Annex 3: **Review of water quality studies in the Inle and Phekon Lake region**

Development of aquaculture in the Pekhon lake area occurs within the larger system of the Inle-Saga Pekhon lake area (Figure 1). Beside monitoring the water quality in fishponds and understanding water management and perception from farmers, establishing a baseline of water quality in Pekhon Lake is important. As positioned at the lower end of the hydrologic system, the lake will likely be impacted by practices within its catchment, including aquaculture.

The Pekhon lake is located downstream and connected to Inle Lake though Balu Chaung. Although they share different characteristics (i.e., natural versus man-made, older vs recent etc.) they also share several similarities in terms of their watershed (agricultural practices), climatic conditions and are connected through the Balu Chaung river. Therefore, in order to develop the monitoring and evaluation plan for Pekhon lake quality, it was considered useful to also review past studies related to water quality monitoring from Inle lake.

Initially, a literature review was planned. However, given the current condition (as of March 2021), this literature review will be later expanded into a larger desktop analysis and mapping of the catchment of Pekhon Saga-Pekhon lake. The main objective of the work will be to highlight threats to the water quality of the lake and surrounding streams used for aquaculture.

At this stage, this document will present:

Short key messages on water quality monitoring in Inle based on thorough review of all available data and reports and lesson learned that are useful for setting up a water quality study for the Pekhon lake area.

A summary (Table 1 in Annex 3.1) lists the parameters tested, the sampling pattern and methodologies and the key results.

It should be noted that although a wide range of studies have been conducted on Inle, the current lit. review only included water quality sampling and analysis.

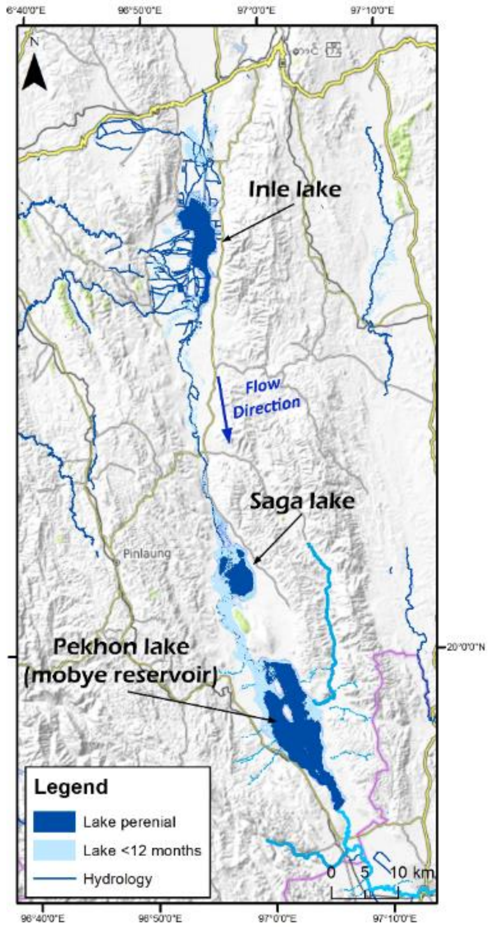


Figure 1 Study area for water quality campaign.

Summary of water quality analysis in Inle lake and key points

Historically, the first account of water quality in Inle lake dates back to early in 20th century with one sample taken at the center of the lake and a basic analysis (N.annadale and R.V. Briggs., 1918; *Cited in* Saw Yu May (2008). For more than 60 years, no further studies were conducted. Some investigations seem to have been done in the 80's and 90's (Nu Nu Khin, 1984; Ni Ni Moe, 1997; both *Cited in* Saw Yu May, 2008) but could not be obtained for the current review.

The interest in Inle lake water quality increased in the 2000's – likely due to increasing concerns about the lake's water quality deterioration. At least 9 of the studies incorporated sampling and 2 sampled the sediments. The key results in terms of water quality monitoring are:

- Stratification seems inexistent or limited, due to shallow depth of the lake.

→ **Note for the lake Phekon Study:** Given the intermontane geomorphology of the valley and the low elevation of Mobye dam, it is likely that Pekhon lake is also shallow and not stratified. This will be checked during the first sampling campaign.

- Quality of the water is overall good; however, the quality indicators are still below accepted values.
- Besides bacterial contamination, eutrophication and pesticides are the major concerns.
- Most studies mention pesticide use, especially, due to the floating gardens. However, none of the studies did analysis on the actual content. This could be explained by several factors:
    1. Sampling for pesticides is usually very complex, due to residence time, degradation in other molecules, punctual or passive approach etc.
    2. Analysis of pesticides residues requires highly qualified laboratories and are usually costly.

