4

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Using the Freshwater Health Index to Assess Progress toward Sustainable Development Goal 6, Clean Water and Sanitation, in Cambodia

1. Introduction

SDG 6: Clean Water and Sanitation

The Sixth Sustainable Development Goal (SDG6) seeks to ensure the availability and sustainable management of water and sanitation for all. Achieving SDG6 requires the freshwater demands of municipalities, agriculture, forestry, industry and natural ecosystems be sustainably met by 2030. The importance of SDG 6 is highlighted by the World Economic Forum (WEF) which ranked water crisis as the number one global impact risk in 2015 (World Economic Forum, 2015), and including water crisis in the top five global impact risks since 2012 (World Economic Forum, 2015). In 2014, the WEF recognized water security as a systemic global risk (World Economic Forum, 2014). A systemic risk is likely to entirely break down a system, as opposed to the isolated failure of individual components (Kaufman & Scott, 2003). Systemic risks can have modest tipping points, which may combine to produce system failure; they maybe contagious, with one failure triggering a chain of others; and, the system may be unable to recover its previous state after a shock due to a lack of resilience (World Economic Forum, 2014). Global risks to water security include floods, droughts and the impacts of water shortages on shared strategic water resources. The latter can have a systemic impact as the combination of water shortages, poverty and social instability can lead to transboundary conflicts (World Economic Forum, 2014).

As human populations grow and become wealthier the need to supply water to cities and factories, increase agricultural production and produce energy is increasing the demand for freshwater. In the 20th century, as the human population quadrupled, freshwater withdrawals increased nine fold (World Economic Forum, 2014). Competition for water is projected to rise along with increases in water withdrawals for agriculture and energy generation (World Bank, 2016). Although global gains in providing people with safe water sources have been made, dwindling supplies of safe drinking water remain a problem (World Bank, 2016), while climate change is altering the spatial and temporal distribution of exploitable water resources. This not only makes future progress difficult, but it threatens to reverse already hard-won gains.

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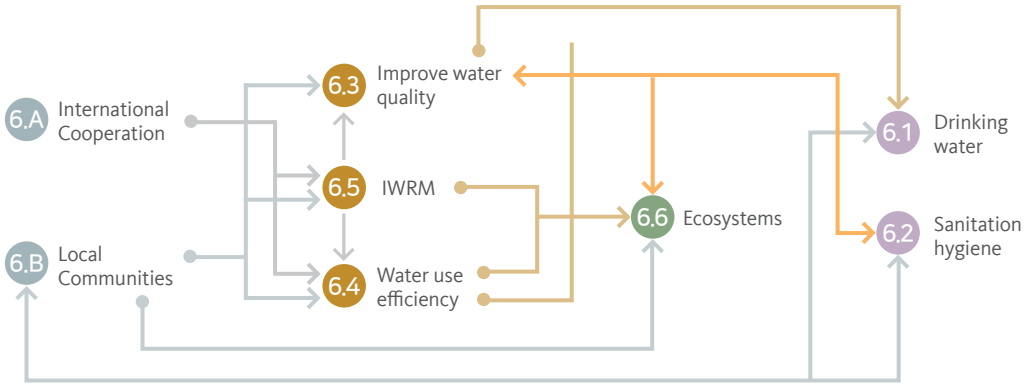
To capture this complexity, SDG 6 has eight targets and eleven indicators, which are interlinked and address the full gamut of human water use and management (Box 1). The basis of SDG 6 is the provision of an adequate supply of clean water for human use and adequate sanitation (Targets 6.1 and 6.2). To achieve these goals, pollution must be controlled (Target 6.3) and water-use efficiency increased (Target 6.4). Meeting these goals requires implementing integrated water resources management (Target 6.5) underpinned by the protection of functioning water-related ecosystems (Target 6.6). Two mechanisms are needed to achieve success: 1) expanding international cooperation and capacity building (Target 6.A) and 2) the participation of local communities in water and sanitation management (Target 6.B). In recognizing that water security is a systemic risk when addressing SDG Goal 6, we must look beyond the provision of safe water and sanitation to include the environment, human health, food security and disaster resilience. It also has been recognized that water security is a pre-condition for economic growth (World Bank, 2016). SDG 6 is a cross-cutting goal, as its achievement is a pre-requisite for achieving many of the other 16 SDGs (Regan et al., n.d.; UN-Water, 2016b).

Inter-relationships between SDG 6 targets



The eight inter-related targets of SDG 6 cannot be achieved in isolation. A simple conceptual model can help clarify important relationships between targets. Clean drinking water (6.1) and sanitation (6.2) are SDG 6's two main human outcomes (purple circles). Sanitation and hygiene have an impact on water quality and are also affected by it. Thus, poor sanitation makes improving water quality difficult, while poor water quality negatively affects hygiene. A similar relationship exists between water quality and ecosystems (6.6). Targets 6.3, 6.4 and 6.5 (brown circles) are management processes, which are directly affected by human input (6.A, 6.B; grey circles) and have an impact on human outcomes or natural processes (6.6; green circle). For example, increased water-use efficiency can make more water available for the environment while providing secure supplies of drinking water. Integrated water resource management impacts the other two management processes as well as water-dependent ecosystems, and its effectiveness can be improved through international cooperation and the input of local communities. Local communities influence all other SDG 6 targets, either through direct input (e.g., catching fish), or making management decisions. They, in turn, benefit from improved supplies of clean drinking water and adequate sanitation.

