ADB

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& Department of Agriculture,
Royal Government of Bhutan

Adapting to Climate Change through IWRM

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Bhutan Water Security Index: Dimensions, Indicators and Computations

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Egis Eau &

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Bhutan Water Partnership

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History of modifications

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Acronyms

ADB	Asian Development Bank
AWDO	Asian Water Development Outlook
BhWP	Bhutan Water Partnership
BNWRI	Bhutan National Water Resources Inventory
BTFEC	Bhutan Trust Fund for Environmental Conservation
CD	Capacity Development
CDTA	Capacity Development Technical Assistance
CFO	Chief Forestry Officer
CMIP5	Coupled Model Inter-comparison Project Phase 5
DAHO	District Animal Husbandry Officer
DAO	District Agricultural Officer
DDM	Department of Disaster Management
DEC	District Environment Committee
DEO	District Environment Officer
DG	Director General
DHPS	Department of Hydropower & Power Systems
DMF	Design & Monitoring Framework
DOA	Department of Agriculture
DOFPS	Department of Forest & Park Services
DOHS	Department of Hydromet Services
DW	Drinking Water
DWS	Drinking Water Supply
ESD	Environment Service Division
FAO	Food & Agricultural Organization (of the United Nationa)
FGD	Focus Group Discussion
GIS	Geographical Information System
GLOF	Glacier Lake Outburst Flood
GNHC	Gross National Hapiness Commission
GNHCS	Gross National Hapiness Commission Secretariat
GW	Groundwater
HP	Hydropower Plants
ID	Irrigation Division in the DOA
IT	Information Technology
IWRM	Integrated Water Management
JICA	Japan International Cooperation Agency
KPI	Key Performance Indicator
KRA	Key Result Area
MOAF	Ministry of Agriculture & Forestry
MOEA	Ministry of Economic Affairs
MOF	Ministry of Finance
MOH	Ministry of Health
MOHCA	Ministry of Home & Cultural Affairs

MOWHS	Ministry of Works & Human Settlements
MPR	Monthly Progress Report
MPR	Monthly Progress Report
NEC	National Environment Commission
NECS	National Environment Commission Secretariat
NIIS	National Irrigation Information System
NIMP	National Irrigation Master Plan
NIWRMP	National Integrated Water Resources Management Plan
NLC	National Land Commission
NWRB	National Water Resource Board
ODE	Organizational Development Exercise
PHED	Public Health Engineering Division
PPT	Power Point (Presentation)
RB	River Basin
RBC	River Basin Committee
RBMP	River Basin Management Plan
RCSC	Royal Civil Service Commission
RGOB	Royal Government of Bhutan
RSPN	Royal Society for Protection of Nature (Bhutan)
TA	Technical Assistance
TAC	Technical Advisory Committee (advising NECS)
TNA	Training Needs Assessment
TOR	Terms of Reference
UNESCO	United Nations Educational, Scientific and Cultural Organization
WMD	Water Management Division in Forestry Dept. of MOAF
WR	Water Resources
WRCD	Water Resources Coordination Division in NECS
WS	Watershed
WUAs	Water Users Associations

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Executive summary

On the request of the Royal Government of Bhutan (RGOB), the Asian Development Bank (ADB) is providing capacity-development technical assistance (CDTA) in building the capacity of National Environment Commission Secretariat (NECS) and the Department of Agriculture (DOA) of the Ministry of Forestry and other agencies for **BHU-8623: Adapting to climate change through IWRM**. The project has 4 main outputs: (i) A National Integrated Water Resources Management Plan; (ii) A River Basin Management Plan for a priority basin; (iii) A National Irrigation Master Plan; and (iv) Water resources governance strengthened.

The Terms of Reference proposed benchmarking Bhutan's current status of water resources management and its service delivery using the Asian Water Development Outlook (AWDO) 2013 water security indicator. This report describes how the AWDO water security index has been adapted to Bhutan, and how its computation has been simpfified. It concludes with listing the parameters that are needed to calculate the score per basin and at the national level, along with the agencies from where these data can be obtained.

The purpose of this draft version of the report is (i) to facilitate peer review within the TA team; (ii) to confirm the structure and composition of the BWSI; (iii) to find the current baseline value of the indicators; and (iv) to confirm the practical range of the indicators.

Introduction

Background

Bhutan has a high water endowment per capita per year. However, the rainfall and corresponding stream flow in the rivers is strongly seasonal. Shortage of water for drinking and irrigation has been widely reported for the lean period, particularly on the hill sides high above the rivers.

The Royal Government of Bhutan (RGOB) has been driving towards better water management. The National Environment Committee (NEC) has been established in XXX, supported by its Secretariat (NECS). Chaired by the Prime Minister, the NEC is the highest authority for regulation and planning of water resources under the Gross National Happiness Commission.

A Water Act has been enacted in 2011 and its Regulation has been promulgated in 2014.

ADB support

To support NEC with the implementation of the Water Act and its Regulation, the RGOB requested the support of the Asian Development Bank (ADB).

To that effect, a capacity-development technical assistance (CDTA) was conceived for building the capacity of National Environment Commission Secretariat (NECS) and the Department of Agriculture (DOA) of the Ministry of Forestry and other agencies for **BHU-8623: Adapting to climate change through IWRM**.

The project has 4 main outputs: (i) A National Integrated Water Resources Management Plan; (ii) A River Basin Management Plan for a priority basin; (iii) A National Irrigation Master Plan; and (iv) Water resources governance strengthened.

AWDO water security index

The Terms of Reference of the project proposed benchmarking Bhutan's current status using the Asian Water Development Outlook (AWDO) 2013 water security indicators[1].

[1] Asian Development Bank. 2013. *Asian Water Development Outlook 2013*. Manila

Purpose of this report

The purpose of this draft version of the report is:

- To confirm the structure and composition of the BWSI
- To find the current base-line value of the indicators
- To confirm the practical range of the indicators

Water security and index

Description of water security

ADB vision of water security is as follows:

Societies can enjoy water security when they successfully manage their water resources and services to:

1. Satisfy household water and sanitation needs in all communities;
2. Support productive economies in agriculture, industry, and energy;
3. Develop vibrant, liveable cities and towns;
4. Restore healthy rivers and ecosystems; and
5. Build resilient communities that can adapt to change.

UN-water defines water security as "the capacity of a population to safeguard sustainable access to adequate quantities of acceptable quality water for sustaining livelihoods, human well-being, and socio-economic development, for ensuring protection against water-borne pollution and waterrelated disasters, and for preserving ecosystems in a climate of peace and political stability."

History of water security index

The concept of water security index was introduced by Asian Development Bank (ADB) & Asian Water Development Outlook (AWDO) for Asia-Pacific water summit in 2007 in Japan. It aimed at providing a broader perspective on water management than (traditional) sectoral approaches. It aimed at comparing the status of water management and its delivery services in a number of Asian countries.

It was revised in 2013 to include quantitative measurement, and provides direction for governance, investments, capacity-building, monitoring/ reporting.

The concept was accepted in Bhutan in a meeting of the Technical Advisory Committee in December 2014. The indicators were adapted to Bhutan conditions in a national IWRM workshop held in March 2015. The results of the workshop were endorsed by the TAC in May 2015.

Structure

The water security index is composed of 5 key dimensions:

1. Rural drinking water supply & sanitation
2. Economic water supply for agriculture, industries and hydropower
3. Urban water supply, sanitation and drainage
4. Environmental water supply
5. Disaster resilience

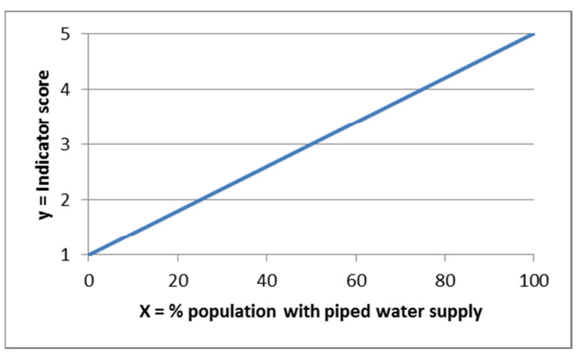
Some key dimensions are directly calculated from a set of indicators. Other key dimensions are composed of sub-dimensions each containing a set of indicators. Indicators may contain more than one parameter, see table below.

Key Dimension	Sub-dimension		Indicators	
	AWDO	Bhutan	AWDO	Bhutan
1. Rural	-	-	3	3
2. Economic	5	4	10	12
3. Urban	-	-	4	5
4. Environment	4	4	23	12
5. Resilience	4	3	18	25
Total 5	13	11	58	57

Computation

The key dimensions and their composing indicators are scored on a scale 1 (bad) to 5 (good). The computation of the AWDO water security index is rather complex, and could in fact not be replicated for all dimensions. A simpel linear scoring has been used for those cases. For example:

The percentage of population with piped water supply is 85% on a scale of 0-100% (as used in AWDO) with corresponding indicator score of 1-5, see figure below.

