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**Recommendations for Small Water Supply Systems
in Newly Industrialized Countries on the Example
of Assessments in the State of Minas Gerais, Brazil**

Dr.-Ing. Wolfgang K. Walter

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Vorwort

Die Wasserversorgung ist Grundlage für gute und gesunde Lebensbedingungen. Leider besteht weltweit ein großes Defizit an Versorgung mit ausreichendem und qualitativ den Anforderungen entsprechendem Trinkwasser. Diese nicht zufriedenstellende Situation ist besonders ausgeprägt in Schwellen- und Entwicklungsländern und dort insbesondere in ländlichen Regionen. Dies liegt zum einen an natürlichen Gegebenheiten wie Wassermangel und zum anderen an mangelhaften Versorgungseinrichtungen, sowie ungenügendem Gewässer- und Grundwasserschutz. Daher müssen erhebliche strukturelle, politische, aber auch technische und wirtschaftliche Anstrengungen unternommen werden, um diese Situation zu verbessern.

Im ländlichen Raum kommen aufgrund der geringen Siedlungsdichte daher weniger zentrale Systeme in Frage, sondern eher dezentrale, um die Versorgungsleitungslängen zu minimieren und damit auch die Kosten. Ziel der Dissertation von Herrn Walter war daher, für den ländlichen Raum in Schwellen- und Entwicklungsländern Versorgungskonzepte mit technischen Lösungen zu entwickeln, die der dortigen Situation angepasst sind. Hierzu wurde einerseits mit einem Hersteller solcher Anlagen eine dezentrale, mobile Anlage konzipiert, gebaut und vor Ort in Brasilien betrieben und ergänzend dazu die Randbedingungen in Schwellen- und Entwicklungsländern analysiert und daraus Vorschläge für die Vorgehensweise in diesen Regionen erarbeitet.

Die außergewöhnlich umfangreiche Dissertationsschrift ist bedingt durch den hohen Anspruch von Herrn Walter, alle denkbaren Randbedingungen und Lösungsmöglichkeiten für die Umsetzung von dezentralen Wasserversorgungsanlagen in Schwellen- und Entwicklungsländern zu berücksichtigen. Seine praktischen Untersuchungen vor Ort in Brasilien in Zusammenarbeit mit den örtlichen und deutschen Partnern, sowie die Bewältigung der Sprach- und Kommunikationsprobleme sind hierbei besonders hervorzuheben, ebenso wie die ganzheitliche Einbeziehung anderer Fachgebiete, wie Sozialwissenschaften, Wirtschaftswissenschaften, aber auch der Wasserpolitik.

Ich wünsche Herrn Walter, dass seine wertvollen Erkenntnisse, Lösungsvorschläge und Hintergründe bei der Planung von weiteren wasserwirtschaftlichen Projekten in Schwellen- und Entwicklungsländern berücksichtigt und umgesetzt werden.

Bei der Firma Grünbeck Wasseraufbereitung GmbH möchte ich mich für die gute Zusammenarbeit zwischen Wissenschaft und Praxis sowie die Unterstützung bedanken, ebenso wie bei der Deutschen Investitions- und Entwicklungsgesellschaft DEG für die Mitfinanzierung des Projektes.

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Glossary and Symbols

Apart from the abbreviations in the table below the “International System of Units SI” has been followed throughout this work.