SDG 6 and Cambodia

Despite abundant water resources Cambodia has Southeast Asia's lowest National Water Security Index (NWSI) score, 37.5 out of 100 (Asian Development Bank, 2016). This classified Cambodia as "Engaged,"which generally means that more than half the population has access to modest potable water and sanitation facilities. Also, initial development of water service delivery to support economic activities, as well as some measures to improve water quality, have begun, and initial attempts have been made to address water-related risks. However, Cambodia's score was only marginally above the "Hazardous" threshold (36), which is characterized by limited water and sanitation facilities, poor infrastructure and water quality, seriously damaged aquatic ecology and poverty inducing floods and droughts (Asian Development Bank, 2016). Of the five dimensions that made up the score, economic water security was the highest (12.7 out of 20) followed by environmental water security (8), household water security (6.7), urban water security (5.6) and resilience to water-related disasters (4.5).

A UNDP assessment of Cambodia's National Strategic Development Plan (NSDP) 2014–2018 and other related plans against SDG targets revealed gaps between national goals and potential indicators that align with the SDG 6 targets (United Nations Development Programme, 2016). This assessment considered that SDG goals 6.1, 6.3, 6.5 and 6.6 were addressed, while 6.2 and 6.4 were only partially addressed by government plans. However, indicators for Targets 6.3, 6.4 and 6.5 were not included in the plans reviewed. Furthermore, the Royal Government of Cambodia has prepared a preliminary, but incomplete, list of national SDG targets.

This brief analysis shows that Cambodia faces considerable challenges in both meeting and reporting on its SDG 6 targets. The Freshwater Health Index (FHI; Vollmer et al., 2018) can help Cambodia assess and report on SDG 6. Results from an FHI assessment of the Cambodian section of the Sesan, Srepokand Sekong River basin are presented below, along with a discussion of how these results can be used to report against relevant SDG 6 targets and indicators in Cambodia.

2. The Freshwater Health Index in Cambodia

The Freshwater Health Index (Box 2) has been applied in Cambodia to the 3S River basin which comprises the Sesan, Srepok and Sekong Rivers (Figure 1) (Regan et al., n.d.). The 3S Rivers originate in Lao PDR and Vietnam, and flow through Cambodia, where they join before discharging to the Mekong River. The 3S basin is a significant source of both flow (Adamson, Rutherfurd, Peel, & Conlan, 2009; Arias et al., 2014) and sediment (Koehnken, 2012) to the Mekong and provides important migratory fish habitat (Ziv, Baran, Nam, Rodriguez-Iturbe, & Levin, 2012). The 3S River system is rapidly changing due to land clearance for industrial agriculture, climate change and hydropower dam development.

The Freshwater Health Index

ECOSYSTEM VITALITY

Water Quantity
- Deviation from natural flow regime
- Groundwater storage depletion

Water Quality
- Suspended solids
- Total nitrogen
- Total phosphorus
- Indicators of major concern

Drainage-Basin Condition
- Channel modification
- Flow connectivity
- Land cover naturalness

Biodiversity
- Species of concern
- Invasive & nuisance species

ECOSYSTEM SERVICES

Provisioning
- Water supply reliabilty relative to demand
- Biomass for consumption

Regulation & Support
- Sediment regulation
- Deviation of water quality metrics from benchmarks
- Flood regulation
- Exposure to water-associated diseases

Cultural
- Conservation/Cultural Heritage sites
- Recreation

GOVERNANCE & STAKEHOLDERS

Enabling Environmet
- Water resources management
- Right to resource use
- Incentives & regulations
- Financial capacity
- Technical capacity

Stakeholder Engagement
- Information access & knowledge
- Engagement in decision-making processes

Vision & Adaptive Governance
- Strategic planning & adaptive governance
- Monitoring & learning mechanisms

Effectiveness
- Enforcement & compliance
- Distribution of benefits
- Water-related conflict

The Freshwater Health Index (FHI) is a multi parameter index of river catchment health (Vollmer et al., 2018). The FHI defines freshwater health as the ability to deliver water-related ecosystem services, sustainably and equitably, at the drainage basin scale. It is implicit that sustainable and equitable long-term delivery of ecosystem services relies on long-term ecosystem function. The FHI is an adaptable composite indicator system that collates monitored and modeled data under three major indicators: Ecosystem Vitality, Ecosystem Services and Governance & Stakeholders. Indicators are scored from 0-100, with higher scores indicating better conditions. Using the FHI, countries can look comprehensively at the sustainability of their freshwater systems.

↘ Figure 1

Location of the Sesan, Srepok and Sekong (3S) River basin (light blue) in Southeast Asia. The dark blue portion is the section of basin located in Cambodia, dotted lines represent river basin boundaries.

