, the effluent concentration was assumed to $3.55*10^6$ cfu/100ml according to Ayoub et al. (2000), Bordner and Carrol (1972), Caplenas et al. (1981), Caplenas and Kanarek (1984), Clark and Donnison (1992), Das et al. (2010), Ekundayo and Fodeke (2000), Gauthier and Archibald (2001), Hoyle-Dodson (1993), Knittel et al. (1977), McCarthy et al. 2001), Megraw and M. Farkas (1993), Pramanik and Abdullah-Al-Shoeb (2011).

For TP raw effluent concentrations from Europe (6.2 mg/l) are also applied to industrial sources in Africa, Asia and Latin America (Demirel et al., 2005; Johns, 1995; Gönen, 2005; Kim et al., 2007).

B1.2.5 Urban surface runoff

Loadings generated from urban surface runoff are calculated by multiplying the typical event mean concentration by the urban surface runoff produced on each cell (Williams et al., 2012). The resulting load is assumed to be reduced to the same treatment levels assumed for the domestic sewered sector. The hydrology module of WaterGAP3 provides the urban surface runoff rates.

Assumptions and literature for the event mean concentrations (EMCs) of BOD and TDS for different sub-regions are shown in Tables B.4 and B.5.

Table B.4: Default BOD event mean concentrations (EMC).

Region/Sub-region	Regional EMC* [mg/l]	Reference
Northern Africa, South Africa	19	Chrystal (2006)
Central Africa, Eastern Africa, Western Africa, Southern Africa (except South Africa)	62	Adedeji and Olayinka (2013), Adekunle et al. (2012), Alo et al. (2007)
South Africa	12	Chrystal (2006)
West Asia	19	Chrystal (2006)
Asia and the Pacific	105	Choe et al. (2002), Chow et al. (2013), Dom et al. (2012), Ho & Quan (2012),Luo et al. (2009), Karn & Harada (2001), Lee & Bang (2000), Li (2010), Maniquiz et al. (2010), Nazahiyah et al. (2007), Sharma et al. (2012), Yusop et al. (2005)
Latin America	12	Derived from Europe

Table B.5: Default TDS event mean concentrations (EMC).

Region/Sub-region	Regional EMC [mg/l]	Reference
Africa	178	Wondie (2009)
Asia	246	Sharma et al. (2012), Zope et al. (2008)
Latin America	205	Al-Houri et al. (2011)

FC event concentrations vary widely. For example, they were measured to be around 10^4 cfu/100ml to 10^6 cfu/100ml in stormwater runoff in South Africa (Jagals, 1997), 10^9 cfu/100 ml in China (Thomann and Mueller, 1987), and 10^4 to 10^6 in the USA (Erickson et al. 2013). An intermediate value of 10^6 cfu/100 ml was assumed for all three continents.

An average TP event mean concentration of 2.04 mg/l was assumed for all three continents based on Lee and Bang (2000), Ho and Quan (2012), Luo et. al (2009), and Taebi and Droste (2004).

B1.2.6 Agricultural inorganic fertilizer

Inorganic fertilizer is assumed to be applied to all agricultural grid cells and is an important source of TP loadings. Baseline fertilizer application rates of phosphorus were estimated from FAO (2006) for the 21 different crop types distinguished by the WaterGAP3 model. The baseline data are representative for the time period 1995 to 1999.

For earlier and later time periods, baseline data are scaled by national fertilizer application rates (IFA, 2014) averaged over 5-years-periods 1990–1994, 2000–2004 and 2005–2010. (Five year periods are used to smooth out uncertainties of annual fertilizer use.)

TP loadings from industrial fertilizer that reach the surface water system are calculated as a function of land surface runoff and soil loss.

B1.2.7 Agricultural livestock wastes

To calculate the amount of BOD, FC, TDS, and TP loadings from livestock (manure) the approach of Sadeghi and Arnold (2002) is applied. Here, the amount of the relevant constituent in manure is multiplied with an appropriate release rate and the surface runoff. The amounts of BOD, FC, TDS, and TP in different types of manure are derived from ASAE (2003) and SCS (1992). To consider different levels of animal nutrition on different continents, the amount of manure constituents are corrected by a livestock conversion factor from FAO (2003) following the approach of Potter et al. (2010) for nutrients. For FC and BOD the release rates of manure vary with manure type and differ according to the source of literature (e.g. EPA, 2003; Ferguson et al., 2007). The best estimate of release rates was found to be 0.1 per cent. Release rates for TP are calculated as a function of land surface runoff and soil erosion. The decay of FC contained in stored manure or after manure is applied to soil is described by Chicks law (Crane and Moore, 1986). The FC decay rate in this case is assumed to be the same as in Europe (Reder et al., 2015). Manure application is assumed to take place all year round because of the continuous presence of livestock. To calculate the wash-off of pollutants from land surfaces, the land surface runoff from the hydrology module of WaterGAP3 is used.