Abbreviation	Name	Dimension
a	year	-
A	annuity	monetary unit
A1 (i.e.: A one)	Attribute One (note: of small water supply systems)	-
A _{UF}	UF membrane area	m ²
ABES	Associação Brasileira de Engenharia Sanitária e Ambiental	-
ABNT	Associação Brasileira de Normas Técnicas	-
AC	activated carbon	-
ADERASA	Asociación de Entes Reguladores de Agua Potable y Saneamiento de las Américas	-
AF	average flow rate	m ³ ·a ⁻¹
Al	aluminium	mg·L ⁻¹
ANA	Agência Nacional de Águas	-
ANF _{n,i}	annuity factor	-
APHA	American Public Health Association	-
ARSAE-MG	Agência Reguladora de Serviços de Abastecimento de Água e de Esgotamento Sanitário do Estado de Minas Gerais	-
ATV	Abwassertechnische Vereinigung	-
AWWA	American Water Works Association	-
B1 (i.e.: B one)	Boundary One (note: of the local situation for small water supply system choice)	-
BA	Basic Assumption	-
BOD	biochemical oxygen demand	mg·L ⁻¹
BRIC	Brazil, Russia, India, China	-
BRICS	Brazil, Russia, India, China, South Africa	-
BV139	river monitoring station at the Rio das Velhas	-
°C	degree Celsius	-
C ₀	net present value	monetary unit
C _{p,i}	inlet concentration	e.g. mg·L ⁻¹
C _{p,o}	outlet concentration	e.g. mg·L ⁻¹
Ca	calcium	mg·L ⁻¹
CAD	computer-aided design	-
cap	capita	-

Abbreviation	Name	Dimension
CFU	colony forming units	-
CIA	Central Intelligence Agency	-
CIP	Cleaning in Place	-
Cl	chlorine	mg·L ⁻¹
CO ₂	carbon dioxide	mg·L ⁻¹
COD	chemical oxygen demand	mg·L ⁻¹
CONAMA	Conselho Nacional do Meio Ambiente	-
COPANOR	Copasa Serviços de Saneamento Integrado do Norte e Nordeste de Minas Gerais	-
COPASA	Companhia de Saneamento de Minas Gerais	-
CRED	Centre for Research on the Epidemiology of Disasters	-
CWS	community water system	-
d	day	-
DxWxL	depth x width x length	m
Da	Dalton	-
DC	Development Country	-
DEG	Deutsche Investitions- und Entwicklungsgesellschaft mbH	-
ΔP_{absHy}	absolute pressure drop across the hydrocyclone	bar
ΔP_{relHy}	relative pressure drop across the hydrocyclone	%
DIN	German Institute for Standardization	-
DMF-T index	Decayed, Missing, Filled Teeth Index	-
DR	Dependency Ratio	%
DSF	dry season flow rate	m ³ ·a ⁻¹
DVGW	German Association for Gas and Water	-
DVQA	Divisão de Pesquisa e Controle da Qualidade de Água e Esgoto (note: of COPASA)	-
DWA	German Association for Water, Wastewater and Waste	-
EAWAG	Swiss Federal Institute of Aquatic Science and Technology	-
ED	electrodialysis	-
EDCs	endocrine disrupter compounds	-
e.g.	exempli gratia	-
EPA	Environmental Protection Agency	-
ETA	Estação de Tratamento de Água	-
η_g	general yield	%
EU	European Union	-
FAO	Food and Agriculture Organization	-
Fe	iron	mg·L ⁻¹

Abbreviation	Name	Dimension
f.e.	for example	-
FITABES	Feira Internacional de Tecnologias de Saneamento Ambiental	-
FO	forward osmosis	-
FRG	Federal Republic of Germany	-
ft	foot/feet	-
FUNASA	Fundação Nacional de Saúde	-
G7	Group of Seven: Canada, France, Germany, Italy, Japan, United Kingdom, United States	-
GDP	Gross Domestic Product	monetary unit
GIS	geographic information system	-
GSMC	Grünbeck Short Membrane Cleaning	-
h	hour	-
Hz	Hertz	-
i	interest rate	%
IAWD	International Association of Water Supply Companies in the Danube River Catchment Area	-
IBGE	Instituto Brasileiro de Geografia e Estatística	-
IC	Industrialized Country	-
i.e.	id est	-
IFH	International Scientific Forum on Home Hygiene	-
IGAM	Instituto Mineiro de Gestão das Águas	-
INSEAD	Institut Européen d'Administration des Affaires	-
ISA	Instituto Socioambiental	-
IWA	International Water Association	-
IWAO	International Water Aid Organization	-
IWRM	Integrated Water Resources Management	-
J_{UF}	UF flux	$L \cdot m^{-2} \cdot h^{-1}$
JE017	river monitoring station at the Araçuaí	-
K_{Hy}	volume split of the hydrocyclone	%
KfW	Kreditanstalt für Wiederaufbau	-
km	kilometre	-
L	litre	-
LAS	linear alkylbenzene sulphonate	$mg \cdot L^{-1}$
LDC	Less Developed Countries	-
m	metre	-
m^3	cubic metre	-
max.	maximum	-