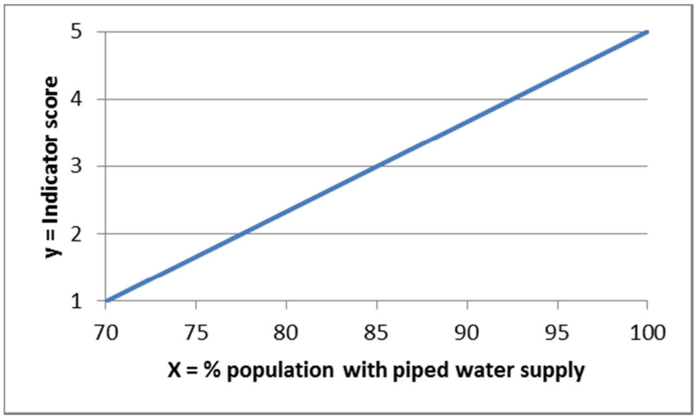


$$\frac{Y - y_1}{Y_2 - y_1} = \frac{x - x_1}{x_2 - x_1}$$, hence Y = 4X/100 + 1.

With 85% piped water supply the score is 4.4
The actual computation is facilitated by a separate EXCEL file with macros.

Data range

The sensitivity of the score depends on the actual range of the indicator values to be scored. Had the data range of piped water supply been 70 – 100%, then



Y = 4x/30 – 250/30 With 85% piped water supply is the score 3.

The advantage of narrowing down the data range to practical values is that the indicator becomes more responsive to change. The downside is that the score of the indicator looks lower.

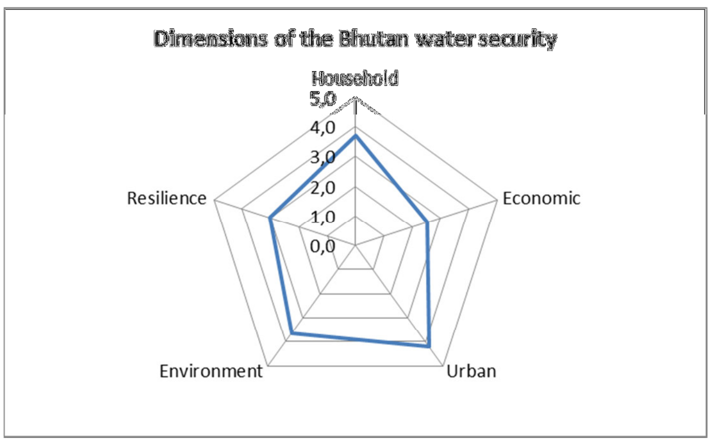
The score of the Bhutan Water Security Index (BWSI) may thus not be the same as calculated by AWDO although most of the AWDO indicators are also used in the BWSI.

The practical data range will be determined by the spread of values found in practice for the respective districts.

NECS and the TAC will advise on what practical data range to adopt.

Visualisation

The water security index can be made visual by means of a web-diagram, see example below.



NB: The scores of the Key Dimensions do not reflect the actual situation.

Level of application

While the AWDO index was designed to compare diffent nations, the BWSI aims at expressing the status of water resources and their management at national level as well as the level of the main river basins.

Data collection

Given the character of the BWSI, data collection will be from the national level (like Gross Domestic Product (GDP) as well as districts in the basin (like population). A summary of data required for computation of the BWSI at national and basin level is given at the end of the report, along with the agencies where these data can be obtained.

KD1 – Rural drinking water supply & sanitation

KD1 assesses the extent to which rural household water and sanitation needs are met, and improved hygiene for public health is provided in all communities. It is a composite of three main sub-indices (i) access to piped water supply (%), (ii) access to improved sanitation (%), and (iii) hygiene (incidence of diarrhoea per 10,000 people).

% of population having piped water supply

This indicator is self-explanatory. It is also used in AWDO, based on connected households in the population. Data requirements per district:

- number of connected households;
- average size of household;
- population

It is being monitored by the Department of Public Health, MOH

Calculation of index score: linear, with data range 0-100%.

(AWDO uses look-up table, see appendix 2)

Remark: For simplicity the indicator does not measure the functionality of the piped water system, nor the quality of the water delivered. These aspects may be included in future. The figures will be used as presently being collected by the responsible agencies.

% of poplation with improved (water-sealed) toilets

As above, this indicator is self-explanatory and is also used in AWDO.

Data requirements per district:

- number of connected households;
- average size of household;
- population

It is being monitored by by the Department of Public Health, MOH, based on number of households with sceptic toilet.

Calculation of indicator score: linear with data range 0-100%.

(AWDO uses look-up table, see appendix 2)

Remark: The term improved is understood to mean water-sealed to prevent flies going in and stench escaping. For a start, the figures will be adopted as being collected by DPH-MOH.

hygiene by incidence of diarrhoea/ 10,000 inhabitants/ year

Diarrhea is an infectious disease that is related to hygiene and thus related to proper sanitation. It is expected that the incidences of diarrhea will reduce when a larger part of the population is using proper (water-sealed) sanitation.

This indicator is also used by AWDO, but *as age-standardised disability-adjusted life years* per 100,000 people for the incidence of diarrhea.

In BWSI it has been simplified as shown on the left.
Data requirements:

- number of incidences of diarrhoea in a year
- population

It is being monitored by the Department of Public Health, MOH and

Calculation of indicator score: inverse linear with data range 0-200.

(AWDO table relates to age-standardised disability-adjusted life years, see appendix 2.)

KD2 – Economic water security

Water is an essential input to grow food and fibre, for many industrial processes, and to generate the energy required by society. The use of water in these sectors is increasingly recognised as closely related and can no longer be addressed in isolation from each other. Debate about the water-food-energy nexus has begun to raise general awareness about the critical interaction among water uses to support economic activities.
Economic water security measures the productive use of water to sustain economic growth in the food production, industry, and energy sectors of the economy. The indicators are aggregates of multiple sub-indicators, defined to highlight key aspects of water security in a particular sector as described in the following sections. There is debate (also in AWDO) to what extent the indicators are applicable at basin level – beside national level.

KD2A - Agriculture

Water is essential for agricultural production and agriculture uses the largest proportion. Three components were considered to characterise water use and to estimate the degree of water security in productive agricultural economies; namely:

- Resilience, see below.
- Agricultural dependency on national trans-boundary inflow. However, since irrigated agriculture in Bhutan usually does not tap water from the main rivers, this subdimension has been omitted from the BWSI.
- Utilisation efficiency, see below.

The subcomponents and their parameters are described below.

KD2A1 - Agriculture resilience

Resilience refers to the ability of a country to cope with the adverse effects of rainfall variability. Recognising that agricultural water use is vulnerable to rainfall variability[2] and that water storage constitutes a viable method to mitigate the effects of that variability, a first indicator focuses on these two key issues.

% of cropped area irrigated from reservoirs future

Rain-fed agricultural production is susceptible to the weather conditions. The larger percentage of cropped areas can be irrigated from reservoirs, the less vulnerable the agricultural production is supposed to be. This indicator is also used in AWDO.

Data requirements per district:

- areas in hectares served by reservoirs/ Rain Water Hharvesting Structures

[2] Other water uses are vulnerable to rainfall variability as well. Given the greater role of water in agriculture and that agriculture, after the environment, is usually the residual water user, agriculture can be considered particularly vulnerable.

	• total cropped area (Hectares) The parameter will be determined by MoAF/DoA/Dzongkhag (DAO). Calculation of index score: linear with data range 0-15% (AWDO uses look-up table, see appendix 3)
Variability of inter-annual rainfall	Agricultural production depends on rainfall and/ or irrigation. The larger the variation of rainfall over the years, the more vulnerable it is. Rainfall cannot be planned as such, but adaptive measures for highly vulnerable areas can be planned for. That is why this indicator has been adopted. (Coefficient of variation = standard deviation divided by the mean annual rainfall) Data requirements per district: CV of inter-annual rainfall over the last 20 years The data will be can be provided by DHMS of MoEA Calculation of the index score: AWDO table, see appendix 3.
Variability of intra-annual rainfall	As mentioned above, agricultural production depends on rainfall and/ or irrigation. The larger the variation of rainfall within a year, the more vulnerable it is. Rainfall cannot be planned as such, but adaptive measures for highly vulnerable areas can be planned for. That is why this indicator has been adopted. (Coefficient of variation = standard deviation divided by the mean monthly rainfall) Data requirements per district: CV of intra-annual rainfall over the last 20 years The data will be can be provided by DHMS of MoEA Calculation of the index score: AWDO table, see appendix 3.

KD2A2 – Agriculture water utilization efficiency

The water utilization efficiency is defined as a function of agricultural water productivity, and proportion of arable land irrigated. To characterise the productivity of water use in irrigated agriculture, we considered the monetary value per unit of water in agriculture, and the percentage of arable land that is irrigated.