B1.2.8 Agricultural irrigation

In WorldQual TDS loadings from irrigated agriculture were estimated by multiplying a mean irrigation drainage concentration by the irrigation surface return flows calculated by the water use model of WaterGAP3. Mean irrigation drainage concentrations show high variations from 1,000 mg/l up to 8,000 mg/l in Asia. To account for the regional differences, salt emission potential classes (SEPC) were defined as described in Voß et al. (2012) and Williams et al. (2012). The definition of SEPC is based on natural salt classes (SC) and the gross domestic product per capita classes (GDPC). Natural SC are a combination of primary salt enriched soils (S) and arid–humid climate conditions (H). The highest SEPC was set to 3,500 mg/l for developing countries (Bakker et al., 1999; Chen et l., 2011; Irrigation Department Lahore, 2014; World Bank, 1999), while the lowest SEPC was set to 165 mg/l (cf. B1.2.9). These values reflect the range from arid regions with salt affected soils and low irrigation technique standards (highest SEPC class) to humid regions with no salt affected soils, and likely high irrigation technique standards (lowest SEPC class).

B1.2.9 Background loadings

A certain amount of phosphorus enters drainage basins in the form of atmospheric deposition. In the present study, global gridded estimates of TP deposition rates were taken from Mahowald et al. (2008). Additionally, natural phosphorus loads also originate from weathering. WorldQual's estimates of P-release by chemical weathering are derived from data of the global analysis of Hartmann et al. (2014).

Large amounts of background salinity in rivers come from weathering processes or surface salt deposits in river basins. Background concentrations of TDS were estimated by averaging GEMStat TDS measurements from pristine stations and sorting these data according to 55 soil types from the FAO Harmonized World Soil Database (Fischer et al. 2008). These data were then applied as background concentrations in each grid cell according to the type of soil in that grid cell. For respective soil types, these background TDS concentrations ranged between 5 mg/l and 832 mg/l. However, about 10 per cent of all river reaches have natural background greater than 450 mg/l the level used in this pre-study to designate "moderate" salinity pollution. For soil types not covered by GEMStat measurements, an average background concentration of 165 mg/l was used.

B1.3 Calculation of in-stream concentrations

River concentrations are computed by combining the loadings of the various substances with the dilution capability of the river discharge in each grid cell. Non-conservative substances (FC and BOD) then decay downstream. Standard one dimensional stream equations from Thomann and Mueller (1987) as described in Voß et al. (2012) are used for these calculations. These equations perform a mass balance between loadings and receiving water and account for the decay of non-conservative pollutants as they travel downstream by assuming first order decay.

The decay coefficient of BOD is assumed to be a function of river temperature (Thomann and Mueller, 1987, Punzet et al., 2012). The decay coefficient of FC is assumed to be a function of solar radiation, temperature, and the settling rate of bacteria (Thomann and Mueller, 1987; Reder et al., 2015). TDS is modelled as a conservative substance with no decay.

The final concentration of each grid cell is routed towards the river mouth following a high-resolution drainage direction map (Lehner et al., 2008).

B1.4 TP retention in surface waters

TP retention is calculated on river basin scale. The conceptual approach and the parameter settings are based on Behrendt et al. (2002), where nutrient retention is empirically calculated with hydraulic load (Behrendt and Opitz, 1999). Hydraulic load is defined as the annual runoff as calculated by WaterGAP3 divided by the surface area of the respective lake (Hejzlar et al., 2009).

B1.5 Model testing

Data used for model calibration and testing were kindly provided from national and international databases of the Agencia Nacional de Aguas, Brasil; Department of Water and Sanitation, Republic of South Africa; Dirección Ejecutiva de la Comisión Trinacional para el desarrollo de la Cuenca del Río Pilcomayo; Instituto de Hidrología, Meteorología y Estudios Ambientales, Colombia; Instituto Nacional de Meterologia e Hidrologia (INAMHI), Ecuador; Mekong River Commission; Ministerio del Medio Ambiente, Gobierno de Chile, Chile; Pollution Control Department (PCD), Ministry of Natural Resources and Environment, Thailand; Secretaría de Ambiente y Desarrollo Sustentable de la Nación (SADS), Argentina; United Nations Global Environment Monitoring System (GEMS) Water Programme; Water Resources Information System of India, India, and literature research.