    →**Note for the lake Phekon Study:** In Pekhon there are no floating gardens. Some seem to exist only in Saga lake. Pesticide presence is then likely to come from agricultural practices in the catchment through inlets or transported by the Balu Chuang river itself. At this stage, targeted pesticide sampling possibilities are being evaluated.

- The Trophic state of the lake is hard to define and varies studies characterize the lake as from slightly eutrophic to 'on way to eutrophication'. Concerns are high, as Nitrate and Phosphate are found most of the time in elevated concentration and low Dissolved Oxygen is a regular occurrence. However, advanced eutrophication (anoxic conditions and its consequences) has not yet been reported. Authors (cf. review table) points to several factors that could possibly hinder eutrophication:
    1. Presence of large macrophytes (Hyacinths) that use up the excess nutrients.
    2. Due to lake's chemistry being influenced by geology (carbonates), excess Phosphates from fertilizer used in floating gardens might be forming Ca-P form and not being bio-available, however Phosphate from sediments inflow are a higher source of concern.
    3. Low residence time of water in the lake.

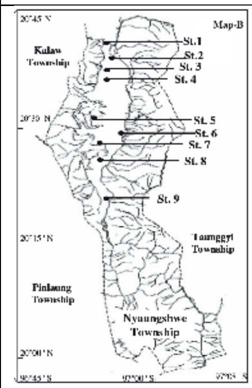
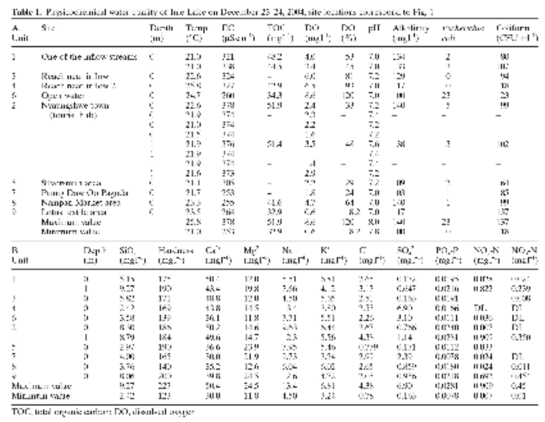
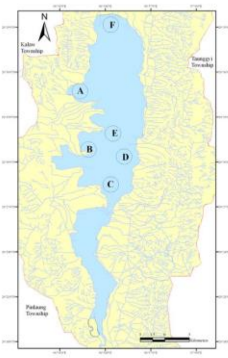
    →**Note for the lake Phekon Study:** There are no past studies on the trophic status of Saga-Pekhon lake. As N, P and Dissolve oxygen play a major role in fish ecology and the water quality of the lake in general, these parameters are seen as key for both risk of eutrophication and water quality degradation.

- Monitoring approach differs between studies.
    1. frequency varying from single time up to monthly frequency.
    2. Most studies used a mix of field kits and further laboratory analysis.

3. Locations are chosen in a selective way (i.e., the densely populated areas, water inlet etc.) in most cases. Only one case used a grid-regular spacing sampling.

→ **Note for the lake Pekhon Study:** Monitoring in Pekhon lake should use the best practices observed. The monitoring plan should involve multiple sampling across the year and select locations that cover the lake spatially but also incorporate specific locations as done in Inle.

Table 1 Summary of studies with Sampling of water quality in Inle lake.