Agricultural contribution to GDP (in Nu)/ MCM (productivity)	Obviously a higher contribution of (irrigated) agricultural production to GDP is desirable. This indicator is also used in AWDO. Data requirements at national level: • contribution of (irrigated) agriculture to GDP in MNu • amount of water used in (irrigated) agriculture in MCM. The data will be obtained from DOA in MoAF. OK at national level, but basin level is difficult (needs contribution to GDP per district). NB: If GDP and MCM are proportionally distributed over the basins as per irrigated areas therein, the ratio will remain the same in Ngultrum/ m3. Proxi: paddy production/ district divided by irrigation water used (applying area * irri demand as calculated in NIMP)

	Calculation of the index score: AWDO table, see appendix 5.
% arabale land irrigated	A higher percentage of cultivable land being irrigated will contribute to higher overall agricultural production as well as reduction of poverty. This indicator is also used in AWDO Data requirements per district: • area of land irrigated in hectares • total cultivable area in hectares. This information is available from DOA in MoAF Calculaton of index score: BWSI: lineair with scale 0-30% AWDO table, see appendix 5.
% of cereal consumption that is imported out of the total cereal consumption.	This indicator has an inverse appraisal: the lower the necessary cereal imports, the higher self-sufficiency are achieved in keeping with the national policies. AWDO uses the concept of water footprint. BWSI adopted the proxy given on the left to indicate how effectively water is utilised for food security. Data requirements at national level: • total amount of cereals imported (and consumed) in MT • total amount of cereals consumed in Bhutan in MT per year This information is monitored by Royal Monitoring Authority (RMA) of MOA Calculation of the index score: inverse linear, with data range 0-100%

KD2B – Industrial water security

Similar measures as above were applied to industrial water use. However, the number of indicators used for industry is smaller than for agriculture. The reduced number of indicators reflects both the reduced proportion of water claimed by industrial uses as well as the relative dearth of data related to water and industry. Our water-industry indicator has only one indicator and focuses on water productivity in industry.

Revenue generated from water-based industries in million Nu/ MCM (productivity)	Like for agriculture, a higher contribution of (water-based) industries to GDP is desirable. This indicator is also used in AWDO Data requirements: • revenue generated by water-based industries (except hydropower) in MNu • amount of water used for industries This information is the responsibility of DoI in MoEA. Calculation of index score: AWDO table, see appendix 6.

KD2C – Hydropower water security

Given the direct linkages between water, hydropower, and energy supply in a country, our indicator directly focused on hydropower. The sub-indicators focus on the dependence of hydropower on trans-boundary inflow into Bhutan, the proportion of a country's technically exploitable hydropower capability that has been tapped, and the relative contribution of hydropower to a country's energy supply, and the plant load factor that indicates how efficiently the turbines are used.

Percentage of volume of trans-boundary inflow/ annual internal renewable water + incoming water

This indicator was used in AWDO for agricultural dependence – which does not really apply in Bhutan. It does have relevance for hydropower. Hydropower generation is to some degree dependent on inflow from China in Amochhu and Drangmechhu basins, leaving Bhutan vulnerable. This aspect is monitored in this indicator. It has an inverse appraisal: the lower the value, the more secure is hydropower generation.

Data requiremenets per basin:

- trans-boundary inflow into Bhutan in MCM/ yr
- total runoff per basin

The ratio is obtained by dividing the inflow by the sum of inflow and intenal runoff. To arrive at a national figure, the basin figures are weighted by volume of water (not area) of the basin.

This information can be supplied by DHMS of MoEA

Calculation of the index score: Linear with scale 0-10%

AWDO uses look-up table, see appendix 7.

% of potential hydropower installed

The RGOB aims at high development of hydropower, which is monitored by this indicator. This indicator is also used in AWDO

Data requirements per basin:

- economically viable potential hydropower capacity in MW
- actually installed capacity in MW

This information is the domain of DHPS, MOEA and DRE, MOEA

Calculation of the index score: AWDO table, see appendix 7.

NB: Scale to be inversed because policy aims at high degree of HP development.

% of hydropower contribution to total energy consumption

A high percentage of hydropower in total power consumption indicates less use of fuel wood or fossil fuel, and is in line with RGOB policy. This indicator is also used by AWDO.

Data requirements at national level:

- total annual hydro-power consumption in GWH
- total power demand in GWH-equivalent (including fire wood and diesel) per year (national level)

The data are to be provided by DHPS, MOEA and DRE, MOEA

Calculation of index score: Directly linear (high % scores 5) by means of AWDO look-up table see appendix 7.

NB: AWDO table does not appear to consider export of hydropower; the data range seems not useful for Bhutan.

Hydropower revenue (in MNu per amount of water used in MCM (productivity)	Like for agriculture and industries, the contribution of hydropower to GDP is monitored. This indicator is not used in AWDO Data requirements: • GDP, • % share of hydropower industry in GDP, • total annual volume of water flowing through the river basin • annual HP production in GWH per basin The basin level indicator is obtained by proportional distribution according to power production per basin (NB: the ratio remains the same for each basin!) This information is the responsibility of DHPS & DRE. Calculation of index score: direct linear with data scale 0-??
Hydropower efficiency as weigthed average annual plant load factor	The plant load factor indicates how efficiently the generators are being used, or how effectively the river flows are used for hydropower generation. This is monitored by this indicator. This indicator was not used in AWDO. It is an indication of efficient use of the plant. Data requirements per HP-station: Plant load factor in % The national and basin level values are also weigthed average as per power production. Data on plant load factor are obtained from DHPS. Scale linear from 0-100% > scale 1-5

KD3 – Urban water security

The urban water security indicators measure the creation of better water management and services to support vibrant and liveable water-sensitive cities. A water-sensitive city is defined as a city that integrates water supply, sewage, storm-water, and the built environment; a city that respects the value of urban waterways; and a city where citizens value water and the role it plays in sustaining the economy, environment, and society (Brown, Keath, and Wong 2009).
The urban water security index is a composite of four sub-indices relating to water supply coverage, wastewater treatment, garbage collection (to keep water ways clean) and urban flooding.

% urban population having potable piped water supply	This indicator is similar to the one applied for rural drinking water supply and is self-explanatory. It is also used in AWDO. Data requirements for Thromdes class A, B, or C urban centers in the districts:: • number of households connected to piped water, • average size of households, and • number of urban population This information is the responsibility of Water and Sanitation Division, DES,

	MoWHS. Calculation of index score: linear with a data range of 0-100%. Remark: Like for rural waer supply, this indicator does not consider equity or quality, or cost recovery of water supply.
% urban water loss	This indicator monitors the difference between the amounts of water delivered to the households and paid for, as compared to the amounts pumped into the system. Obviously, the difference should be minimized. It is not explicitly mentioned in AWDO. Data requirements for urban centers: • Revenue from water distribution system in Nu per year • Tariff in Nu/m3 • Total volume of water produced at the treatment plant The revenue divided by tariff yields the accounted-for water volume. The accounter-for volume divided by the total volume treated * 100% is the urban water efficiency. This information is in the domain of Water and Sanitation Division, DES, MoWHS. Calculation of index score: inverse linear with data range 15-60% > 5 – 1, values above 60 =1; values below 15 = 5.
% of population with improved sanitation	This indicator is similar to the one applied for rural areas and speaks for itself. It is also used in AWDO. In our case it is determined as 100% minus % of population without improved sanitation. The term 'improved' is open for interpretation but is understood to mean that no sceptage will spill untreated into the environment. However, sewage treatment can be to various degrees of sophistication. Data requirements per urban center: • total number of households in urban area <u>without</u> improved sanitation, • average number occupants per household, • total population of urban area The information is under jurisdiction of Water and Sanitation Division, DES, MoWHS The score is linear with scale 0-100%
% of urban population with at-least weekly waste collection & disposal service	When solid waste is not properly collected and disposed of, it will often end-up in the open water ways and spoil the quality of the water. This aspect is more pronounced in urban areas, where solid waste collection and disposal can be more efficiently organized than in thinly populated rural areas. This indicator is not used in AWDO. From this information can be deducted how much garbage potentially ends-up in the water ways deteriorating the water quality and obstructing drainage. Data requirements per urban center: • number of households served with at-least weekly garbage collection • household size, and • urban population This information is the responsibility of Water and Sanitation Division, DES, MoWHS Calculation of the index score: linear with data range 0-100%

Damage of urban flooding/ per-capita GDP	Monsoon floods can damage economic assets and property, particularly when drainage is inadequate and/or when the water ways or drains are eroding their banks. The flood dame is monitored by this indicator. AWDO considered this indicator at national level as a proxy for urban situations. Data requirements per urban center: • average annual estimated flood damage over the last 5 years in MNu • current population • GDP in million Ngultrum Calculation: average annual estimated flood damage over last five years in Ngultrum/ divided by current population of the area = standard ised loss. Devided by per-capita GDP. * 100%. The information on flood damage will be generated by Flood Engineering Management Division, DES MoWHS. Calculation of the index score BWSI: inverse linear scale 0-15%. AWDO look-up table, see appendix 8.