Biochemical Oxygen Demand Model

The BOD model calculations are compared to observations in Figure B.3a. This figure contains measured data from 2902 Latin American stations (in total 36,756 measurements), 21 African stations (in total 523 measurements), and 648 Asian stations (in total 41,851 measurements). The agreement of model outcomes with observations is considered acceptable considering the approximations of the model, the uncertainties in the data, and the scale of the coverage of the model. Thousands of points are quite close to the 1:1 line in Figure B.3a but not visible because they are overlapping.

An important criterion for judging the performance of any model is to consider the purpose of the model and modelling application. In the case of this pre-study, the purpose of the model was not to compute concentrations exactly, but to estimate "pollution classes" (e.g. low, moderate, severe) as defined in Chapter 3, Table 3.8 for BOD, for example. Results in this form are more meaningful for assessments because they conform to the approach used by countries and river basin managers to interpret the status of their own freshwaters (national water quality standards typically divide the range of water quality conditions into "high", "low" and "medium" classes of water quality).

Figure B.3b shows that the model computes the same pollution class for BOD as observed in two-thirds of the grid cells with measurements. In more than 80 per cent of the grid cells the model computes the correct class plus or minus one class.

Faecal Coliform Bacteria Model

The model results of FC versus observations are shown in Figure B.4a. The following measurements were available for this comparison: 2818 Latin American stations (in total 47,888 measurements), 485 African stations (in total 14,068 measurements), and 501 Asian stations (in total 24,577 measurements). Again, most of these measurements are close to the 1:1 line, but not visible because they overlap.

The model performance as indicated by the scatter plot (B.4a), and comparison of FC pollution classes (B.4b) is as satisfactory as that of BOD.

Total Dissolved Solids Model

A comparison of calculated versus observed TDS is shown in Figure B.5a. The figure is based on a set of measurements that were available for Latin America, Africa and Asia: 760 Latin American stations (in total 18,040 measurements), 1,544 African stations (in total 162,551 measurements), and 655 Asian stations (in total 33,656 measurements).

The scatter plot (Figure B.5a) shows the same spread as for BOD and FC. However, the agreement between model and observations is not as symmetrical as it is for BOD and FC, indicating more bias in the TDS model than in the other models. On the other hand, the comparison of computed and observed pollution classes (Figure B.5b) shows a more than 80per cent agreement in pollution classes between model results and observations. In 90 per cent of the grid cells the model computes the correct class plus or minus one class.

Total Phosphorus (TP) Loading Model

The testing for phosphorus was somewhat different than for BOD, FC or TDS, because in this pre-study the model was used only to compute the loadings of total phosphorus from lake basins into lakes, not the in-stream concentrations of phosphorus.

In testing the model, its performance was examined through computing TP loads from both lake basins and river basins due to insufficient lake data, and because the model should perform equally well in computing loads from large lake basins as large river basins.

A comparison of calculated versus measured TP loadings into selected lakes is given in Figure B.6. Far fewer data were used for this comparison than for the other water quality parameters. For this selection of data, agreement of the model with measurements is quite good.