year	Authors	Title	Abstract	# of Samples / Sampling Location /Map	Sampling map	Result	Annotated comment
1918	N.annadale; R.V. Briggs. Cited in Saw Yu May (2008)	Fauna of the Inle Lake	Not available	1 sample . "Center of the Lake" . 1#		No units given. *Total Solids* *0.1710 (per liter)* *Organic matter* *0.0160* *Calcium* *0.0222* *Magnesium* *0.0279* *Chlorine* *0.0017* *Sulphate (So4)* *0.0017* *Silica* *0.0010* *Carbonic Acid (CO3)* *0.1030*	This provides the first measurement in Inle, although no reference to season and units for analysis it provides a useful historical value.
1984	Nu Nu Khin Cited in Saw Yu May (2008)	Abundance of Trace Elements in Representative Fish and Vegetables of Inle Area	n.a.	n.a	n.a.	n.a	Cited in Saw Yu May PhD Thesis – Document not available during this study.
1997	Ni Ni Moe Cited in Saw Yu May (2008)	Chemical Analysis on the Quality of Inle Lake Water for Drinking and Agricultural Purposes	n.a.	n.a	n.a.	n.a	Cited in Saw Yu May PhD Thesis – Document not available during this study.
2006 (2004)	Fumiko Akaishi · Motoyoshi Satake · Masahiro Otaki Noriko Tominaga	Surface water quality and information about the environment surrounding Inle Lake in Myanmar	Abstract: Inle Lake is the second largest lake in Myanmar and one of the nine key sites for sightseeing there. An analysis of its water quality has not been published before. The objective of this study is to reveal the current situation and find any major problems with the lake. For this purpose, the natural and cultural environments were examined. Some physical and chemical aspects of the surface water were assayed in situ for 2 days in November 2004. The principal ions were analyzed in our laboratory. The main cation and anion species in the lake surface water are Ca2+ and HCO3-. Its high calcium content can be attributed to the limestone of Shan Plateau around the lake. The alkalinity of the lake water was 3829–4114 acid-neutralizing capacity (ANC) (pH 7.8–8.0); it can be attenuated by Ca2+. The concentrations of PO4-P, NO2-N, and NO3-N were relatively high; these could originate from domestic, and agriculture uses. The trophic state is eutrophic. The concentrations of coliform bacteria indicated that the lake water was unfit to drink, but some people use it for drinking anyway. The bacteria could enter the lake through the direct latrine system used there. The thermal type of the lake is presumed to be warm polymictic. More extensive studies are needed because the lake is thought to be the most changing site in Myanmar as a result of both the tourism boom and increasing agricultural activity.	#9 locations. one sampling (Dec 2004). Chemical and physical water quality was surveyed at one of the inflow streams [station (St.) 1], near densely populated areas (St. 2, 6, 7, 8, 9), near upstream (St. 3, 4), and a remote area with a fine wide view (St. 5). Nine water samples were taken from the surface (St. 1–9), and two samples were taken from 1-m depth, approximately 0.5–1m above the bottom (St. 1, 2). Temp, EC, pH, DO on site. E coli and coliform with test kits Other chemistry sampled in plastic bottles and sent to lab		Table 1. Physicochemical water quality of Inle Lake on December 23–24, 2004; site locations correspond to Fig. 1 TOC, total organic carbon; DO, dissolved oxygen	This study is useful as it provides a comprehensive set of parameters. However there is no seasonality. Authors describe the lake as a polymictic lake (no stratification). In terms of Chemistry results it appears that Low DO, E Coli and Nitrate are the problematic parameters exceeding standards. It seems the trophic category of the lake is difficult to establish. To further establish it they recommend to analyze: data on transparency, chlorophyll, and total phosphates, and recognize the limitation of measuring out of the tomato growing season (mainly march to September). Floating tomato gardens and sewage are pointed are main source of pollutions. With also touristic development and boating mentioned.
2008 (2004-2006)	Mar Lar Htwe	Analysis Of Water Pollution In Freshwater Inle Lake Based On Eutrophication Phd Dissertation	The present study was conducted in the Inle Lake, Nyaung Shwe Township, Southern Shan State. Inle lake is the third largest lake in Myanmar in which several tens of thousands of people live in the lake. The lake has several risk factors that could pollute its water as the chemical fertilizers and pesticides are being continually used in the agricultural farms in the area. Six study sites were selected to collect the water samples. Water samples were collected monthly from the year 2006 to 2007 to determine the pollution level and eutrophication. Increased nutrient loading can stimulate algal growth found abundantly in the lake. Six physical parameters consisting water depth, turbidity, water temperature, electrical conductivity, hardness, and total dissolved solids (TDS), and six chemical parameters consisting pH, arsenic, chlorides, fluoride concentrations and dissolved oxygen (DO), biochemical oxygen demand (BOD), and two nutrient parameters of nitrates and phosphates levels were investigated to determine the pollution level. All parameters were analyzed by using comparative and correlation statistical methods. Monthly means and the range of each parameter were calculated. The data were presented by graphic presentations. Two water parameters, nitrates and phosphates, were observed to be higher than WHO standard level, while four parameters, DO, BOD, chlorides and fluoride, were found to lower than the WHO standards. Hence the use of chemical fertilizer in this lake is assumed to start water pollution contributing to eutrophication. Lowering of DO could also affect aquatic fauna in the lake. Suggestions for future work are outlined based on the recorded data.	6 sites / monthly 2006 – 2007. Used Field Kits + portable spectrophotometer. + Lab analysis. Six physical parameters water depth, turbidity, water temperature, electrical conductivity, hardness, and total dissolved solids (TDS) six chemical parameters consisting of pH, arsenic, chlorides, fluoride concentrations and dissolved oxygen (DO), biochemical oxygen demand (BOD) two nutrient parameters nitrates and phosphates		Tables provided in paper per parameter. Summary given as follow: 1. Fourteen water parameters were monthly detected in six study sites in Inle Lake from March 2006 to February 2007. 2. The highest water depth was recorded in the center of the lake in October. The water level was higher in wet season than in dry season in all study sites. Water depth was more fluctuated in the margin of the lake than in the center. 3. Electrical conductivity and total dissolved solid were highest in human sediment area (Namlit-chaung) than other study sites. The parameter was higher in dry season than the raining season. The pH level was found to vary in different study sites. The water temperature was relatively constant with seasons compared with air temperature. 4. Observed some native water gardens, which used agricultural fertilizers, pesticides, herbicides, fungicides that are influence in lake water. 5. Correlation between water quality of physical, chemical and nutrients were recorded. 6. The nitrate and phosphate indicated that Inle lake water quality is in the condition of initial state of eutrophication. → authors com: "lake is on way to eutrophication"	This study provides very useful inputs as timeframe is monthly over a year and across various locations. The data from the Theses has been reentered and summarized as in following table. It provides good estimates of the ranges of values that should be expected in Pekhon lake. Also, the authors showed that high N values were seen both near villages, near gardens, near active boating area but also at center of the lake. It seems the reason for high Nitrate are complex. Phosphate is relatively low, and author suggest it is because they are quickly taken up by plants. .