KD4 – Environmental water security

Rivers have become vulnerable to pressures from pollution, diminished flows, watershed deterioration, and increasing populations and industrial activities. The environmental water security indicator assesses the health of rivers and measures progress on restoring rivers and ecosystems to health on a national and regional scale. The environmental water security index is composed of four themes – watershed disturbance; pollution; water resource management; and biotic factors.

AWDO assesses these themes along the following steps. (i) by telemetric determination of in total 23 drivers on a 0.5 degree longiture-latitude grid. (ii) The threat of drivers was modelled (for dilution) by routing down the river basin. (iii) The routed drivers were normalised by dividing by mean annual river discharge. (iv) Next they were standardised on scale 0-1 based on cumulative distribution function. (v) Each driver was asigned weight within their theme. (vi) Each theme was assigned weight within the key dimension. This procedure could not be replicated. Instead, the BWSI assumes a linear calculation of the index based on the indicators.

KD4A – Watershed disturbance

The Catchment Disturbance theme captures the local-scale impact of land-use change and poor stewardship within catchments. Drivers include (i) conversion from natural land cover to cropland; (ii) construction of impervious surfaces; (iii) degradation of uplands and riparian zones by livestock; and (iv) disconnection of floodplains from rivers.

Fraction of cropland relative to total area

Conversion of natural land cover to cropland often increases the rainfall runoff and erosion, particularly in steep sloping areas like mostly occur in Bhutan. Thus, this aspect has a negative appraisal from environmental point of view.

This indicator was also used in AWDO.

Data requirements per district:

- total cropped area in hectares
- total area in the district in hectares

This information will be supplied bu the DOA in MOAF.

Calculation of the index score: inverse linear with data range 5-30%.

(NB: physical limit with 60% forest cover as per constitution.)

Fraction of impervious layer relative to total area

Similar to above, built area like houses, roads, parking places tend to increase the rainfall runoff and have disturbing impact on the watershed. This indicator was also used in AWDO.

Data requirements per district:

- total paved (compacted) area (urban built-up area and roads) in hectares
- total area of district in hectares

This information will be supplied bu the DOA in MOAF.

Calculation of the index score: inverse linear with data range 0-10%.

Livestock density

Free roaming cattle have a disturbing impact on the watershed by trampling and compacting the soil, browsing the vegetation and thus increasing rainfall runoff and erosion. The cattle population density is a measure to monitor this effect.

This indicator was also used in AWDO.

Data requirements per district:

- total number of (large) livestock
- total area in the district in km2

This information will be supplied bu the DOL in MOAF.

Calculation of the index score: inverse linear with data range 5-20 animals/ km2.

Fraction of natural wetland relative to total area

Natural wetlands have an important function in the watersheds in terms of their buffering effect on water flow, and natural cleaning effect of water quality, and providing habitat for a range of organisms and species. Economic development often goes at the expense of natural wetlands by draining them (and convert them into built or agricultural areas) or by cutting them off from the rivers. This type of watershed disturbance is monitored by this indicator.

This indicator was also used in AWDO.

Data requirements:

- surface area (km2) of natural wetland – excluding glacier lakes that are classified as posing GLOF risk
- total area in concerned district

This information will be supplied by WMD in DOFPS .

	Calculation of the index score: linear with data range 0-5%.

KD4B - Pollution

This sub-dimension encompasses a number of pollutants that have well known direct or indirect effect on water resources and/ or bio-diversity. Indicators include (i) soil salinization; (ii), nitrogen; (iii) phosphorus; (iv) mercury deposition; (v) pesticide loading; (vi) sediment loading; (vii) organic loading (as Biological Oxygen Demand, BOD; (viii) potential acidification; (ix) thermal alteration. As can be seen below, not all these drivers have been adopted in the BWSI.

Total suspended solids in ppm

The sediment load in the rivers is a factor to be considered in hydropower generation. Sediments are detrimental to the turbines and should settle in stilling basins that are included in the design of the hydropower plant. This indicator is also used in AWDO.

Data requirements:

- % of compliance with sediment load in ppm that will be determined on the basis of random sampling by DHMS.

Calculation of index score: inverse linear with data range of 0-100 ppm.

Organic loading/ BOD5

Biochemical oxygen demand is a measure of pollution in terms of the amount of dissolved oxygen utilized by microorganisms during the oxidation of organic components in the water. After incubation, the amount of dissolved oxygen consumed is obtained by titration and the results expressed as parts per million of BOD. Complete biological oxidation generally requires about 20 days at 68°F. However, the test has been standardized to be completed in 5 days, hence the term BOD5. BOD can be used as a gauge of the effectiveness of wastewater treatment plants. This indicator is also used in AWDO.

Data requirements:

- % of compliance with BOD5 in mg/l that will be determined on the basis of random sampling by NOP, DOA, MoAF.

Calculation of index score: inverse linear with data scale 0-10 mg/l.

KD4C – Water resources management

The Water Resource Development sub-dimension includes a variety of ways in which people have altered the quantity of water available to human populations and providing essential ecosystem services. Indicators include (i) the density of dams within catchments; (ii) the fragmentation of river networks by dams; (iii) consumptive water loss; (iv) human water stress; (v) agricultural water stress; (vi); and (vii) flow disruption.

Dam density

Hydropower & large

Dams in rivers disrupt the free movement of migrating fish species. The reservoirs change the temperature of the water as well as the sediments load. These factors

<table>
<tr><td>irrigation dams
(operational or under construction)</td><td>have an impact on the environment. Therefore the density of dams in the river system is an indicator for water resources management. A high value has a low appreciation. This indicator is also used in AWDO. Proxy for river fragmentation and flow regulation.

Data requirements per district:

• number of large (to be defined) dams for hydro-power or irrigation operational or under construction
• total area of the district in km2

The information will be generated by DHPS, MoEA and DRE, MOEA.

Calculation of the index score: inverse linear with data range 0-20.</td></tr>
<tr><td>River length de-watered</td><td>This aspect relates to run-off-the river hydropower plants, whereby the river flow is diverted through the so-called head race tunnel to the generators of the power plant. This practice leaves the river bed with a fraction of the original water flow, particularly when environmental flow requirements are not met. This indicator is not mentioned in AWDO

Data requirements per district:

• the length of original river course(s) in km that has/ have been dewatered (for hydropower stations) – specify which river.
• total length of the main river (specify which river) and primary tributaries in km within the country

The information will be supllied by DHPS, MoEA.

Calculation of the index score: inverse linear with data range 0-2%</td></tr>
<tr><td>Dependable water availability per capita during lean season

Any norm? Falkenmark?</td><td>The amount of water available per capita is a measure of water resource management. In Bhutan, this figure is only meaningful during the height of the lean season, which is January. This indicator is not explicitly mentioned in AWDO, but it is required for calculation of the indicators below.

Data requirements per district

• dependable water availability (MCM)
• population

The dependable water availability follows from the hydrological assessments done by Bhu-8623.

Calculation of indicator score: linear with data range 0-500 m3/capita.</td></tr>
<tr><td>Relative total water consumption during lean season (January)

All users</td><td>The percentage of available water used for consumption is an indicator for water stress. The irrigation demand is low in January. A high percentage has a low appreciation.

This indicator is also used in AWDO but it does not specify lean season. The month of January is representative for potential scarcity of drinking water (irrigation demand is low)

Data requirements per district:

• total (additional) water consumption till 2030
• the dependable internal water available in January

The parameters have been estimated in the water balance studies done by Bhu-</td></tr>
</table>

8623. Calculation of index score: inverse linear with data range 1-100%

Relative total water consumption during peak irrigation demand (May)

The domestic and industrial consumptive water use is believed to be fairly constant over the year. But irrigation water demand varies strongly over the months within a year. Peak irrigation demand occurs in May, when land is prepared for transplanting paddy and the monsoon rains are only just starting. Like for total (drinking) water consumption in January, total (irrigation) water demand as percentage of available water is an indicator for water stress in May.

Data requirements per district:

- total (additional) water demand in May by 2030
- dependable internal water available in May

The parameters have been determined in the water balance study done by Bhu-8623. Calculation of the index score: inverse linear with data range 0-100%.

KD4D – Biotic factors

This theme aims to capture the local and spatially-distributed impacts of changing the biota of river ecosystems. Humans have altered riverine faunas in many ways. The focus is on three categories of impacts: (a) introduction of non-native species, (b) fishing, and (c) aquaculture. Specific drivers include (i) the percentage of non-native fish species; (ii), number of nonnative fish species; (iii), fishing pressure; (iv) and aquaculture pressure. Each of these drivers has a variety of detrimental effects on fresh waters, ranging from changes in the loading and cycling of nutrients to destabilizing food webs to altering species interactions. Since fishing and aquaculture play a minor role in Bhutan, these factors are not included in the BWSI.

Number of non-native fish species

The number of foreign fish species is monitored. This indicastor is also used in AWDO.