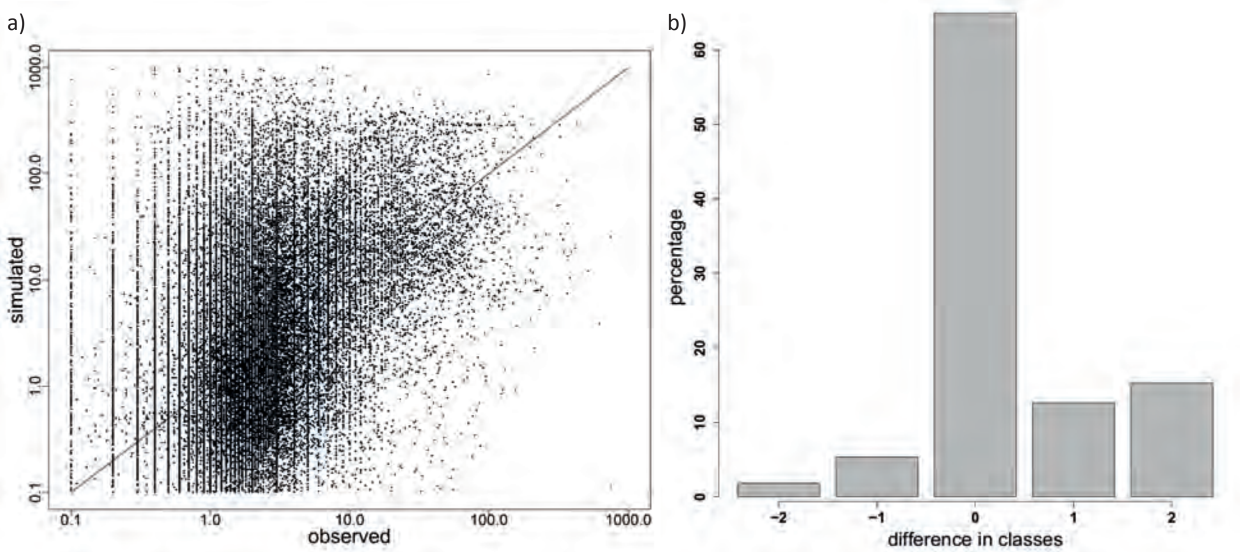

Figure B.3: a) Observed versus calculated (WorldQual) biochemical oxygen demand for the period 1990–2010 for stations from Latin America, Africa, and Asia between 1990 and 2010. Vertical streaks of data are an artefact of data collection and processing. Units are in mg/l. b) Measured and simulated BOD in-stream concentrations were grouped into three water pollution classes which were derived from thresholds given by governments and international organizations. The difference in classes between observed and simulated in-stream concentrations was determined and displayed as percentage of grid cells (having measurements) in which a difference occurred between the observed class (see Table 3.8) and the computed pollution class. "0" indicates that there was no difference between the observed and computed pollution class. Same data set as for Figure B.3 (a).

a) b)

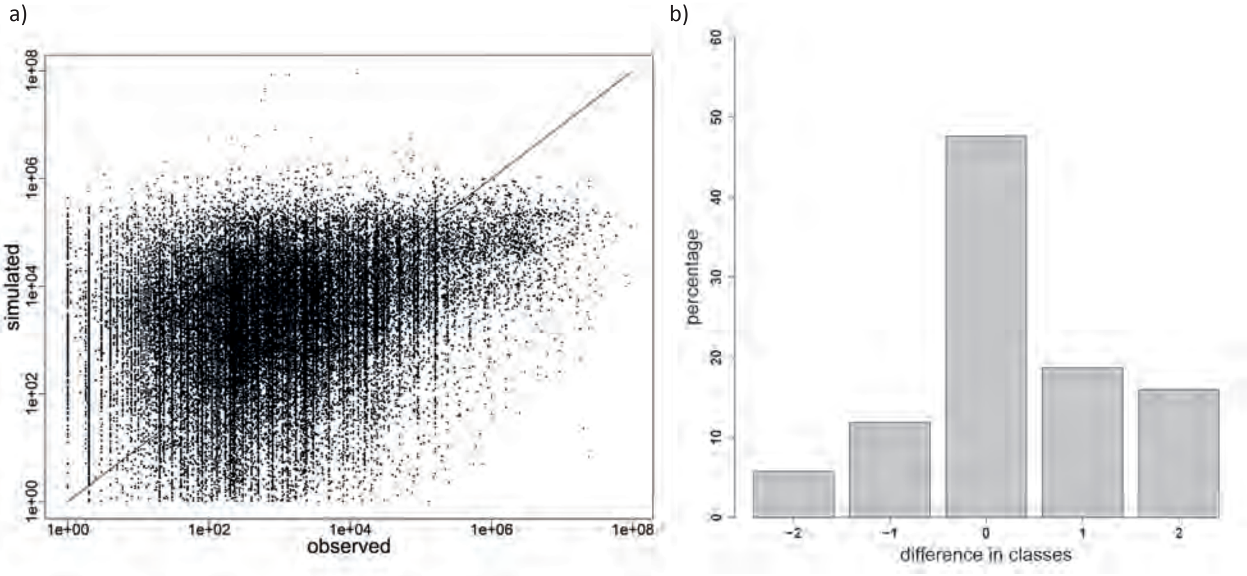

Figure B.4: a) Observed versus calculated (WorldQual) faecal coliform bacteria for the period 1990–2010 for stations from Latin America, Africa, and Asia between 1990 and 2010. Vertical streaks of data are an artefact of data collection and processing. Units are in cfu/100ml. b) Measured and simulated FC in-stream concentrations were grouped into three water pollution classes which were derived from thresholds given by governments and international organizations. The difference in classes between observed and simulated in-stream concentrations was determined and displayed as percentage of grid cells (having measurements) in which a difference occurred between the observed class (see Table 3.1) and the computed pollution class. "0" indicates that there was no difference between the observed and computed pollution class. Same data set as for Figure B.3 (a).