Abbreviation	Name	Dimension
MDG	Millennium Development Goals	-
MF	microfiltration	-
MG	Minas Gerais	-
min	minute	-
min.	minimum	-
Mn	manganese	$\text{mg}\cdot\text{L}^{-1}$
MU009	river monitoring station at the Mucuri	-
MWCO	molecular weight cut-off	Da
n	service life	a
N-11	Next Eleven: Bangladesh, Egypt, Indonesia, Iran, Mexico, Nigeria, Pakistan, Philippines, South Korea, Turkey, Vietnam	-
n.a.	no author	-
n.d.	not determined	-
n.eds.	no editors	-
NF	nanofiltration	-
n.i.	no issue	-
NIC	Newly Industrialized Country	-
n.l.	no location	-
Nm^3	normal cubic metre	-
n.p.	no pages	-
n.pub.	no publisher	-
NTNCWS	non-transient non-community water system	-
NTU	nephelometric turbidity unit	-
n.v.	no volume	-
n.y.	no year	-
O&M	operation and maintenance	-
$p_{\text{feed flow Hy}}$	measured pressure of the hydrocyclone feed flow	bar
$p_{\text{overflow Hy}}$	measured pressure of the hydrocyclone overflow	bar
$p_{\text{UF,i}}$	measured UF inlet pressure	bar
$p_{\text{UF,o}}$	measured UF outlet pressure	bar
P_{UF}	UF permeability	$\text{L}\cdot\text{m}^{-2}\cdot\text{h}^{-1}\cdot\text{bar}^{-1}$
$P_{\text{UF}20^\circ\text{C}}$	UF permeability normalized on 20°C	$\text{L}\cdot\text{m}^{-2}\cdot\text{h}^{-1}\cdot\text{bar}^{-1}$
P_{UF0}	UF starting permeability	$\text{L}\cdot\text{m}^{-2}\cdot\text{h}^{-1}\cdot\text{bar}^{-1}$
$P_{\text{UF0},20^\circ\text{C}}$	UF starting permeability normalized on 20°C	$\text{L}\cdot\text{m}^{-2}\cdot\text{h}^{-1}\cdot\text{bar}^{-1}$
$P_{\text{UF1},20^\circ\text{C}}$	UF permeability before regeneration normalized on 20°C	$\text{L}\cdot\text{m}^{-2}\cdot\text{h}^{-1}\cdot\text{bar}^{-1}$
$P_{\text{UF2},20^\circ\text{C}}$	UF permeability after regeneration normalized on 20°C	$\text{L}\cdot\text{m}^{-2}\cdot\text{h}^{-1}\cdot\text{bar}^{-1}$

Abbreviation	Name	Dimension
PIMC	Programa de Formação e Mobilização para a Convivência com o Semi-árido: Um Milhão de Cisternas Rurais	-
PAC	Programa de Aceleração do Crescimento	-
PLC	Programmable Logic Controller	-
POEWS	Point-of-Entry Water System	-
pop	population	-
POUWS	Point-of-Use Water System	-
PPP	Public Private Partnership	-
Pr	pilot plant sampling point	-
PRODES	Programa Despoluição de Bacias Hidrográficas	-
PROSAM/MG	Programa de Saneamento Ambiental para a Região Metropolitana de Belo Horizonte	-
PV	photovoltaic	-
PVC	polyvinyl chloride	-
PVDF	polyvinylidene fluoride	-
Q ₁	first quartile	-
Q ₂	second quartile, median	-
Q ₃	third quartile	-
Q _{feed flow Hy}	measured feed flow of the hydrocyclone	L·h ⁻¹
Q _i	inlet flow raw water	L·h ⁻¹
Q _o	outlet flow product water	L·h ⁻¹
Q _{overflow Hy}	measured overflow of the hydrocyclone	L·h ⁻¹
Q _{UF filtrate}	measured UF filtrate flow rate	L·h ⁻¹
R	retention	%
R ²	coefficient of determination	-
R _{UFP20°C}	UF permeability-recovery normalized on 20°C	%
R1 (i.e.: R one)	Recommendation One (note: for small water supply services of public interest in NICs)	-
R\$	Real, i.e. the currency of Brazil	-
RE	renewable energy	-
res.	residual	-
RO	reverse osmosis	-
s	second	-
SABESP	Companhia de Saneamento Básico do Estado de São Paulo	-
SCADA	Supervisory Control and Data Acquisition	-
SDI	Silt Density Index	%
SDWA	Safe Drinking Water Act	-