The FHI assessment of the 3S River basin provides a baseline health status as of December 2016, using a combination of real and modeled data as well as stakeholder surveys. Ecosystem Vitality and Ecosystem Services scored 64 and 80, respectively, out of a possible 100, and Governance & Stakeholders scored 43 (Regan et al., n.d.). This shows that the 3S basin is providing a range of ecosystem services, but there are signs of ecological and hydrological stress, and there is limited capacity to cope with rapid change. Although the provision of Ecosystem Services is relatively high in comparison with Ecosystem Vitality, if vitality declines further, service provision may also decline.

As the previous assessment was not exclusive to Cambodia, but also included portions of Lao PDR and Vietnam, SDG 6 relevant FHI indicators were recalculated for the Cambodian section of the basin only. These results are then used to report against relevant SDG targets.

↘ Image 1

The Sekong River basin in Cambodia

Credit : Nola Lee Kelsey, Conservation International

3. The Freshwater Health Index and the SDGs

Individual FHI components provide information that is relevant to, or directly corresponds to, indicators for measuring progress towards SDG6 (Table 1). The following section describes a suite of relevant indicators applied to the Cambodian section of the 3S River basin. Unless otherwise stated, the methods used are described in detail in FHI (2017) and Regan et al. (n.d.). Scores are presented or, if needed, recalculated for Cambodia only as per Regan et al's (n.d.) Lower Sesan II scenario, which represents the situation as of October 2017.

↘ Table 1

The relationship between relevant SDG Goal 6 Targets and Indicators and FHI indicators/sub-indicators; the FHI score for the Cambodian 3S basin and whether the SDG targets are being achieved.

SDG Target/Indicator	FHI Indicator/ sub-indicator	Relationship	FHI score	Level of achievement
6.1 Safe and affordable drinking water	Distribution of benefits from ecosystem services (GS)	Complementary indicator	41	Not achieved
6.2 Access to sanitation	Financial capacity (subset) (GS)	Complementary indicator	-	
6.3 Improve water quality	Deviation of Water Quality Parameters from Benchmarks (ES)	Alternative indicator	78	Achieved
6.3.2 : Proportion of water bodies with good ambient water quality				
6.4 Increase water-use efficiency	Water Supply Reliability Relative to Demand (ES)	Direct indicator	87	Achieved
6.4.2 : Level of water stress: freshwater withdrawal as a proportion of available freshwater resources				
6.5 Implement IWRM	Water Resource Management (GS)	Alternative indicator	59	Not achieved
6.6 Protect and restore water related ecosystems	Ecosystem vitality (EV)	Direct indicator	61	Not achieved
	Conservation/ Cultural Heritage Sites (ES)	Direct indicator	95	
	Financial capacity (subset) (GS)	Complementary indicator	-	
6.6.1 : Change in the extent of water related ecosystems	Water Resource Management (GS)	Alternative indicator	59	Not achieved
6.B Support and strengthen local community participation	Information Access and Knowledge (GS)	Complementary indicator	43	Not achieved
6.B.1 : local community participation in water and sanitation management	Engagement in Decision-making Processes (GS)	Alternative indicator	54	Not achieved

*Note : EV : EcosystemVitality / ES : Ecosystem Services / GS : Governance & Stakeholders)

Targets 6.1 and 6.2 – Safe and affordable drinking water and access to sanitation

The FHI Governance & Stakeholders indicators provide contextual information for SDG Target 6.1: by 2030, achieve universal and equitable access to safe and affordable drinking water for all; and Target 6.2: by 2030, achieve access to adequate and equitable sanitation and hygiene for all, and end open defecation, paying special attention to the needs of women and girls and those in vulnerable situations. The Governance & Stakeholders indicators were assessed via a targeted survey based on interviewee perceptions. The results of the eight Cambodian experts who completed the survey were used to calculate a score between 0-100 for the sub indicator– Distribution of Benefits from Ecosystem Services – as this addresses access to safely-managed drinking water and sanitation services. While standard methods for calculating SDG indicators for Targets 6.1 and 6.2 already exist (UN-Water, 2016a), assessing the distribution of benefits from ecosystem services provides additional context which can help future actions aimed at meeting these two Targets.

In assessing distribution of benefits from ecosystem services, survey respondents were provided with the statement:

Equity is an important issue in water resource management, most closely associated with access to safe water and sanitation. Here we extend the concept to include all benefits from ecosystem services in the basin (water and sanitation, fisheries, flood mitigation, water quality maintenance, disease regulation, and cultural services).

Respondents were then asked to rate the following four statements on a scale of 1-5 (see Regan et al., n.d. Supplement for full category details).

1. Economically vulnerable populations benefit from ecosystem services (e.g., poor households' access to improved water supply sources at a reasonable cost, protection from inland flood risks, or rural compared to urban populations' benefits).
2. Indigenous people benefit from ecosystem services (e.g., exercising customary rights related to water, including for consumptive as well as cultural uses, or maintaining traditional fisheries).
3. Women and girls benefit from ecosystem services (e.g., amount of time collecting water for households, or provision of toilets for females).
4. Resource-dependent communities' benefit from ecosystem services (e.g., fishermen and small holder farmers' incomes compared to other economic sectors).