Data requirements per district:

- the number of fish species that originally do not belong in the locality,

The information will be supplied by the National Fishery Centre, MoAF.

Calculation of index score: inverse linear with data range 0-30.

% of non-native fish species

The percentage of foreign fish species is also considered since it puts the number of foreign fish species in a context. This indicator is also used in AWDO.

Data requirements per district:

- the number of non-native fish species (above)
- the total number of fish species

This information will be supplied by the National Fishery Center, MOAF

Calculation of index score: inverse linear with data range 0-100%

KD5 – Disaster & climate change resilience

There is an increasing global consensus on the importance of water-related risk management. Risk management requires quantification of water-related disaster losses at a finer temporal and spatial resolution than currently available for the analysis of trends. Such analysis will provide estimates of vulnerability and resilience and allow assessment of the effectiveness of mitigation policies and investments. AWDO used a combination of i) hazard, ii) vulnerability, iii) exposure, and iv) coping capacity constitutes the risk faced by a population. For BWSI this has been modified into i) Hazards and threats; ii) Sensitivity to exposure; and iii) Coping and adaptive capacity.

For AWDO 2013, the indicators of resilience to water-related disasters (KD5) utilise measures of each country's level of hazard, exposure, vulnerability, and coping capacity to estimate the resilience index. The complexity of assessment of water-related disasters is such that the computations of the resilience indicators are the most complex in the AWDO water security index. In fact, these could not be replicated and therefore the BWSI uses a simple linear scoring.

KD5A – Hazards and threats

Disaster risk (R) is defined as an indicator of expected disaster damage per capita, taking into account the likelihood of occurrence and likely severity. Likelihood of occurrence is not measured by a strict joint probability of hazard occurrence and vulnerability but by a statistical average of hazardous phenomena, such as an area's average daily maximum precipitation. Hence, a hazard is a potentially damaging physical event, phenomenon, or human activity that may cause the loss of life, injury, property damage, social or economic disruption, or environmental degradation.

Maximum total one-week precipitation during the year.

Extreme high rainfall is an obvious threat and potential cause of disaster; hence it is used as an indicator. This indicator was also used in AWDO.

Data requirements per district:

- maximum one-weekrainfal (mm) in a year

The information is to be supplied by DHMS. (moving average 3 years)

Calculation of the index score: inverse linear with data range 100-500 mm.

Inventory of hazardous GLOF lakes

Glacial Lakes at risk of having an outburst flood are also a threat. An inventory of such lakes is used as an indicator for assessing resilience. This indicator was not used in AWDO.

Data requirments per district:

- the number of lakes with potential GLOF risk (high-medium-low),

NB: If lakes can be classified as high-medium-low risk, they can be given corresponding weight.

This information shall be provided by DGM, MOEA.

Calculation of index score: inverse linear with data range 0-50.

Frequency of rainfall > 100 mm/day

A high frequency of high rainfall events is indicative for risk of flooding. This indicator is also used in AWDO. It provides information about the peak rainfall that occurs in the given area, which an important factor contributing

	to risk of flash floods. Data requirements per district: • the number of events with more than 100 mm/ day rainfall per year – averaged over the last 3 years The information will be supplied by DHMS. Calculation of index score: inverse linear with data range 0-10 days.
Maximum number of consecutive dry days (< 1 mm/day)	Prolonged periods of drought form the opposite risk of flooding, but put a high demand on management of the water resources. Hence, drought periods are an indicator in the BWSI. This indicator is also used in AWDO. Data requirements per district: • the number of consecutive dry days in a year – averaged over the last 3 years The information is to be supplied by DHMS. Calculation of index score: linear with data range 30-100 days.

KD5B – Sensitivity to exposure

Exposure relates to the people, property, systems, or other elements present in the area that may be affected by a hazard or threat.

Dry-land (Khamzing) as percentage of total area	A high percentage of dry-land of total area means that much of the agricultural production is at risk from extreme weather events. This indicator is also used in AWDO. Data requirements per district: • the total area of rainfed agriculture in hectares • the total surface area of the district The information will be provided by DoA, MoAF. Calculation of the index score: inverse linear with data range 0-10%.
Percentage change in forest cover over the last 5 years.	This indicator measures the rate of de-forestation and the related increase in runoff and erosion. This indicator is also used in AWDO. Data requirements per district: • the current forest cover in sq km • the previous forest cover (5 years before) in sq km The information will be supplied by DOFPS, MOAF. Calculation of the index score: invers linear with data range -2 to +2 %.

Deviation from constitutionally mandated forest cover (60%) at national and basin level	Not in AWDO, but adopted in the BWSI. A high forest cover provides (some) protection against extreme weather conditions. Data requirements per district: • forest cover in sq km NB: The values will be compiled at basin level. Forested basin area/basin area*100% minus 60%. The information will be provided by DOFPS, MOAF Calculation of the index score: If negative > score =1. If deviation =+30% > score 5. Linear in-between 0-30% scores 2-5. (Theoretically the upper limit = 40%, but that ignores agriculture & built areas).
Population density	This indicator is also used in AWDO. A higher population density is likely to be more effected from bad weather events than a low population density. Data requirements per district: • the total number of population • the surface (sq km) of the concerned district. The information will be provided by NSB. Calculation of index score: inverse linear with data range 10-50.
Urban population density	This indicator is not explicitly used in AWDO Data requirements per urban center in respective districts: • the number of population • the surface area in sq km of the urban centers (all Thromdes in district) The information is to be provided by NSB. Calculation: inverse linear with data range 1000-5000 persons/ sq km.
Urban population growth rate (Thromdes)	This indicator is also used in AWDO. Data requirements per urban center in respective districts: • (estimated) annual % increase of urban population This information will be supplied by MOHS (or NSB). Calculation of index score: linear with data range -5 to +10%.
Total population growth rate	This indicator is also used in AWDO. Data requirements per district: • Percentage increase of total population per year

	This will be supplied by NSB. Calculation of index score: linear with data range 0-2%.

KD5C – Coping and adaptive capacity

Coping relates to the ability of dealing with disaster in terms of preparedness and/or mitigating measures. Adaptive capacity is the ability to adjust to a changing environment. The indicators are mentioned below.

Governance	This indicator is used in AWDO in connection with likelihood of corruption. While that may be useful to compare different countries in a region, it is not so useful comparing different river basins within Bhutan. Therefore the parameter has been re-defined as below. Data requirements per basin: Number of basins with functional RBCs with: • Secretariat formed • RBMP prepared or under implementation • At least one RBC meeting held /yr Calculation of index score: linear with data range 1-7.
Poverty rate	This indicator is also used in AWDO. The rationale for this parameter is that poor people will be more vulnerable to threats. Data requirements per district: • percentage of people living below the poverty line NB: The district figures will be compiled at basin level as weighted average based on population. The information will be supplied by NSB Stick to definition of NSB. Basin figure computed based on population of districts in basin. Weighted according to district populations in basin to derive the basin value. Calculation of index score: inverse linear with data range 10-50%.
Child mortality rate (0-6).	This indicator is also used in AWDO. The rationale for this indicator is that a high child mortality rate stands for a weak population with little resistance to threat and adverse conditions. Data requirments per district:

- annual number of children per thoudand dying before the age of six

NB: District figures are compiled at basin level according to number of population in districts in the basin

The information is to be provided by Bhutan Health Management Information System, PPD, MoH.

Calculation of the index score: inverse linear, with data range 0-200.

Net official development assistance as percent of gross national income

With high development assistance, the community is expected to cope better with disaster. This indicator is also used in AWDO. The indicator is important to trace changes over time and use as basis to justify/ attract more development assistance.

Data requirements:

- net official development assistance in Ngultrum/ year
- GDP in Ngultrum/ year

To obtain from Min of Finance: Total amount in dollars in terms of grants and/or concessionary loans. Compare to GDP.

Calculation of index score: linear with data range 0-20%

Establishment of Emergency Response Mechanisms

This indicator is not used in AWDO, but is relevant for coping with disasters. It is planned to have (at least) one ERU shall be established per district.

Data requirements per district:

- the number of operational District Emergency Response Units that have been established

The information will be be provided by DDM/districts/MOHCA.

Calculation of index score: linear with data range 0-25.

Reservoir capacity

If more water is stored in reservoirs, the community is better prepared to cope with periods of drought. This indicator is also used in AWDO.

It requires information on the volume of reservoirs located in the concerned area (basin, district), to be supplied by DoHPS/DOA.

Calculation of index score: linear with data range 0-27,000 MCM.

Flood Hazard zonation maps produced and updated

This indicator is not used in AWDO, but flood hazard zonation mapping will be an asset in dealing with risk of flash floods.

Data requirements per district:

- The number of district-level flood hazard zonation maps that may have been prepared/ kept updated (< 5 years ago).

The information will be provided by FEMD, DES, MOWHS.

Calculation of index score: linear with data scale 0-20.