Abbreviation	Name	Dimension
SS	suspended solids	$\text{mg}\cdot\text{L}^{-1}$
STP	sewerage treatment plant	-
Surfactants	surface active agents	-
SWS	Small Water System	-
t	ton	-
T	temperature	$^{\circ}\text{C}$
TC	temperature correction factor 20 $^{\circ}\text{C}$	-
TDS	total dissolved solids	$\text{mg}\cdot\text{L}^{-1}$
THM	trihalomethane	$\mu\text{g}\cdot\text{L}^{-1}$
TMP	UF transmembrane pressure	bar
TNCWS	transient non-community water system	-
TRWR	Total Renewable Water Resources	$\text{m}^3\cdot\text{cap}^{-1}\cdot\text{a}^{-1}$
TS	total solids	$\text{mg}\cdot\text{L}^{-1}$
TSS	total suspended solids	$\text{mg}\cdot\text{L}^{-1}$
UF	ultrafiltration	-
UK	United Kingdom	-
UN	United Nations	-
UN HABITAT	United Nations Human Settlements Programme	-
UNDP	United Nations Development Programme	-
UNEP	United Nations Environment Programme	-
UNESCO	United Nations Educational, Scientific and Cultural Organization	-
UNESCO-IHE	United Nations Educational, Scientific and Cultural Organization Institute for Water Education	-
UNICEF	United Nations International Children's Emergency Fund	-
USA	United States of America	-
USGS	U.S. Geological Survey	-
UV	ultraviolet	-
V	Volt	-
WxL	width x length	m
WEC	wind energy conversion	-
WEF	Water Environment Federation	-
WHO	World Health Organization	-

Abbreviation	Name	Dimension
WSP	Water and Sanitation Program	-
WTP	water treatment plant	-
WWAP	World Water Assessment Programme	-

English abstract

Newly Industrialized Countries, NICs, are characterized by numerous contrasts. With respect to water supply a sharp difference between urban and rural areas is common. Related WHO reports show that the water supply situation in rural areas is often inadequate. An important challenge for NICs is the implementation of appropriate water supply technology in rural areas. From a demographic and migrational point of view infrastructure availability is one key factor to keep the resident population in rural areas. In this work small water supply systems in NICs are examined on the example of assessments in the Brazilian state of Minas Gerais.

The characteristics of water supply triggers in NICs, e.g. climate, demographics, etc., are assessed on the macro level for Brazil and for 15 other NICs. The representation of small water supply systems in scientific, legislative, normative, regulatory and textbook literature is examined. Arguments and application cases for small water supply systems are identified. Technology for small water treatment and supply is comprehensively structured into energetically independent or conventionally driven basic technology, commercial market technology and research technology. 90 different systems are discussed. On the basis of this technology investigation and literature review definitions for small water supply systems are formulated.

The successful sustainable operation of a small water treatment system involves the precise knowledge of the conditions at the local application site and of the water treatment system properties. To describe the local situation the *“Open System of Boundaries for Small Water Supply Applications”* is created. It comprises 13 groups of boundaries, e.g. geographical factors, state of local sanitary engineering, macro- and microeconomics, social and cultural factors, etc., each with numerous sub-boundaries. To describe the properties of water treatment and supply systems the *“Open System of Attributes of Small Water Supply Systems”* is created. It comprises 15 groups of attributes, e.g. system type, process engineering, transportability, social aspects, macro- and microeconomics, etc., each with numerous sub-attributes.