The average score for each of the four statements was 2.6, which meant that the share of benefits was only rarely, to sometimes (~50%), adequate. This gave a Distribution of Benefits from Ecosystem Services sub-indicator score of 41 out of 100.

Further information is also provided by the Governance & Stakeholders-Financial Capacity sub-indicator, which has three questions related to the provision of safe drinking water and sanitation. In assessing Financial Capacity, respondents were provided with the statement:

Water resource development and management is often under-financed, particularly for services that do not generate revenue, such as ecosystem

protection. Although financial capacity can be measured directly as a function of existing allocations relative to estimated budget needs, qualitative information is also useful in providing insights and identifying priorities.

Respondents were then asked to rate five statements on a scale of 1-5, of which the following three can provide complimentary information.

1. Level of investment in water supply development (e.g., financial resources for building and maintaining reservoirs or irrigation systems). Giving an average score of 2.3.
2. Level of investment in service delivery systems (e.g., financial resources for building and maintaining water distribution networks, i.e., piped supply, or household wells). Giving an average score of 2.4.
3. Level of investment in wastewater handling and treatment (e.g., financial resources for building and maintaining community toilets or treatment systems to process waste water). Giving an average score of 2.1.

These scores revealed that the financial capacity in the Cambodian 3S basin required to undertake water resources development was unsatisfactory.

These results suggest that meeting SDG Targets 6.1 and 6.2 in the Cambodian portion of the 3S River basin will be challenging. They also suggest that little progress has been made since 2011 when the Millennium Development Goal scores were calculated for both Ratanakiri and Mondulkiri provinces, which make up the majority of the 3S catchment in Cambodia (Table 2; Ministry of Planning, 2012).

↘ Table 2

Selected Cambodian Millenium Development Goal scores from Ratanakiri and Mondulkiri provinces in 2011

Cambodian Millennium Development Goal	Ratanakiri	Mondulkiri
7.3 : Percentage of families with technically designed and installed latrines	14	18
7.4 : Percentage of families using clean water	33	61
7.5 : Percentage of families using clean drinking water	27	44

Source : Ministry of Planning, 2012 *Note : Scores are out of 100

Target 6.3 – Improve water quality

The FHI assesses water quality against both ecological and human health standards as components of both the Ecosystem Vitality and Ecosystem Services assessments. This provides decision-makers with a standard way to assess compliance with good quality standards and will help in setting interim targets and monitoring progress toward meeting SDG Target 6.3: by 2030, improve water quality by reducing pollution, eliminating dumping and minimizing release of hazardous chemicals and materials, halving the proportion of untreated wastewater and substantially increasing recycling and safe reuse globally.

The FHI Ecosystem Services sub-indicator, Deviation of Water Quality Parameters from Benchmarks (DvWQ), addresses SDG Indicator 6.3.2: proportion of bodies of water with good ambient water quality. The

DvWQ sub-indicator was determined by calculating and aggregating spatial (F_1) and temporal/magnitude (F_3) aspects of water quality within the basin to produce a number between 0 (lowest water quality) and 100 (highest water quality). The DvWQ value for each parameter was combined into a DvWQ sub-indicator score by taking the geometric mean.

Twenty surface water quality parameters were used to calculate the DvWQ sub-indicator (Table 3). The parameters were collected from four Mekong River Commission monitoring stations located in the Cambodian section of the 3S basin: one on the Sekong River, two on the Sesan River and one on the Srepok River. Six-hundred and fifty-eight samples were collected during 2004-2014, monthly in most years and bimonthly in others. Protection of human health thresholds for the lower Mekong Basin were used to assess pH (6-9), Dissolved Oxygen (DO, 4 mg/L), Chemical Oxygen Demand (COD, 5 mg/L), Total Nitrite and Nitrate (NO_2 + NO_3, 5 mg/L) and Ammonia (NH_3, 0.5 mg/L), whilst the agricultural threshold was used to assess Electrical Conductivity (EC, 700 mS/m) (Ly & Larsen, 2016). The lowland rivers threshold was used for Total Nitrogen (<1.6 mg\L) (Hart, Maher, & Lawrence, 1999). Water quality data for the last five years of sampling (2010-2014) were compared against these benchmarks. For the other parameters, the protocol used to establish monthly minimum and maximum thresholds as described in Regan et al. (n.d.) was followed.

UN-Water (2016a) recommends that Indicator 6.3.2 be assessed using five parameters: Total Phosphorus, Total Nitrogen, Electrical Conductivity, Dissolved Oxygen and faecal coliform/Escherichia coli bacteria. A similar metric was calculated using the first four of these parameters (Table 3), whilst faecal coliform/Escherichia coli bacteria was excluded due to a lack of data.

↘ Table 3

Deviation of water quality metrics from benchmarks spatial (F_1), temporal/magnitude (F_3) and final sub-indicator (DvWQ) scores for 21 water quality parameters for the period of 2010-2014, collected from the Cambodian section of the 3S River basin. Parameters in italics are those recommended by UN-Water (2016a).