Number of flood protection measures pending for implementation	This indicator is not explicitly used in AWDO. The rationale is that flood protection measures (when identified and implemented) will reduce the impact of flood threats. Hence the indicator measures how many identified flood protection measures are pending for implementation. Data requirements per district: • the number of identified/ planned flood protection measures that are yet to be implemented The information will to be provided by FEMD, DES, MOWHS. Calculation of the index score: inverse linear with data range 0-100.
Number of flood/GLOF Early Warning Systems pending for implementation	This indicator is not explicitly mentioned in AWDO, but deemed relevant for Bhutan. There are presently 24 glacial lakes at risk of outburst. Data requirements per district: • The number of identified/ planned early warning systems that are yet to be implemented. This information is the responsibility of DHMS, MOEA. Calculation of index score: inverse linear with data range 0-30
Literacy ratio	This indicator is also used in AWDO. It is assumed that a literate community can better cope with (instructions during) disaster. Data requirements per district: • literacy rate in the concerned area The information is to be provided by PPD, MoE. Calculation of the index score: linear with data range 30-100%.
Education level of women for enhanced coping capacity (with CC impacts)	This indicator is also used in AWDO, but not gender specific. The assumption here is that women are generally more receptive to new ideas for coping with climate change and other kind of natural disasters Data requirements per district: • female school enrolment/ attainment ratio in the concerned area The information is to be provided by PPD, MoE. Calculation of the index score: linear with data range 30-100%.
Access to information – TV, radios	This indicator is also used in AWDO. Obviously, the more people have access to TV or radio, the easier they can be informed about (imminent) disaster. Data requirements: • number of TV/ radio sets per 1000 inhabitants

	The information is to be provided by PPD, MOIC. Calculation of index score: linear with data range 0-300.
Access to Information – mobile phones	This indicator is also used in AWDO. Same as for previous indicator: the more people have access to TV or radio, the easier they can be informed about (imminent) disaster. Data requirements per district: • number of mobile phone connections per 1000 inhabitants, The information is to be provided by PPD, MOIC. Calculation of index score: linear with data range 0-600.
Gross domestic savings relative to GDP	This indicator is used in AWDO and was maintained in the BWSI. A larger aount of savings enables the country to cope better with the impact of disaster by investing in mitigating or adaoptation measures. Data requirements: • gross domestic savings in MNu • GDP in MNu The information will be available from NSB, NAPD. Calculation of index score: linear with data range 0-20%.

Discussion points

Distinguish indicators that are manageable from the ones determined by nature	Planning applies only to manageable indicators, like area under irrigation. However, indicators like rainfall are determined by nature and may identify areas where intervention deserves priority, for instance high-risk areas. It could be useful to separate the actionable inficators from the ones determined by nature.
Do all indicators point in same direction of water *security*?	Double-check whether all indicators 'point in the same direction' of water *security*; like % HP potential developed versus % of HP in GDP.
Single data or moving average	Should the data that are used for the indicators pertain to one reference year, or should they be a moving average (for example over 3 years) in order to dampen yearly fluctuations?

Summary of data requirements and responsible agencies

Data sheet	This summary has been updated

References

1. Indicators for assessing national water security, Asia Water Development Outlook 2013, Authors: Ian W Makin, Wouter Lincklaen Arriens, and Narciso Prudente (Draft not published?)
2. Nature: Supplementary information (on KD4 – Environmental water security), Nature, doi:10.1038/nature09440 (year?)

Appendices

1. Summary data sheet
2. AWDO table for index score on household water security
3. AWDO table for index score on water stored in reservoirs and CV- rainfall
4. AWDO table for index score on trans-boundary water flow
5. AWDO table for index score on agricultural productivity and % land irrigated
6. AWDO table for index score on industrial productivity
7. AWDO table for index score on % hydropower installed
8. AWDO table for index score on extent of urban flooding
9. Biological monitoring of water quality
10. Making, AWDO (separate WORD file)
11. Nature09440-s1 on KD4-Environmental water security (separate in PDF)

Appendix 1: Summary sheet for data collection

Key Dimension	Parameter	Data or Unit	Formula	Agency responsible for data
KD-1	**RURAL DRINKING WATER SUPPLY & SANITATION**			
1	% of population linked to piped water supply	Number of households in the Gewog Population of the Gewog Number of households with functional piped water supply	(Number of hourseholds connected to treated water supply * Average size of household)/ (Population of the area) *100	Department of Public Health, MOH
2	% of population with access to improved (water sealed toilets)	Number of households in the Gewog Population of the Gewog Number of households with improved (water sealed) toilets	similar to above	Department of Public Health, MOH
3	hygiene by incidence of diarrhea/ 10,000 inhabitants per year	Total population of the District Number iof cases of diarrhoea for the year	Number of incidences in the year/ population/ 10,000	Department of Public Health, MOH
KD-2	**ECONOMIC WATER SECURITY**			
KD-2A1	**Agriculture resilience**			
1	% of cropped area irrigated from reservoir	Total cropped area in the District (Ha) Area served by reservoir and rain water harvesting facilities (Ha)		MoAF/DoA/Dzongkhag (DAO)/ MoAF/DoA/Dzongkhag (DAO)/
2	variability of inter-annual annual rainfall	Coefficient of variation of annual rainfall over last twenty years		DHMS, MoEA
3	variability of intra-annual rainfall	Coefficient of variation on a monthly		DHMS, MoEA

Key Dimension	Parameter	Data or Unit	Formula	Agency responsible for data
		basis over last twenty years		
KD-2A2	**Agricultural water utilization**			
1	Agricultural productivity - Agricultural contributuon to GDP in Nu/ MCM of water used for irrigation	Agriculture contribution to GDP in Ngultrums Total amount of water used for irrigation (MCM) for the year	Agriculture contribution to GDP in million Ngultrums/ Total amount of water used for irrigation (MCM)	DOA, MoAF DOA, MoAF
2	% Arable land irrigated	Total Arable land (Ha) in the District Total irrigated land (Ha) in the Disrict	Total Arable land (Ha) in the district/ Total Arable land (Ha) in the district *100	DOA, MoAF
3	How effectively water is utilized for food security - percentage of quantity of cereals imported annually out of total cereals consumed in country (metric tonns)	Quantity of cereal imported annualy in metric tonns Quanity of cereals consumed annually (metric tonns)	Quantity of cereal imported annualy in metric tonns/ Quanity of cereals consumed annually (metric tonns) *100	MoA /RMA
KD-2B	**Industrial water security**			
1	Revenue generated from water based industries	Revenue generated from **water based** inductries in Nu. Indistrial water utilization excluding Hydropower (Million cubic meters)	Nu. Per mllion cubic meters	Dept. of Industry, MOEA NECS?
KD-2C	**Hydropower water security**			
1	Volume of annual national trans-boundary inflow as percentage of the sum of annual renewable water resource and annual inflow	Annual volume of water flowing in from outside Bhutan into the basin Annual volume Run off for the basin (million cubic meters)	Volume inflow/(Volume inflow +Run off for the basin)*100	DHMS

Key Dimension	Parameter	Data or Unit	Formula	Agency responsible for data
2	% of Hydropower developed (installed capacity) against the economically hydropower potential in MW	Total economically viable potential hydropower cpacity (Mega Watt) Actuall installed capacity of Hydropower (in MW)	Actuall installed capacity of Hydropower (in MW)/ Total economically viable potential hydropower cpacity (Mega Watt) * 100%	DHPS, MOEA/ DRE, MOEA
3	% hydropower contribution to national/ basin energy consumption	Hydropower consumption in Gigawatt hours per year Total amount of energy consumption in GWh equivalent	Hydropower consumption (in GWh)/ Total amount of energy consumption in GWh equivalent *100	DHPS, MOEA/ DRES, MOEA
4	Hydropower contribution to GDP in milion Nu. Per million cubic meters of water used.	Amount of Hydropower revenue (Nu.) generated in the basin per year Volume of water flowing through the river basin per year		
5	Hydropower Efficiency (weighted average annual plant load factor for the basin)	plant load factor	Plant load factor (%) as derived by DHPS	DHPS
KD-3	**URBAN WATER SECURITY**			
1	% of urban population having potable water supply- Urban	Population of the urban area (class A, B. or C) Average size of household Number of hourseholds connected to treated water supply	(Number of hourseholds connected to treated water supply * Average size of household)/ (Population of the urban area (class A, B. or C)*100	Water and Sanitation Division, DES, MoWHS