a) b)

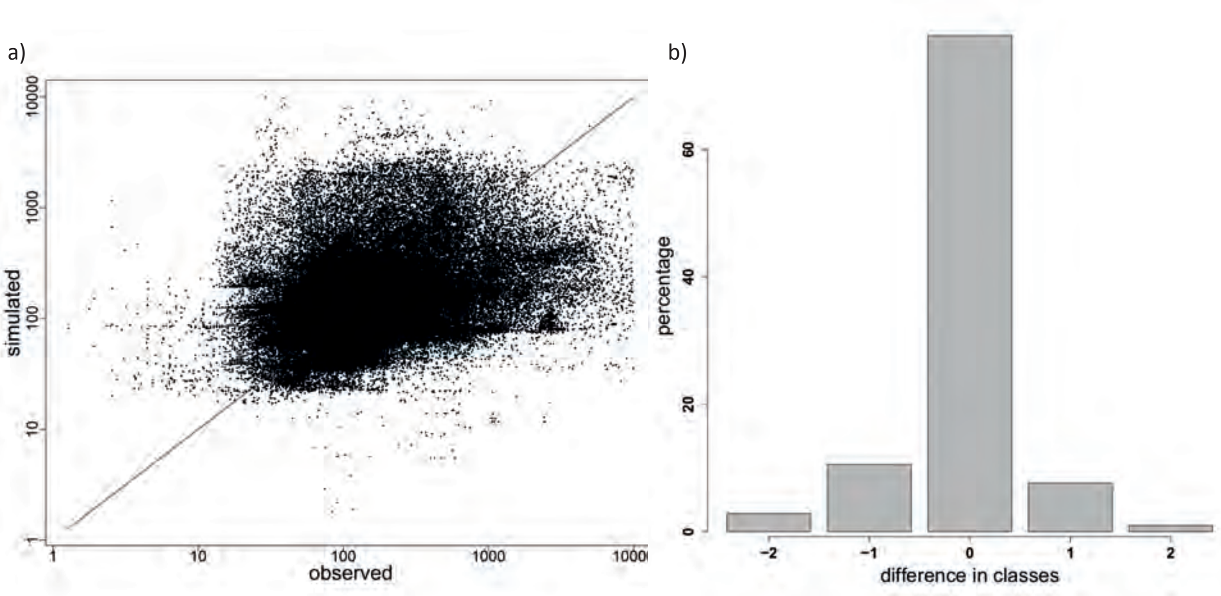

Figure B.5: a) Observed versus calculated (WorldQual) total dissolved solids for the period 1990–2010 for stations from Latin America, Africa, and Asia between 1990 and 2010. Units are in mg/l. b) Measured and simulated TDS in-stream concentrations were grouped into three water pollution classes which were derived from thresholds given by governments and international organizations. The difference in classes between observed and simulated in-stream concentrations was determined and displayed as percentage of grid cells (having measurements) in which a difference occurred between the observed class (see Table 3.12) and the computed pollution class. "0" indicates that there was no difference between the observed and computed pollution class. GEMStat data are not used for this scatter plot so as to avoid overlap with the stations used to estimate TDS background concentrations (Section B1.2.9). Also stations influenced by marine saltwater intrusion were omitted.

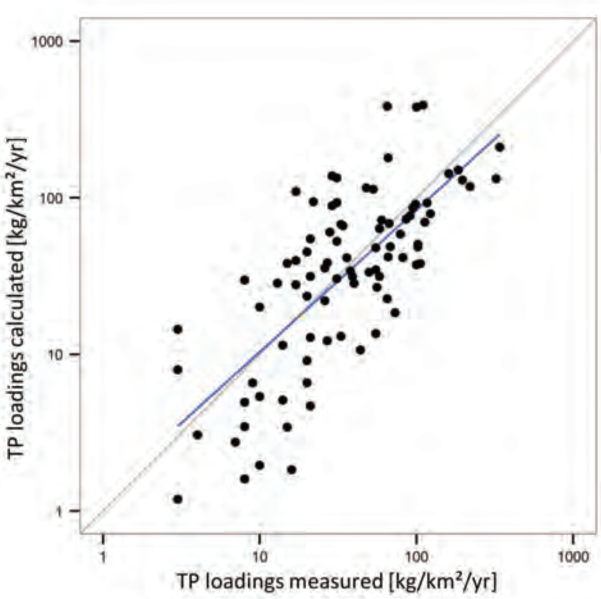

Figure B.6: Observed versus calculated (WorldQual) total phosphorus loads per lake basin or river basin area for the period 1990–2010 for worldwide stations. Units are in kg/km^2/year.