	F_1	F_3	DvWQ score
Total Suspended Solids (TSS)	100	10.3	67.9
Total Phosphorus (TP)	100	8.1	71.5
Total Nitrogen (TN)	50	0.6	94.4
pH	75	0.1	96.8
Electrical Conductivity (EC)	0.0	0.0	100
Dissolved Oxygen (DO)	25	0.001	99.9
Chemical Oxygen Demand (COD)	50	0.5	95.1
Total Nitrite and Nitrate (NO_2 + NO_3)	0	0.0	100
Ammonia (NH_3)	0	0.0	100
Ammonium (NH_4)	100	26.8	48.2
Calcium (Ca)	100	1.8	86.6
Magnesium (Mg)	100	4.3	79.2
Sodium (Na)	100	2.4	84.5

Potassium (K)	100	22.3	52.7
Alkalinity	100	2.3	85.0
Chloride (Cl)	100	5.8	75.8
Sulphate (SO_4)	100	4.2	79.5
Ca/Mg	100	3.6	70.5
Na/Cl	100	6.3	74.8
Na/K	100	22.8	52.2
Ca/SO_4	100	14.6	61.7

The aggregated DvWQ sub-indicator score of 78 reveals good water quality at the four Cambodian monitoring sites. Using only the four indicators recommended by UN-Water (2016a) gives a score of 91, which is also good. However, an examination of the indicators spatial component (F_1), questions the utility of global Indicator 6.3.2: proportion of bodies of water with good ambient water quality. Fourteen of the 20 metrics failed to meet the desired standard at least once per site (an F_1 value of 100; Table 3). Thus, at some time each site had poor water quality, potentially giving an 6.3.2 indicator score of zero for both the full suite of parameters and the four UN-Water (2016a) metrics (as the Total phosphorous F_1 value was 100). However, the magnitude (F_3) results show that, although many of the parameters failed across multiple sites, this was infrequent and minor in magnitude. This supports the DvWQ assessment of good water quality at the monitored sites.

The provisional Cambodian SDG indicators do not include indicator 6.3.2. There are, however, 22 water quality monitoring stations maintained by the Mekong River Commission in Cambodia, and while they do not cover the entire country, they could be used to calculate an indicator for SDG Target 6.3.

Target 6.4 – Increase water-use efficiency

The FHI Ecosystem Services sub-indicator- Water Supply Reliability Relative to Demand allows decision-makers to see, at a sub-basin scale, where demand is exceeding sustainable supply and where action is needed to strengthen environmental flow requirements or improve water-use efficiency. By providing a measure of Indicator 6.4.2: Level of water stress: freshwater withdrawal as a proportion of available freshwater resources, this sub-indicator directly addresses SDG Target 6.4: by 2030, substantially increase water-use efficiency across all sectors and ensure sustainable withdrawals and supply of freshwater to address water scarcity and substantially reduce the number of people suffering from water scarcity.

Due to a lack of sectoral specific water use data, Water Supply Reliability Relative to Demand was calculated using the global 0.5° resolution self-calibrated Palmer Drought Severity Index (Osborn, Barichivich, Harris, van der Schrier, & Jones, 2016; van der Schrier,

Barichivich, Briffa, & Jones, 2013). Monthly mean values of the Index for the period 2011-2015 were compared with the full range (1901-2015) to derive the shift in spatial scope and frequency of water availability (see Regan et al. (n.d.) for full details of the methodology). Applied only to the Cambodian portion of the 3S basin, the sub-indicator gave a score of 87. This suggests that Indicator 6.4.2 is being met in the Cambodian 3S basin.

While the Water Supply Reliability Relative to Demand sub-indicator revealed a low level of water stress, it is only a coarse measure. It does not assess local scale water scarcity, which may occur due to processes such as changes in river flow or local groundwater depletion.

The provisional Cambodian SDG indicators do not include Indicator 6.4.2. The method used above and described in Regan et al. (n.d.) could be used on a national level in the absence of more comprehensive data.

Target 6.5 – Implement IWRM

The FHI Governance & Stakeholders survey assesses Integrated Water Resources Management (IWRM) through its Water Resource Management sub-indicator. The FHI helps decision-makers identify specific aspects of IWRM that need attention and, critically, where there is disagreement among decision-makers on their collective priorities or progress. The survey results can be used to measure progress toward SDG Target 6.5: by 2030, implement integrated water resources management at all levels, including through transboundary cooperation as appropriate. While there are standard methods for assessing Indicator 6.5.1: degree of integrated water resources management implementation (0-100) and Indicator 6.5.2: proportion of transboundary basin area with an operational arrangement for water cooperation (UN-Water, 2016a), the Water Resource Management sub-indicator provides a complementary source of data. Because it can be administered to a large sample population of decision makers, it can provide more detailed and nuanced information than the standard method.

In assessing the framework for basin management sub-indicator, survey respondents were provided with the statement:

Integrated water resources management is a guiding framework for coordinating both development and management of all resources within a basin, to maximize welfare without compromising ecological sustainability. In some cases, a single agency, such as a river basin authority, is responsible for coordinating and overseeing these functions; the questions below focus on the specific functions regardless of whether they are all carried out by the same agency.

Respondents were then asked to rate the following four statements on a scale of 1-5.