Key Dimension	Parameter	Data or Unit	Formula	Agency responsible for data
2	urban water losses	Revenue from water disribution sysem (Nu.) per year Tariff (Nu. Per Cubic meter) Total amount of water produced at the treatment plant (MCM) per year	(Revenue from water disribution sysem (Nu.) per year /Tariff) - Total amount of water produced at the treatment plant (MCM) per year	Water and Sanitation Division, DES, MoWHS
3	% of population without improved sanitation (i.e., linked to sewer, inidividual or communal septic tanks)	Number of households **without** improved sanitation Average size of household Total number of households in the urban area	(Number of households without imporved sanitation * Average size of household) /(Total number of households in the urban area * Average size of household) * 100	Water and Sanitation Division, DES, MoWHS
4	% of urban population with at least weekly solid waste collection and disposal service	Number of households having at least weekly solid waste collection and disposal Total number of households in the urban area Average size of household	(Number of households at least weekly solid waste collection and disposal * Average size of household)/ (Total number of households in the urban area *Average size of household) *100	Water and Sanitation Division, DES, MoWHS
5	Damage from urban flooding/ capita / GDP per capita	Average annual flood damage over last five years in Ngultrum Total population of the area Per capita GDP	(Average annuall flood damage over last five years in Ngultrum/ Total population of the area)/(Per capita GDP) *100	Flood Engineering Management Division, DES MoWHS
KD4	**ENVIRONMENTAL WATER SECURITY**			
KD-4A	**Environment - Watershed disturbance**			

Key Dimension	Parameter	Data or Unit	Formula	Agency responsible for data
1	Fraction of cropland (considering	Total arable land (Ha) Total land area of the concerned district or country	Total arable land (Ha)/Total land area (Ha) *100	DoA, MoAF
2	Fraction of impervious surface area.	Area of paved (compacted) area (urban built up area and road)		DoA, MoAF
3	Livestock density.	Population of Livestock in the area Land area of the district (Km2)	Population of Livestock in the area/ land area of the disrrict	DoL, MoAF
4	Natural Wetland status.	Surface area of natural wetlands (excluding glacial lakes classified as posing GLOF risks) - Km2 Land area of the district (Km2)	Surface area of natural wetlands (excluding glacial lakes classified as posing GLOF risks) - Km2/ Land area of the district (Km2) *100	WMD, DOFPS
KD-4B	**Environment - pollution**			
1	*Total suspended solids.*	% of compliance (samples) ppm		DHMS
2	*Organic loading/ BOD*	% of compliance (samples) Mg/l		NOP, DOA, MoAF
KD-4C	**Environment - Water resources management**			
1	Dam density	No. of operational or under construction hydropower dams in given area No of operational or under construction large irrigation dams Total area of the district	(No. of operational or under construction hydropower dams in given area + No of operational or under construction large irrigation dams/ Total area of the district or basin)*100	DHPS, MoEA and DRE, MOEA

Key Dimension	Parameter	Data or Unit	Formula	Agency responsible for data
2	River network fragmentation: Percentage of the length of original courses of main and primary river(s) dewatered (for Hydropower) in Kms within the basin of the country against the legnth of the rivers	length of original courses of main and primary river(s) dewatered (for Hydropower) in Kms within the basin	(sum of length of dewatered river courses in the basin (Km)/ sum of length of original course of main river and primary tributaries in the basin)*100	DHPS, MoEA
		Length of original course of main and primary river(s) Kms within the basin		
		Spefify the name of the river		
3	Relative total water consumption in the lean period - January	a) Total water consumption for domestic urban and rural, livestock, industries, agriculture consumptive uses in January (in MCM)	a)/ b)*100	WSD, DES
		b) total dependable water available in January		
4	Relative total water consumption in the lean period - May	a) Total water consumption for domestic urban and rural, livestock, industries, agriculture consumptive uses in May (in MCM)	a)/ b)*100	WSD, DES
		b) Total 80% dependable water available in May		
KD-4D	**Environment - Biotic factors**			
1	Number of nonnative fish species.	No. of nonnative species		National Fishery Centre, MoAF
2	% non-native fish species	Number of non-native fish species	[Number of non-native fish species/ Total number of fish species]*100	
		Total number of fish species		
KD-5	**DISASTER & CLIMATE CHANGE RESILIENCE**			
KD5A	**Hazards and Threats**			

Key Dimension	Parameter	Data or Unit	Formula	Agency responsible for data
1	Maximum total one week precipitation (millimeter) averaged over the last three year	Total rainfall (mm) for the week with the maximum total rainfall for last yr1, yr 2, yr 3	(SUM Total rainfall (mm) for the week with the maximum total rainfall for Yr1 to Yr 5)/5	DHMS
2	Inventory of Potential hazardous lakes for GLOF Risk	Number of GLOF lakes with risk category H, M, L	Give weight to incidences H, M, L risk	DGM, MOEA
3	Frequency (>100 millimeter/day rainfall) per year (averaged over last three years)	Number of times with rainfall in excess of 100mm/ day for last Yr1, Yr2, Yr3	(Number of times with rainfall in excess of 100mm/ day for last Yr1+ Yr2+Yr3)/3	DHMS
4	Drought hazard *Number of consecutive dry days (< 1 millimeter rainfall) averaged over last three years*	Longest duration of days with less than 1mm rainfall over the last Yr1, Yr2, Yr3	(Longest duration of days with less than 1mm rainfall over the last Yr1+Yr2+ Yr3)/3	DHMS
KD5B	**Sensitivity to exposure**			
1	Dry-land (Kamzhing) area as percentage of total area	%	Khamzing area (Ha) Total area (Ha)	DoA, MoAF
2	Percentage change in forest cover over the the last five years	Current forest cover (Km2) Forest cover 5 years ago (Km2)	[(Forest cover this year (km2)-Forest cover 5 years ago(km2))/Forest cover five years ago(km2)]*100	DOFPS, MOAF DOFPS, MOAF
3	Deviation from constitutionally mandated forest cover (60%) at national and basin level	Forest cover at basin level at basin level (km2)	(Forest cover of the basin/ Land area of the basin) *100 - 60	DOFPS, MOAF
4	Population density (numbers per Km2)	Total population of the area (Nos) Area of the disrict (Km2)	Total population of the area (Nos)/ Area of the disrict (Km2)	NSB NSB

Key Dimension	Parameter	Data or Unit	Formula	Agency responsible for data
5	Urban Population density	Population of all the Thromdes in the district (Nos)	Population of all the Thromdes in the district (Nos)/ Total area of all the Thromde's in the district (Km2)	NSB
		Area of the Thromdes in the district		NSB
6	Urban population growth rate (Projected based on 2005 baseline data)	Population growth rate for Thromdes (Refer to NSB)	[Current population of the Thromde's in the district - population of the Thromde's in the district in the past/ population of the Thromde's in the district in the past]*100	MOWHS/ NSB (To be computed by concerned agencies and entered in the database)
7	Total population growth rate (projected)	Percent	[Current population of the district in the - population of the district in the past/ population of the district in the past]*100	NSB (To be computed by concerned agencies and entered in the database)
KD5C	**Coping and Adaptive capacity**			
1	Governance	Number of RBCs that has 1) formed a Secretariat 2) met at least once meeting in the last year 3) RBM Plan prepared/ implemted.		NEC
2	Poverty Rate	Percentage at district level (weighted by population of district for basin level calculation)		NSB
3	Child mortality rate (0-6).	Incidences per 1000 live birth		Bhutan Health Management Information System, PPD, MoH

Key Dimension	Parameter	Data or Unit	Formula	Agency responsible for data
4	Net official development assistance as percent of gross national income	Percentage		DPA, MOF
	Net official development asssistance in Ngultrum	million Ngultrum		MOF
	GDP	million Ngultrum		MOF
5	Establishment of Emergency Response Mechanisms (EOCs/EC..)	No of units that can respond within 2 hours		DDM/districts/MOHCA
6	Total reservoir capacity per Districts	volume in MCM		DoHPS/DOA
7	Flood Hazard zonation maps produced and updated	No. of Dzongkhags having updated (< 5 yrs ago) flood hazard zonation map		FEMD, DES
8	Flood protection measures pending for implementation	Number of identified projects pending		FEMD, DES
9	Flood/GLOF Early Warning Systems	Numbers		DHMS, MOEA
10	Literacy ratio	Percent		PPD, MoE
11	Education (enrollment ratio)	Percent		PPD, MoE
12	Information (television/Radio receivers per 1,000 inhabitants)	No		PPD, MOIC
13	Information (mobile phone subscription)	Percent		PPD, MoIC
14	gross domestic saving	Savings % of GDP		NAPD, NSB

Appendix 2 on Household water security

Table on Categorization matrix - Household water security

Piped Water Access		Access to Sanitation		Hygiene		Household Water Security	
%	Category [a]	%	Category [b]	DALYS	Category [c]	Indicator [d]	Index
0	1	0	1	0	5	0	1
60	2	60	2	100	4	4	2
70	3	70	3	200	3	7	3
80	4	80	4	500	2	13	4
90	5	90	5	760	1	14	5

Note: Household Water Security Indicator $d = a + b + c$

Appendix 3 – AWDO table for water stored in reservoirs and CV-rainfall

Table on Resilience assessment matrix

Storage		Inter-annual rainfall		Intra-annual rainfall	
% of MARR	Indicator	CV	Indicator	CV	Indicator
	A		B		C
0	1	0	5	0	5
3	2	0.025	4	0.20	4
5	3	0.050	3	0.40	3
20	4	0.100	2	0.60	2
50	5	0.150	1	0.75	1