	Unit	min	max	avg	WHO
Depth	cm	140	480	252.08	
EC	uc.cm	42	481	160.75	*1500*
TDS	mg.l	25	289	89.76	*1000*
harness	mg.l	44	210	141.36	*500*
temp	oC	17.9	28.6	25.93	
Cl	mg.l	0	260	50.32	*200-600*
pH	-	6.54	8.92	7.63	*6.5 - 9.5*
F	mg.l	0	1.15	0.53	*1.5*
DO	mg.l	2	19.5	5.76	*4*
BOD	mg.l	0.25	3	1.35	*3*
N	mg.l	0.01	0.85	0.28	*0.2*
P	mg.l	0	1.0	0.18	*0.005 - 0.02*

Year	Authors	Title	Summary	Sampling	Map	Results	Comments
2008 (2006)	Saw Yu May	Changes of water quality and water surface area in Inle Lake (Myanmar): facts and perceptions	PhD thesis (Yangon University) deals with two main features of the Inle Lake (Shan State, Myanmar). First, we consider the water quality in 2006, and highlight the issues at that time. Then, we focus on the evolution of the water area from 1990 to 2005 and show that it decreased.	9 locations. 3 sampling time as. March / sept / Dec 2006 (see Table 1.4 below). Authors used MULTIPLE depth (3) – acknowledging that lake was relatively shallow.	see map 1 below	see results 2008 below	see comments 2008 below

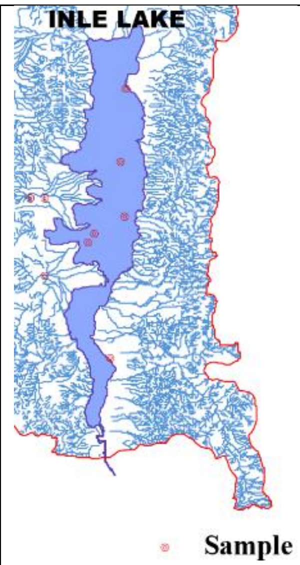
2008 (2006) – Sampling (continued)

Table 1.4 Collection Sites of Water Samples in Inle Lake

Sr.	Position	Coordinate	Reasons
1	Thangdaung Spring	N 20° 32' 18.4" E 96° 49' 34.8"	Inflow water quality (Western)
2	Ywama Village	N 20° 29' 32.8" E 96° 53' 19"	Population growth, Shallow part of the lake
3	Indein Stream	N 20° 27' 32.5" E 96° 50' 38.5"	Inflow water quality (Western)
4	Myaynigone Village	N 20° 32' 14.5" E 96° 50' 38.5"	Lake water quality (passing villages, agriculture land)
5	At the mouth of Tale-U Stream	N 20° 31' 6.9" E 96° 55' 30.5"	Inflow water quality (Eastern)
6	Kela Village	N 20° 30' 8.3" E 96° 53' 39.3"	Floating Garden, Human impact
7	Between Inya and Taungto Village	N 20° 22' 31.5" E 96° 54' 39.3"	Outflow water quality (Southern)
8	Rest House	N 20° 34' 32.4" E 96° 55' 16.3"	Open Space (central point of the lake)
9	Nyaung Shwe Jetty	N 20° 39' 0.17" E 96° 55' 36.8"	Starting Point of the lake (Northern)

Source: Field Observation, 2006

Authors used MULTIPLE depth (3) – acknowledging that lake was relatively shallow.