1. Policies and actions to advance water resource development and management are coordinated (e.g., if there is river basin organization or commission, how effective is it in coordinating the different agencies, levels of government – national, provincial, local – and private interests when establishing integrated development plans for the basin?). Giving an average score of 3.8.
2. Infrastructure such as dams, reservoirs, and treatment plants are centrally managed or coordinated (e.g., dam operators communicating

the timing and volume of reservoir releases, or assessing cumulative impacts of dams). Giving an average score of 3.4.

3. Financial resources are mobilized to support water resource development and management needs (e.g., cost-sharing for common projects, or collecting user fees/taxes). Giving an average score of 3.4.
4. Ecosystems conservation priorities are developed and actions implemented (e.g., protecting forested watersheds, maintaining wetland/river connectivity, or developing an aquatic species biodiversity action plan). Giving an average score of 3.

The range of scores for each individual statement showed that the functions listed were sometimes (~50%) and often satisfactory. The overall Water Resource Management sub-indicator score was 59.

This suggests that the degree to which water resources management has been implemented (Indicator 6.5.1) in the Cambodian portion of the 3S basin has been only moderately satisfactory. For Indicator 6.5.2, although not measuring a proportion of the transboundary 3S basin area, results suggest that an operational arrangement for water cooperation remains under development.

The provisional Cambodian SDG indicators do not include any indicators for SDG Target 6.5. The method demonstrated above could be implemented across the country to provide this data and be included as an alternative indicator.

Target 6.6 – Protect and restore water related ecosystems

Several FHI indicators and sub-indicators can be used to assess SDG Target 6.6: by 2020, protect and restore water-related ecosystems, including mountains, forests, wetlands, rivers, aquifers and lakes. The full suite of FHI Ecosystem Vitality metrics – Water Quantity, Water Quality, Drainage Basin Condition and Biodiversity – directly assess the Target and help set priorities for improving water-related ecosystems and setting priorities for their protection or restoration. The Ecosystem Services - Conservation/Cultural Heritage Sites sub-indicator can assess the proportion of the river network under formal protection. Questions in the Financial Capacity sub-indicator provide insight on the ability of governments to protect and restore natural systems.

Ecosystem Vitality

The Ecosystem Vitality score for the Cambodian section of the 3S basin was 61. The indicator and sub-indicator evaluations that made up this score are detailed below.

Water Quantity

The FHI Water Quantity indicator comprises two sub-indicators: Deviation from Natural Flow Regime (DvNF) and Groundwater Storage Depletion. Due to a lack of data, Groundwater Storage Depletion could not be calculated. Regan et al. (n.d.) calculated DvNF at several locations in the 3S River basin. For the Cambodian section of the 3S basin, the score at the outlet to the Mekong River, 68, was used as the water quality indicator.

Water Quality

Four surface water quality parameters: Total Suspended Solids, Total Phosphorous, Total Nitrogen and pH were used to calculate the Water Quality parameter from the same samples used for the DvWQ sub-indicator. Where appropriate, threshold values for the protection of aquatic ecosystems were used or calculated using historic data and were combined into a water quality index (see Regan et al. (n.d.) for full details). Recalculation of the Water Quality index for the four sites in Cambodia gave a score of 78.

Drainage Basin Condition

Drainage Basin Condition comprises three sub-indicators: Bank Modification, Flow Connectivity and Land Cover Naturalness. Drainage Basin Condition scored 69 based on the following sub-indicators.

Bank Modification measures the extent of unmodified river channel. The river channel can be modified by various means including inundation by reservoirs, or engineering works such as channelization and bank stabilization. As these engineering works are minor in the 3S system the extent of reservoir inundation in the Cambodian section of the 3S was determined by calculating the proportion of the river network inundated by the lower Sesan II and O Chum II dams. As this amounted to only 2.7% of the stream network, this gave a sub-indicator score of 97, which shows little change from the natural state.

Flow Connectivity was measured using the Dendritic Connectivity Index (DCI: Cote et al. 2009) which assesses river channel fragmentation caused by dams and other in stream structures. As the movements of aquatic animals are not restricted by international boundaries and the construction of dams in the 3S system is a transboundary issue, it is not appropriate to calculate the DCI for only the Cambodian portion of the catchment. Thus, the value presented in Regan et al. (n.d.) for the lower Sesan II dam scenario, 38, was used as this represents the current situation. The low value reflects the severe disruption in connectivity caused by the construction of the lower Sesan II dam.

Land Cover Naturalness (LCN) is most closely aligned with the currently recommended indicator for Target 6.6, indicator 6.6.1: change in the extent of water-related ecosystems over time. However, LCN captures not only extent, but some measure of quality, by assuming that “naturalness” exists on a gradient from completely natural to completely artificial (Angermeier, 2000). Human conversion of lands and waterways are associated with increases in pollutant loads (non-point source from agriculture, point-source from urban and industrial), changes to infiltration and runoff regimes, and losses of regulating services (flood mitigation, erosion prevention, water purification). LCN provides a proxy indicator of the degree to which these naturally-occurring functions are preserved within the basin. Regan et al. (n.d.) used 2010 dry season land cover data from the Mekong River Commission as the classification categories and temporal coverage were consistent across the 3S basin. This resulted in an LCN assessment of the entire 3S basin, and this dataset was used to calculate LCN for the Cambodian portion of the basin, for a score of 88. These data can also be used to calculate SDG Indicator 15.1.1: Forest area as a percentage of total land area.