Note: Resilience = 2*(A+B+C)/3

Appendix 4 – AWDO table for agricultural dependency (trans-boundary water flow)

Table on Matrix for assessment of agricultural dependency

External water dependency		Agricultural consumption independence	
% external RWR	Indicator [a]	Agricultural footprint	Indicator [b]
0	5	<1	1
20	4	1	2
40	3	9	3
60	2	20	4
90	1	60	5

Note: Agricultural water security = [a] + [b]

Appendix 5 – AWDO table on agricultural water productivity

Table on Agricultural water utilisation efficiency matrix

Agricultural water productivity		Arable land irrigated	
$M/Km³	Indicator [a]	%	Indicator [b]
0	1	0	1
100	2	20	2
200	3	30	3
350	4	45	4
1,000	5	60	5

Note: $M/Km³ = US$ million per cubic kilometre of water use; Utilisation Efficiency = [a] + [b]

Appendix 6 – AWDO table for industrial water productivity

Table on Water security in industry matrix

Industrial water productivity		Industrial consumption	
$M /Km³	Indicator [a]	Industrial footprint	Indicator [b]
0	1	0	1
2,100	2	0.6	2
5,500	3	1.0	3
20,000	4	1.75	4
50,000	5	2.0	5

Notes: $M/Km³ = US$ million per cubic kilometre of water use; Water Security in Industry = [a] + [b]

Appendix 7 – AWDO table on % hydropower installed

Table on Water security for energy production matrix

Hydropower potential		Hydropower dependency	
% developed	Indicator [a]	% of energy use	Indicator [b]
0 <= 1.5	5	0 <= 4.0	1
1.5 <= 8.0	4	4.0 <= 8.0	2
8.0 <= 14.3	3	8.0 <= 17.0	3
14.3 <= 30.0	2	17.0 <= 50.0	4
> 30.0	1	> 50	5

Note: Utilisation Efficiency = [a] + [b]

Appendix 8 – AWDO table on extent of flooding

Table on Urban flood damage assessment matrix

Standardised loss % per capita GDP/yr	Urban flood damage indicator
0.0	5
0.5	4
6.0	3
10.0	2
14.0	1

Appendix 9 – Biological monitoring of water quality

BHUTAN CLASS IX SCHOOL MANUAL ON WATER QUALITY MONITORING

Field Data Sheet 5: How Clean is our Stream?

The Biotic Index

Assemble the same team who did the insect collecting for Field Data Sheet 4

When all the water animals have been identified for a ***Section*** of the catchment, the next stage is to calculate a ***Biotic Index*** for that section. This works by giving each animal a ***score.*** Some of the animals we have collected can only live in ***clean*** water and are given a ***high*** score. Others which can live happily in ***polluted*** water are given a ***low*** score. Use the ***Biotic Score-card*** to find out what the scores are for your list of water animals. (**Please Note:** not all the animals collected will have a score. So don't worry if an animal you have on your list is not on the Score-card, just don't include it in any of the calculations).

Name of School__________________________ Name of Stream_________________________________

Section of Catchment_____________ Date of Survey________________ Time of day_____________

Biotic scores for our water animals

	Name of animal collected	Tick in this column only if the animal is listed on the Biotic Score-card	Biotic score for this animal
Totals	Number of different animals	number of ticks	Sum of biotic scores

The Biotic Index of the water

Calculate an average score by dividing the Total Biotic score by the number of ticks (representing the number of types of animal contributing to the score). This is the Biotic Index.

The Biotic Index of this Section =

Biotic Score-card

Animal name	Biotic Score
Stonefly nymph	10
Burrowing mayfly nymph	10
Flattened mayfly nymph	10
Desmoiselle nymph	8
Dragonfly nymph	8
Freshwater limpet	8
Cased caddis larvae	7
Swan mussel	6
Swimming mayfly nymph	6
Freshwater shrimps	6
Other damselfly nymphs	6
Caseless caddis larvae	5
Blackfly larvae	5
Cranefly larvae	5
Pond skater	5
Water beetle	5
Water boatman	5
Water scorpion	5
Water measurer	5
Alderfly larvae	4
Flatworm	4
Water mite	4
Leech	3
Pea-cockle	3
Water hoglouse	3
Rat-tailed maggot	3
Snails	3
Non-biting midge larvae	2
True worm	1

About Biotic Scores

Water pollution can be measured chemically, or more easily by looking at the animals living in the water. To measure pollution using water animals involves giving each type of animal a biotic score. Animals that live best in very clean water (for example stonefly nymphs and most mayfly nymphs) have a high biotic score, whereas animals that have found ways of living happily in polluted water (for example worms and non-biting midge larvae) have a low biotic score◊.

Discussion

The Trent Biotic Index uses the presence or absence of 6 key organisms (plecopteran larvae, ephemeropteran larvae, trichopteran larvae, Gammarus, Asellus and tubificids plus red chironomid larvae) to indicate the relative level of pollution in a stream.

- Advantage: Easy to use, especially for moderately or heavily polluted sites.
- Disadvantages: not specific enough, doesn't fully account for habitat quality

There are different classes of indicator species also. The types of macro-invertebrates and other organisms found during sampling are broken into 4 groups:
1: Pollution intolerant: These organisms are highly sensitive to pollution. (IE: Stonefly or Alderfly Larva)
2: Semi-Pollution intolerant: These organisms are sensitive to pollution. (IE: Dragonfly Larva or Crawfish)
3: Semi-Pollution tolerant: These organisms will be found in clean and slightly polluted waterways. (IE: Snails or Black Fly Larva)
4: Pollution tolerant: These organisms will be found in polluted, as well as clean aquatic ecosystems (IE: Leechs,Bloodworms)
Some index worksheets combine groups 2 and 3 together giving only 3 groups. Each group has a number assigned to it and is multiplied by the number of organisms found in that group. This is why identifying the type of organism is important.

It has been reported in Austria that the applicability of these methods is restricted in high mountainous areas (e.g. glacial torrents (very specific biological community with high natural variation – influence of glacier discharge is very changeable)).

Biochemical Oxygen Demand: A measure of the amount of dissolved oxygen required to break down the organic material in a given volume of water through aerobic biological activity.

- high BOD indicates there are many organisms using oxygen for respiration
- low BOD indicates relatively few organisms needing oxygen for respiration
- high BOD = low DO levels = high pollutant levels, especially nitrate & phosphate
- low BOD = high DO levels = low pollutant levels

Dissolved oxygen is important for life in waterways. Oxygen enters the water in several ways. Like terrestrial plants, aquatic plants use the sun's energy for growth during photosynthesis. Since oxygen is a byproduct of photosynthesis, it is then available in the water for consumption by aquatic organisms. Oxygen also enters the water from the atmosphere through mixing as the water flows or due to wind or wave action. At higher elevations, less oxygen can be dissolved in water. The more nutrients in the water, the greater opportunity for plant growth. With more plants, there will be more photosynthesis, but also more respiration. This means that dissolved oxygen concentrations may be very low in the morning, and very high in the afternoon.

Water **temperature** can affect the survival of aquatic organisms. Organisms need fairly stable temperatures for survival. For instance, brook trout require waters to be in the range of 55 to 65 degrees Fahrenheit (12.8 to 18.3 degrees Celsius) to survive. Other organisms, such as carp can survive in waters with higher temperatures. Organisms are generally adapted to seasonal changes in water temperature or levels. For instance, by emerging as adults, insects avoid warmer temperatures or drought conditions in the stream, and their eggs may be resistant to low dissolved oxygen levels. If a stream is subject to a large or abrupt change in temperature, organisms present in the stream may die or, if able, leave the area that has been affected.
Stream water temperature might be affected by urban runoff which flowed from parking lots and was heated before entering the stream. Cutting riparian vegetation alongside a stream can decrease shade to the stream, and therefore increase stream water temperature. Streams or rivers that receive waters that are used for cooling in factories will also have temperature fluctuations. Rivers that are dam controlled may also have temperature fluctuations as waters are held back from flowing downstream of the dam (thus lowering water levels and increasing ability of the sun to heat the water).

Increased **turbidity** can increase the temperature of the water because particles suspended in the water absorb the sun's heat more than pure water.
Increased turbidity will limit the amount of light that can enter a waterbody, and may therefore limit plant photosynthesis, and thus, oxygen production. This means that the water may have less ability to support aquatic life with increased turbidity. Increased turbidity beyond background levels can irritate gills in fish and macro-invertebrates, thus negatively affecting their growth and/or survival. Turbid conditions can make it difficult for sight-feeding predators, such as bass, pike, and trout to find their food in aquatic systems. Other fish, such as carp, which do not depend on sight to feed, are better able to survive in turbid conditions. Habitat, particularly substrate which may provide hiding spots or nesting sites, can also be negatively affected by sedimentation.

Aspects of stream **habitat** are: rocky or soft bottom; bank stability, channel flow status, sediment deposition, riparian vegetation, etc.◊