2008 (2006) – Results

The author showed that

- → Turbidity varies greatly depending on location and nature of the stream. Silt dams seem to be efficient in reducing turbidity.
- → pH, TDS, EC do not vary muc (20 -50 m s/m2)
- → Highlight importance of Nitrate. A lot of variation.

Phosphate is also found at all locations in low quantity.

- → Arsenic was found at 1 location in small quantity

→ authors highlight the VARIABILITY of DO: Fluctuations of Dissolved Oxygen depend upon the temperature, wind and algae weed bed. Generally, in Inle Lake, Dissolved Oxygen was high at noon and low in the evening in algae bed. At the same time Dissolved Oxygen was high at midnight and low in the daytime in less algae areas.

Identified the following sources of pollution for Inle lake

Table 1.22 Relationships between Watershed Area and Water Quality

Sr.	Watershed Area	Characteristics	Pollutants
1	formed with limestone	chemical	alkalinity, hardness
2	cleared of vegetation, soil erosion on mountain slope	sedimentation	Turbidity, TDS, TSS
3	have intensive agriculture (floating garden, mountain agriculture)	fertilizer, pesticide and herbicide	Nitrogen, phosphate
4	population growth (domestic and animal effluents and sewage)	solid waste and waste water	Phosphate
5	surface run-off, storm water	sediments, chemical and others (non-point source of pollution)	Several Chemical
6	urban runoff	municipal waste water, sewage or specific sites (point source of pollution)	Several Chemical

Source: Based on Field Observation, 2006

- → Conclusion of authors
lake is starting towards eutrophication.

2008 (2006) – Comments

Introduces the concept of multi depth. but result do not show variability in depth in most cases. (shallow lake).

Detailed data are provided and are useful in developing a monitoring network.

Similarly to previous studies, Nitrate. D.O seem to be the parameters of concern; and pesticides have not been tested.

The Trophic status of the lake is not determined, as it is suspected to start towards eutrophication, but most parameters remain in fairly good values.
Based on data available in the Thesis, a synthesis table has been built as follow – this table provides a good indicator of expected values in Pekhon lake.

Time	MIN	MAX	MAX
Physical Characteristic			
Temperature oC	19	29	22
Turbidity (NTU)	18	590	117
TDS (mg/l)	150	430	256
Conductivity (m s/m)	24	63	39
Alkalinity (ppm)	110	225	174
Chemical Characteristic			
pH	7	9	8
DO (mg/l)	2	9	6
COD (mg O2 /l)	0	70	17
Nitrate (ppm)	0	3	1
Phosphate (ppm)	0	24	1
Arsenic (ppm)	0	7	0
Total Coliform	0	550	161

Year	Authors	Title	Summary	Sampling
2012	Zaw Lwin and M.P. Sharma	Environmental Management of the Inle Lake in Myanmar	The Inle Lake, the second-largest lake in Myanmar, is located in Shan State in Myanmar. More than 170,000 people inhabit the lake and its surroundings, and their main business is agriculture with the floating gardens. Due to its picturesque siting and diverse fauna, combined with the unique lifestyles and traditions of human inhabitants, the lake is considered as one of the primary tourist destinations in Myanmar. The Inle is not only designated as the 190th World's Eco-region but also nominated as one of the freshwater biodiversity hotspots. Since the last decade, the lake has been facing serious threats due to natural and man-made pressure leading to the deterioration of its water quality and shrinkage of the open water area. According to the assessment of its water quality in 2012, the trophic state index of the Inle Lake is found to be in the range of eutrophication. The present paper aims to identify the problems based on data collected from the lake authorities and prepare a management plan for its conservation. The estimated cost is 31.18 million US$ and is expected to improve the lake health significantly if the conservation plan is implemented by the government in the true sense.	#9 locations. Sampling 1 time in JANUARY 2012 pH, Temperature, Turbidity, Total Dissolved Solids, Total Hardness, Chloride, Alkalinity, Ammonia, DO, PO4-P, NO3--N and NO2--N

2012 – Results

. The Trophic Stage Index (TSI) of the Inle Lake was also determined at various locations.