Biodiversity

The FHI Biodiversity indicator comprises two sub-indicators: Species of Concern, and Invasive and Nuisance Species. As per the method outlined in Regan et al. (n.d.), the Species of Concern sub-indictor for the Cambodian portion of the 3S was calculated using IUCN Red List spatial data (http://www.iucnredlist.org/technical-documents/spatial-data) for amphibians, terrestrial mammals, reptiles and the freshwater polygon groups for fish, molluscs, plants, Odonata, shrimps, crayfish and crabs, and water bird data from Birdlife International (http://datazone.birdlife.org/home). The number of Invasive and Nuisance Species was determined through a literature review and interviews with regional experts.

Four-hundred and ninety-two aquatic species present in the Cambodian section of the 3S basin were assessed for the Species of Concern indicator. Of these, nine were critically endangered, 14 endangered and 34 vulnerable. Of the nine critically endangered species, six were fish. This gave a Species of Concern score of 32. As the nine invasive species present in the whole 3S basin are also believed to be present in the Cambodian section, the Invasive and Nuisance Species score was calculated as 46. This gave an overall biodiversity sub-indicator score of 39, which is reflective of the high proportion of threatened species and large number of invasive species.

Conservation/Cultural Heritage Sites

The FHI Ecosystem Services - Cultural/aesthetic indicator includes a Conservation/Cultural Heritage Sites sub-indicator. This sub-indicator was calculated as a weighted proportion of stream length, within, or on the boundary of, protected areas (see Regan et al. (n.d.) for full methods). The proportion score for the Cambodian section was 75, as following the creation of an extensive biodiversity corridor network, much of the Cambodian section of the 3S basin is contained within protected areas. This gave a sub-indicator score of 95. This indicator can also be used to report against SGD Indicator 15.1.3: percentage of important sites for terrestrial and freshwater biodiversity that are covered by protected areas and fisheries conservation areas, by ecosystem type.

Governance & Stakeholders Financial Capacity

The Governance & Stakeholders - Financial Capacity sub-indicator had two further questions which can provide complimentary information regarding SDG Target 6.6.

1. Level of investment in ecosystem conservation and rehabilitation (e.g., financial resources for protecting wetlands to mitigate flood risk, remediating impaired streams, or rehabilitating fish stocks). Gave an average score of 2.5.
2. Level of investment in monitoring and enforcement (e.g., financial resources for evaluating Environmental Impact Assessments, collecting environmental data, inspecting facilities, and enforcing regulations). Gave an average score of 2.4.

Both revealed an unsatisfactory level of financial investment in conservation, rehabilitation, monitoring and enforcement.

Assessing Target 6.6

The Ecosystem Vitality score of 61 suggests that the water-related ecosystems in the Cambodian section of the 3S basin are functioning but showing signs of stress. On this basis the SDG Goal 6.6 is not being met in the Cambodian 3S basin. The results also point to the need for restoration. This is despite a large proportion of the 3S's rivers being either entirely in, or on the border of, protected areas. Options for restoration include providing environmental flows and the construction of viable fish passage over the lower Sesan II dam (Shaad, Souter, Farrell, Vollmer, & Regan, 2018). It also shows that further infrastructure development or land clearance within the 3S basin will reduce the score and may compromise ecosystem function. Financing restoration may prove difficult due to the low levels of investment in ecosystem conservation and rehabilitation, as well as monitoring and enforcement. These results also suggest that resourcing Target 15.1: by 2020, ensure the conservation, restoration and sustainable use of terrestrial and inland freshwater ecosystems and their services, in particular forests, wetlands, mountains and dry lands, in line with obligations under international agreements, may prove to be challenging.

SDG Target 6.6 has one global indicator - Indicator 6.6.1: change in the extent of water-related ecosystems over time. UN-Water (2016a) divides this into three components for assessment, for which there are corresponding FHI indicator/sub-indicators (Table 4). The three UN-Water components correspond to LCN, DvNF and Ecosystem Vitality. However, these three scores cannot simply be combined into a single metric as LCN and DvNF are included in the calculation of the Ecosystem Vitality score. However, if LCN and DvNF are removed from the Ecosystem Vitality (Reduced Ecosystem Vitality) score and recombined as equal components (using the geometric mean) this gives an FHI derived SDG 6.6.1 indicator score of 70. This, in contrast to the full Ecosystem Vitality indicator score, suggests that Target. 6.6 is being met in the Cambodian section of the 3S basin.

↘ Table 4

Assessment of SDG Indicator 6.6.1 using FHI indicators and sub-indicators in the Cambodian portion of the 3S basin. The Ecosystem Vitality score has been calculated without the Land Cover Naturalness or Deviation from Natural Flow Regime indicator.