For small water supply in Minas Gerais the *“Boundaries Profile”* is prepared. The *“Attributes Profile”* of a small, SCADA equipped, containerized, mobile, membrane water treatment pilot plant is compiled for a decentralized application in Minas Gerais. Results of on-site tests for the pilot plant’s local applicability are evaluated and discussed. Selected recommendations for small water supply systems in NICs are given. General important elements of and suggestions for the configuration of small water treatment systems are identified.

German abstract/Kurzfassung

Schwellenländer sind charakterisiert durch unzählige Gegensätze. Im Hinblick auf die Wasserversorgung besteht ein großer Unterschied zwischen der urbanen und der ländlichen Situation. WHO Studien belegen, dass die Wasserversorgung in ländlichen Gebieten vielfach unzureichend ist. Die Implementierung angepasster Wasserversorgungsinfrastruktur in ländlichen Zonen stellt für Schwellenländer eine große Herausforderung dar. Um die Landflucht einzudämmen ist die allgemeine Bereitstellung von Infrastruktur ein wichtiger Aspekt. In dieser Arbeit wird die Wasserversorgung aus Kleinanlagen in Schwellenländern am Beispiel von Erhebungen und Versuchen im brasilianischen Staat Minas Gerais analysiert.

Für die Makroebene werden Einflußfaktoren auf die Wasserversorgung, z.B. Klima, Demographie, etc., für Brasilien und für 15 weitere Schwellenländer untersucht. Die Darstellung von Kleinanlagen zur Wasserversorgung in Forschungs-, Normungs- und Fachbuchliteratur sowie in Gesetzestexten wird diskutiert. Anwendungsbereiche und Gründe für die Anwendung von Kleinanlagen zur Wasserversorgung werden identifiziert. Es erfolgt eine Strukturierung dezentraler Wasserversorgungstechnologie in energetisch unabhängige oder konventionell betriebene Basistechnologie, kommerzielle Technologie und Technologie im Erforschungsstadium. 90 verschiedene Systeme werden diskutiert. Auf Basis dieser Technologieanalyse wird eine Definition für kleine Wasserversorgungssysteme formuliert.

Die genaue Kenntnis der örtlichen Gegebenheiten und der Eigenschaften einer Wasseraufbereitungsanlage sind Voraussetzung für deren erfolgreichen nachhaltigen Betrieb. Um die lokale Situation strukturiert beschreiben zu können wird das *„Offene System von Randbedingungen für die Wasserversorgung mit Kleinanlagen“* aufgestellt. Es umfasst 13 Gruppen von Randbedingungen, z.B. geographische Faktoren, Stand der Siedlungswasserwirtschaft, Makro- und Mikroökonomie, soziale Faktoren, etc., jeweils mit zahlreichen Unterpunkten. Um die Eigenschaften von Kleinanlagen zur Wasseraufbereitung zu erfassen wird ein *„Offenes System von Eigenschaften kleiner Wasserversorgungssysteme“* erstellt. Es umfasst 15 Eigenschaftsgruppen, z.B. Systemtyp, Verfahrenstechnik, Transportierbarkeit, soziale Faktoren, etc., jeweils mit zahlreichen Unterpunkten.

Für die Wasserversorgung mit Kleinanlagen in Minas Gerais wird das *„Randbedingungenprofil“* aufgestellt. Das *„Eigenschaftsprofil“* einer SCADA bestückten, auf Membranaufbereitung beruhenden Kleinanlage zur Wasseraufbereitung wird für eine Anwendung in Minas Gerais erstellt. Die Ergebnisse von on-site Testläufen zur Bestimmung der lokalen Anwendbarkeit dieser Anlage werden bewertet und diskutiert. Ausgewählte Empfehlungen für Kleinanlagen zur Wasserversorgung in Schwellenländern werden präsentiert. Allgemein wichtige Elemente und Varianten für die Konfiguration solcher Anlagen werden identifiziert.