B2 Water quality standards

To establish the thresholds of water pollution classes for FC, BOD and TDS (Tables 3.1, 3.8, 3.12 in Chapter 3.) the below water quality standards from African, Latin American and Asian countries were compiled. European and American standards were also consulted.

Table B.5: Default TDS event mean concentrations (EMC).

Description	Country	Reference
Water quality standards for protected areas, source water, drinking water, aquatic fauna, industry, agriculture	China	MEP (2002)
Water quality standards for primary contact, irrigation, aquaculture, sailing, and animal farming	Costa Rica	Mora and Calvo (2010)
Water quality standards for primary contact	Europe, EEC	WHO (2000)
Water quality standards for bathing and swimming, irrigation	South Africa	DWA (1996), Britz (2013)
Water quality standards for primary contact	Colombia	WHO (2000)
Water quality standards for primary contact	Cuba	WHO (2000)
Water quality standards for primary contact	Ecuador	WHO (2000)
Water quality standards for primary contact	Puerto Rico	WHO (2000)
Water quality standards for primary contact	USA, California	WHO (2000)
Water quality standards for primary contact	Venezuela	WHO (2000)
Water quality standards for primary contact	France	WHO (2000)
Water quality standards for primary contact	Uruguay	WHO (2000)
Water quality standards for primary contact	Peru	WHO (2000)
Water quality standards for primary contact	Brazil	WHO (2000)
Water quality standards for primary contact	Israel	WHO (2000)
Water quality standards for primary contact	Japan	WHO (2000)
Water quality standards for primary contact	Mexico	WHO (2000)

Table B.7: Collected BOD water quality standards of different countries.

Description	Country	Reference
Freshwater standards	Brazil	Ministry of the Environment, Brazil (1984–2012)
Agriculture water use standards	China	Ministry of Agriculture of the People's Republic of China + FAO
River water quality	Egypt	El Bouraie et al. (2011), Egyptian law 48/1982
Drinking water quality and outdoor bathing standards	India	CPCB (2007–2008)
Freshwater quality standards (fisheries, conservation)	Japan	Ministry of the Environment, Japan
Freshwater standards	Mexico	Mexican Official Standard (NOM-001-ECOL-1996)
Water quality standards for drinking water, aquatic water, and irrigation water	Pakistan	adopted from WWF (2007)
freshwater species	South Africa	DWA (1996)
Surface water quality standards	Taiwan	EPA Taiwan (2010)
Drinking water quality standards	Tanzania	Environmental Management Act (2004)
Surface water quality standards	Thailand	Pollution Control Department (2004)

Table B.8: Collected TDS water quality standards of different countries.

Description	Country	Reference
Freshwater standards	Brazil	Ministry of the Environment, Brazil (1984–2012)
Agriculture water use standards	China	FAO (2013)
River water quality	Egypt	Egyptian law 48/1982 in El Bouraie et al. (2011)
Water quality guidelines for irrigation water use	FAO	Ayers and Westcot (1985)
Water quality standards for irrigation, industrial cooling, controlled waste disposal	Japan	Ministry of the Environment, Japan
Water quality standards for domestic, industry, and agriculture water use	South Africa	DWA (1996)
Water quality standards for domestic and irrigation water use	Kenya	Water Quality Regulations (2006)
Water quality standards for irrigation water use	Morocco	Moroccan regulation on irrigation water quality (2002)
Water quality standards for drinking water use	Oman	Victor and Al-Ujaili (1999)
Water quality standards for drinking water, aquatic water, and irrigation water	Pakistan	Government of Pakistan (2008), WWF (2007)

To establish levels of concern of water quality parameters with respect to inland fisheries, water quality standards were consulted (Table 3.7 in Chapter 3).

Table B.9: Collected water quality standards also with respect to inland fisheries

Reference	Water quality parameter
EPD (2011)	Chloride
European Commission (2006)	BOD, Oxygen
Geneviève M.C. & C.J. Rickwood (2008)	Ammonia, Oxygen, pH
LAWA (1998)	Ammonia, BOD, Chloride, Oxygen
Manivanan, R. (2008)	BOD
Michigan Water Quality Standards (1994)	Oxygen, pH
U.S. EPA (1986, 2015)	Ammonia, Chloride, Oxygen, pH
UNECE (1994)	Oxygen

B3 Literature on vulnerable groups

Table B.10: Literature consulted for data on percentage of population coming in contact with polluted water, and for estimating the most vulnerable groups to pathogen pollution.