S.No.	Name of Location	Carlson Trophic State Index (CTSI) TP µg/l (2004)	TP µg/l (2012)	Lake Status
1	Near the inflow of Paungpain stream	(2004)	TP µg/l	Oligotrophic
2	Naung Shwe tourist hub	(2012)	43	Mesotrophic
3	Near hotel zone area	-	-	
4	Upstream of Nanpan Stream	5.2	8.22	Oligotrophic
5	Floating garden area	-	-	
6	Open water area	3.5	7.27	Oligotrophic
7	Paung Taw Oo Pagoda	2.4	12.33	Mesotrophic
8	Nanpam market	5.7	69.26	Eutrophic
9	Sliver smith area	6.9	41.11	Mesotrophic

Table 2. Evaluation of CTSI of Inle Lake.

2012 – Comments

Provides a good concise summary of pressures on the lake quality.

Only results in TP (total phosphate) are given. not the other parameters.

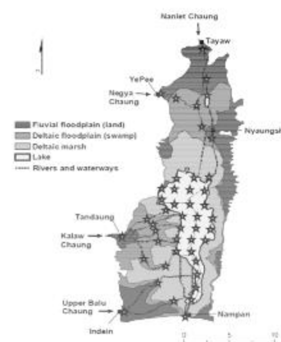
Also determination of the Trophic status of the lake using only a single sampling date might be difficult to interpret as concentration may vary significantly over time (applications period of fertilizers etc.)

gives a summary of the threats to the lake's water quality:

S.No.	Problem of Lake	1990	2010	Increase
1	Population growth (million)	0.53	0.59	1.02%
2	Sewage Generation (MLD)	58	64	No treatment facility available
3	Solid waste Generation (MT)	192	212	No management facility available
4	Sanitation facility (% of the population)	20	50	Facilities are Partially available
5	Shrinkage of open water area (km^2)	68	53	22% loss of area
6	Deforestation (close forest and open forest) (km^2)	2058	1418	31% loss of forest
7	Agriculture land (km^2)	574	1604	180% increase in agriculture land
8	Settlement area (inside the Lake) (km^2)	310	318	2.6% increase

Table 1. Problems of the Inle Lake and its Catchment.

Year	Authors	Title	Summary	Sampling
2013 (2010-2011)	Thida Swe , Khin Hnin (MOECAF)	Assessment of water quality of Inle lake	This paper summarizes the results of data collected in2009 and 2010. The purpose is to assess the water quality and trophic state of the lakes based on the available data. The pH of water is in alkaline condition. With respect to high content of hardness, electrical conductivity, Total Dissolved Solids and Total suspended solids, the water from Inlay Lake is not suitable for drinking anymore. The fertilizers and pesticides from the floating gardens and sewage from the catchment are also reaching the lake in addition to sediments and nutrients causing the lake eutrophic. The immediate attention should be paid on the problems of sedimentation associated with the construction and management of floating gardens if the open lake area is to be preserved. Public awareness is essential in playing vital role in the preservation of Inlay Lake and protection of the health of the watershed residents.	SUMMER (no frequency given) 2009 – 2010 Sampling points: scattered over 1 mile (1.6kmk) interval. If depth more than 1 m . one sub water sample. 49 samples in total in three groups (Open Water area/ Floating Garden Area / Village areas / Streams)



2013 (2010-2011) – Results

Authors give processed result on ly in form of table and grouped in sites. No data table is available in the report.

authors used the Nitrate levels across location to define the status of the lake as eutrophic:

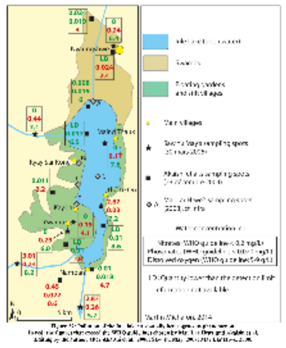
Table (8) Trophic status of Inlay Lake

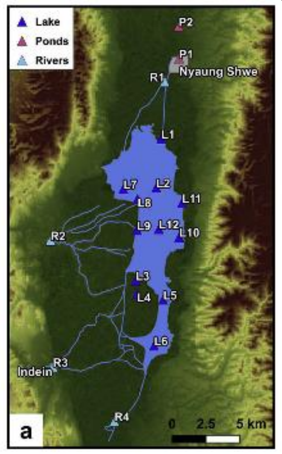
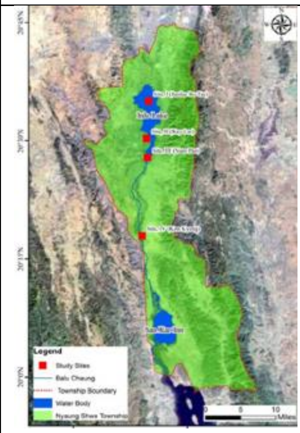
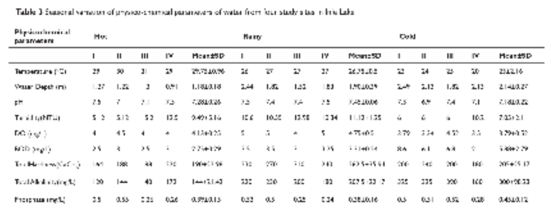
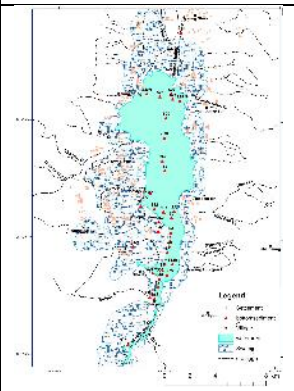
Area	Total N level(µg/L) Mean (sd)	Min	Max	Trophic Status
Open lake area	657 + 360	280	1790	Oligotrophic – Eutrophic
Floating garden	350 ± 297	560	640	Mesotrophic Eutrophic
Villages	470 + 408	140	1250	Oligotrophic - Eutrophic
Main Streams	848 ± 494	280	1480	Oligotrophic - Eutrophic

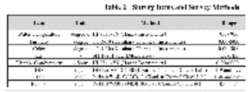
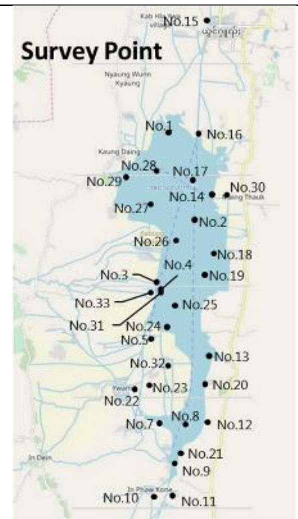
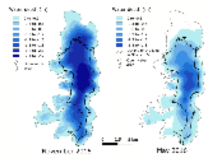
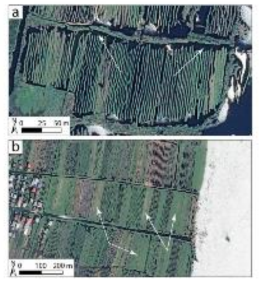
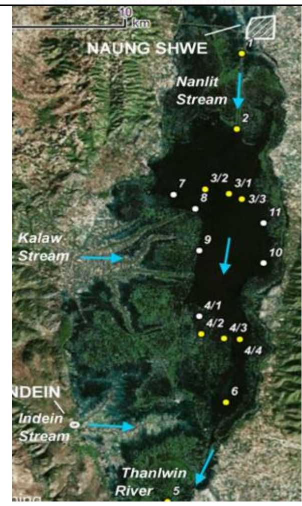
2013 (2010-2011) – Comments

The number of sample collected is the highest density recorded. Unfortunately, the full results are not published and cannot be re-interpreted.

This report is likely the first in a series of UNDP – NIWA funded project on the lake conservation and restoration.