Indicator assessment (UN-Water, 2016a)	FHI indicator/ sub indicator	Cambodian 3S basin score, out of 100.
Spatial extent of water-related ecosystems (wetlands, forests and drylands)	Land Cover Naturalness sub-indicator	88
Quantity of water in ecosystems (rivers, lakes and groundwater)	Deviation from Natural Flow Regime sub-indicator	68
Resulting ecosystem health	Reduced Ecosystem Vitality	57

The provisional Cambodian SDG indicators do not include any for SDG Target 6.6. The full suite, or at least a sub-set, of the FHI Ecosystem Vitality measures could be calculated for the whole of Cambodia using pre-existing data to measure progress toward Target 6.6. This should be achievable as at least some of the data that needs to be collected for indicators listed under SDG Target 15 can also be used to assess SDG Target 6.6.

Target 6.B – Support and strengthen local community participation

The FHI Governance & Stakeholders survey has two sub-indicators that can report against SDG Target 6.B: support and strengthen the participation of local communities in improving water and sanitation management. The first is Information Access and Knowledge, as sound water governance requires information on a range of topics from many sources. Even in cases where data and information are abundant, if they are not made accessible (across agencies, to citizens, etc.), they are unlikely aid wise decision-making. The second is Engagement in Decision-making Processes. Stakeholder engagement is the process by which any person or group with an interest in a water-related topic can be involved in decision-making and implementation. It is associated with improved information transfer, better targeted and more equitable plans and policies, improved transparency and accountability, and reduced conflict.

In assessing Information Access and Knowledge, respondents were asked to rate the following statements:

1. Information is accessible to interested stakeholders (e.g., reports are made freely available through a website, or data is available upon request to the agency with the information). Giving an average score of 2.5.
2. Information meets expected quality standards, in terms of frequency, level of detail, and subjects of interest to stakeholders (e.g., time series data on stream flow, water levels, or water quality for specific locations within the basin). Giving an average score of 2.6.
3. Information is transparently sourced (e.g., methods used to collect data are documented, or authors (source) of these data are clearly identified). Giving an average score of 2.9.
4. All available, sound and relevant information is routinely applied in decision-making (e.g., modifying an infrastructure project based on EIA results, or adjusting fisheries management guidelines based on fish catch data). Giving an average score of 2.9.

The range of scores for each individual statement meant that Information Access and Knowledge was only rarely or sometimes (~50%) satisfactory. This gave an overall Information Access and Knowledge score of 43.

In assessing Engagement in Decision-making Processes, respondents were asked to rate the following:

1. All relevant stakeholders have been identified and notified when considering major decisions (e.g., mapping and notifying stakeholders affected by a proposed water supply infrastructure project, such as construction of a water supply dam). Giving an average score of 3.3.
2. Stakeholders are able to provide comments prior to major decisions being taken (e.g., consultation meetings or an information gathering period where stakeholders may provide input regarding a policy or project). Giving an average score of 3.3.
3. Decisions are responsive to stakeholders' participation (e.g., processes for reaching joint agreements among a group of

stakeholders prior to approval of a major policy or project, or projects being revised subsequent to stakeholder feedback). Giving an average score of 3.

The range of scores for each individual statement meant that decision-making processes occurred sometimes (~50%) or often. The overall score for Engagement in Decision-making Processes was 54.

These results suggest that while there has been a degree of local participation in decision-making, the level of participation needs to be improved, as does the flow of information to communities.

SDG target 6.B has a single global indicator 6.B.1: proportion of local administrative units with established and operational policies and procedures for participation of local communities in water and sanitation management. However, neither this nor a national Cambodian indicator has been adopted. Whilst the FHI does not measure the proportion of administrative units, it provides a measure of the current level of community engagement in water resource management. In the Cambodian portion of the 3S basin these results show that community engagement needs to be improved before Target 6.B can be met.

4. Conclusion and Future Directions

The FHI contains a range of indicators that, at either the international or national level, can measure and report on progress toward a range of SDG 6 targets (Table 1). Results from calculating these FHI indicators suggest that, if the SDG 6 targets are to be met in the rapidly developing 3S basin:

- Additional resources are required to ensure safe and affordable drinking water and access to sanitation (Targets 6.1 and 6.2).
- All future development needs to ensure that water quality remains good (Target 6.3), and that water is used efficiently (Target 6.4).
- The current good progress toward implementing basin wide (including transboundary) water management continues (Target 6.5).
- Future development does not further degrade water-related ecosystems and that restoration and protection of important components (e.g., fish passage and threatened species conservation) is undertaken (Target 6.6).
- These goals can only be achieved with a greater level of local community participation (Target 6.B).

Given the systemic risk associated with water systems, meeting all SDG 6 goals is essential to reduce the likelihood of system collapse. Of the indicators listed above, the Ecosystem Vitality score of 61 is especially concerning, given the rapid development of the 3S basin. Meeting Target 6.6 is crucial to meeting SDG 6 (Regan et al., n.d.) and avoiding system collapse. As most Cambodians living in the 3S basin are dependent on natural resources, including fisheries, for their daily survival, any failure of the natural systems they rely on could have catastrophic consequences.

In many cases, the indicators proposed above can be readily calculated for the rest of Cambodia using pre-existing data. As shown above, this can be achieved using well-developed methods and at minimal cost. Thus, the FHI presents a range of indicators that can be adopted by the Royal Government of Cambodia to supplement their provisional SDG indicator list and allow them to report on their SDG commitments.

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