Publication	Continent/country/region within country	Most vulnerable groups (e.g. “women washing clothes, children bathing; … “)	Other vulnerable groups For example: “Poor people bathing; poor farmers using polluted irrigation water;…”
Adeoye et al. (2013)	Nigeria		
North central	children fetching water	women (more “young female” than “adult female”) fetching water	
Aiga et al. (2004)	Ghana, Ashanti Region	children (2–14 years) swimming (play and exercise)	adult men fishing, fetching water, bathing
Barbir and Prats Ferret (2011)	Mozambique, N’Hambita Village, Sofala Province	women body and laundry washing	
Choy et al. (2014)	Malaysia, Peninsular (West) and Sabah (East)	people in the Peninsular Malaysia compared to the state of Sabah (East Malaysia)	children under 12 years & large households (more than 7 family members)
Day and Mourato (1998)	China, Beijing Region	children playing in and around the river	
Engel et al. (2005)	Ghana, Volta River Basin	children	
Feachem (1973)	Papua New Guinea, Highlands	women journeys to collect water	children or teenagers journeys to collect water
Gazzinelli et al. (1998)	Brazil, Nova União	children playing and fishing	
Gazzinelli et al. (2001)	Brazil, Rua da Grota	female (10–19 yrs.) using water for domestic and hygienic activities	
Kabonesa and Happy, March (2003)	Uganda	women using water for domestic purposes	children collecting water for domestic use
Lindskog and Lundquvist (1989)	Malawi, Rift Valley	women collecting water, bathing, laundry	children bathing
Manyanhaire and Kamuzungu (2009)	Zimbabwe, Mutasa District	women collecting water, bathing, doing laundry, cooking	
Mazvimavi and Mmopelwa (2006)	Botswana, Ngamiland	men carrying water for drinking and cooking	
North and Griffin (1993)	Philippines, Bicol Region	28% of poorest income quintile using water from springs, lakes, or rivers as main source	second, third and fourth income quintile using water from springs, lakes, or rivers as main source (20% each)
Sow et al. (2011)	Senegal, Ndombo village	female adolescents (10–19 yrs.) bathing, collecting water	women collecting water, household activities
Thompson et al. (2001)	Kenya, Uganda, Tanzania	women drawing water	children drawing water

B4 Lake data

Table B.11: Data for lakes used in Chapter 3.

Continent	Lake/reservoir	Basin area [million km²]	Lake surface area [million km²]
Africa	Victoria	0.263	0.0670
Africa	Tanganyika	0.238	0.0328
Africa	Malawi	0.130	0.0296
Africa	Turkana	0.073	0.0077
Africa	Volta	0.402	0.0074
Asia	Balkhash	0.174	0.0174
Asia	Issyk-kul	0.010	0.0062
Asia	Urmia	0.051	0.0049
Asia	Qinghai Lake	0.019	0.0044
Asia	Boeng Tonle Chhma	0.058	0.0026
Europe	Baikal	0.584	0.0317
Europe	Ladoga	0.271	0.0177
Europe	Onega	0.054	0.0098
Europe	Vaenern	0.048	0.0056
Europe	Kuybyshevskoye	1.187	0.0050
North America	Superior	0.207	0.0819
North America	Huron	0.575	0.0597
North America	Michigan	0.180	0.0573
North America	Great Bear Lake	0.145	0.0305
North America	Great Slave Lake	1.006	0.0278
South America	Itaparica	0.497	0.0087
South America	Titicaca	0.057	0.0082
South America	Lagoa Mirim	0.046	0.0039
South America	Tucurui	0.757	0.0034
South America	Itaipu	0.840	0.0024

B5 References

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Appendix C

C1 Case study 4 – Chao Phraya

Table C.1: Water Quality Index in the Chao Phraya River Basin and Tha Chin River Basin (DO = dissolved oxygen, BOD = biological oxygen demand, TC = total coliform bacteria, FC = fecal coliform bacteria, NH_3 – N = ammonia nitrogen).

Min - Max, Median, and Percentage*						
Water Body	**WQ Class**	**DO (mg/l)**	**BOD (mg/l)**	**TC (MPN/100 ml)**	**FC (MPN/100 ml)**	**NH_3 – N (mg/l)**
Upper Chao Phraya	2	3.2 – 8.2 5.4 18% (5/28)	0.7 – 2.8 1.4 57% (16/28)	450 - >160,000 6,000 50% (14/28)	<180 – 54,000 1,350 43% (12/28)	ND – 0.45 0.12 100% (28/28)
Central Chao Phraya	3	1.1 – 7.6 3.1 20% (4/20)	0.9 – 4.4 2.0 55% (11/20)	3,300 – 35,000 7,900 85% (17/20)	200 – 17,000 1,300 90% (18/20)	<0.02 – 0.51 0.19 95% (19/20)
Lower Chao Phraya	4	0.1 – 5.5 1.2 38% (9/24)	1.8 – 7.7 4.1 50% (12/24)	1,100 - >160,000 24,000 46% (11/24)	400 - >160,000 7,900 29% (7/24)	0.20 - 2.30 0.85 29% (7/24)
Upper Tha Chin	2	1.8 – 7.5 3.1 19% (3/16)	1.1 – 8.2 3.8 6% (1/16)	200 – 54,000 4,900 63% (10/16)	120 – 4,900 780 53% (8/15)	<0.10 – 0.18 0.10 100% (16/16)
Central Tha Chin	3	1.0 – 7.0 2.4 25% (3/12)	1.2 – 8.2 4.2 17% (2/12)	2,700 – 160,000 11,000 67% (8/12)	450 – 92,000 1,200 75% (9/12)	<0.10 – 0.49 0.10 100% (12/12)
Lower Tha Chin	4	0.7 – 5.6 2.2 50% (14/28)	1.4 – 9.6 4.5 43% (12/28)	3,300 – 540,000 28,500 39% (11/28)	200 – 240,000 4,900 32% (9/28)	<0.10 – 2.09 0.61 39% (11/28)
Standard Class 2		> 6.0	< 1.5	< 5,000	< 1,000	< 0.5
Standard Class 3		> 4.0	< 2.0	< 20,000	< 4,000	< 0.5
Standard Class 4		> 2.0	< 4.0	-	-	< 0.5

* Percentage of the measurement that meets the standard of surface water quality (a total of the standardized measurement/a total of all measurements) (Source: Thailand State of Pollution Report 2013, PCD)

C2 Case study 5 – Vaal

Table C.2: Resource Quality Objectives (RQOs) for salinity in priority Resource Units in the Upper Vaal WMA (only a few results are illustrated here).

RU	RQO	Indicator/ measure	Numerical limit	95th %ile	Context of the RQO	Threshold of Potential Concern (TPC)
RU67	Salts need to be improved to levels that do not threaten the ecosystem and to provide for users.	Electrical conductivity*	≤ 111 mS/m	79.1	Local industrial activities are having a negative impact on the water quality causing salinization of the Taaibosspruit. Salt concentrations should be improved to a D category. Where available the 95th percentile of observed or modelled data has been provided. The 95th percentile threshold is a standard procedure which has been selected to remove the extreme values considered to represent outliers.	98 mS/m
RU71	Salts need to be improved to levels that do not threaten the ecosystem and to provide for users.	Electrical conductivity*	≤ 111 mS/m	87	Salts: Upstream mining activity releases have causes acid mine drainage conditions in the system. The salts need to be returned to a state where it is not having a serious impact on the ecosystem, i.e. a D category. Where available the 95th percentile of observed or modelled data has been provided. The 95th percentile threshold is a standard procedure which has been selected to remove the extreme values considered to represent outliers.	98 mS/m
RU73	Salts need to be improved to levels that do not threaten the ecosystem and to provide for users.	Electrical conductivity*	≤ 111 mS/m	90.5	Salt loads associated with acid mine drainage impacts from upstream mining activities are of concern for the ecosystem and also for downstream users. The salt concentrations should be managed to a D category. Where available the 95th percentile of observed or modelled data has been provided. The 95th percentile threshold is a standard procedure which has been selected to remove the extreme values considered to represent outliers.	98 mS/m
		Sulphates*	≤ 500 mg/L	132		350 mg/L
RU75	Salts need to be improved to levels that do not threaten the ecosystem especially fish and to provide for users.	Electrical conductivity*	≤ 85 mS/m	84	Excessive salt in this system causes salinisation of agricultural land and also fouling of industries. It is also a potential problem for maintenance of the Orange-Vaal largemouth yellowfish population, recruitment of which may be sensitive to high salt loads. Salt concentrations must be improved to a C category. Where available the 95th percentile of observed or modelled data has been provided. The 95th percentile threshold is a standard procedure which has been selected to remove the extreme values considered to represent outliers.	70 mS/m
		Sulphates*	≤ 200 mg/L	173		140 mg/L

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