2014	Michalon Martin	The gardener and the fisherman in globalization: The Inle Lake (Myanmar), a region under transition – Master's thesis.	This master's degree thesis examines the Inle Lake region (Myanmar) is stepping into globalization, and how the latter is structuring and transforming the local territory. The infamous floating agriculture is highly integrated in globalization, while fishing is facing severe hardships. Tourism is now becoming the main and the most transformation-inducing process in the region and connects it with the rest of the world and with the globalization.	No sampling campaign, Summarizes previous 3 campaigns (cf. maps) Investigation on pesticide application and sales.		Over use of pesticides and fertilizers in floating gardens reluctance to switch to organic fertilizers detailed form interviews. In its secondary analysis of N and P values, the author, based on (Jensen – pers.com) argues that the algae bloom does not occur at large scale as water Jacinth are using it up and these do not cover the entire lake as they are harvested for agriculture. As put by Jensen and the author: positive retroaction seems to have started: ye-chan generate eutrophication that leads to water hyacinths bloom, which benefits back to floating agriculture.	Thesis is mainly descriptive and do not provide specific sampling and water quality analysis. However, it is of very good quality and describe in detail the agronomic system of the floating garden. Relevance to Pekhon might be limited (due to absence of floating gardens in Pekhon) but it is interesting to be aware of upstream practices. It is one of the first to specifically address and investigate the pesticide use in detail, with interviews with agri- shop owners and farmers. And a list of most common used pesticides in the floating gardens. However given the seemingly absence of floating gardens in Pekhon it is difficult to state on relevance of these for monitoring Pekhon.
2014 (2012)	MOECAF, UNDP – Norwegian (NIVA?)	Long Term Restoration and Conservation Plan for Inle Lake	Comprehensive hydrological, ecological and socio-economic assessments involving all Stakeholders and local communities were conducted. Information gathered was analyzed and verified onsite and in consultation with experts and related Government Departments to identify "key issues". The main emphasis of the Plan is on the Restoration of the Lake and its total Watershed area; to prescribe management methodologies and practical approaches to conserve them sustainably	Some results are showed as table – they mention sampling occurring across 21 locations. It could refer to the other report from Thida Swe (2013). There is conflicting dating of sampling between main text and Annex. Annex gives GPS coordinates and description and dates in 2012 a. Colour b. Odour c. pH d. Dissolved Oxygen (DO e. BOD f. Coliform g. Electrical Conductivity h. Sodium i. Potassium j. Temperature k. Carbonate l. Bicarbonate m. Chloride n. Sulphate o. Total Dissolved Solid p. Sodium Absorption Ratio q. Residual Sodium Carbonate r. Turbidity s. Salinity t. Ammonical Nitrogen	No map given. Only XY in Annex.	Authors compared the 2012 result with earlier 2010 results. But recognize location s are different and that a snapshot of august 2012, with rainfall might not be representative. Further they observed that : The quality of water within streams and the Lake are within tolerance limits, and a few physical parameters meet WHO standards: a. Dissolved Oxygen is high near Yay Pei village (Yay Pei stream), Tar Yaw bridge (Nam Lat stream near Shwe Nyaung Town), Thann Daung village (Kalaw stream) and Indein village (Bi Lu stream) respectively. b. The water at Ywa Ma village on Bi Lu stream and near Zayat Gyi village in the Inle Lake have high turbidity. c. The water at Mye Ni Gone and Inn Oo villages on the west bank of the Lake, have high concentrations of Total Alkalinity as CaCo3. It was observed that waste water entering the major streams / Lake is not being intercepted, diverted or properly treated before disposal. Monthly sampling of the Lake water at various critical locations, need to be taken all the year round, to acquire site specific pollution load data. It needs to be noted that samples collected were tested for physical and bacteriological parameters only. Water samples were collected from such locations only after mixing of effluents. The volume of effluents is small as compared to Lake Storage capacity and as such, impact of dilution has not been accounted for. Samples collected from stream / effluent sites were not tested. Furthermore, no tests were carried out by the testing organization to assess the presence of pesticides, heavy metals, ammonical nitrogen etc.	Compared to specific studies (PhD, Master thesis, and scientific papers. This document gives only aggregated data, without details fine results analysis etc. However, the authors recognize the limits of their monitoring plan. Further this document is a comprehensive plan, so it is expected that not all details are given.
2017 (2014-2015)	NIV (Andreas Ballot)	Integrated Water Resources Management in Myanmar Assessing ecological status in Inlay Lake Preliminary report	The report is one of the deliverables of the project Integrated water resources management – Institutional building and training. The main purpose of the report has been to achieve improved knowledge about aquatic biodiversity and water chemistry in Inlay Lake, and to give an example for assessing the ecological status. In addition, to develop preliminary recommendations for a monitoring programme for Inlay Lake. **Physical measurements, water and phytoplankton samples and aquatic macrophytes were collected at several sites in different parts of the lake in 2014-2015**. Inlay Lake can be characterized as a mid-altitude, very large and very shallow, calcareous, clear lake, and the nutrient concentration show mesotrophic-semi-eutrophic conditions. Preliminary ecological status for phytoplankton and aquatic macrophytes are suggested based on different indices. Preliminary recommendations for a monitoring programme for Inlay Lake are included.	14 locations. Nov 2014 Feb 2015 / Nov 2015. + monthly March to Oct 2015 + some rivers inlets included.		Most of the report focuses on the ecological state and particularly macrophytes and plankton. Summary of results: Inlay Lake is a shallow lake with inflow from 4 large rivers. The water is clear; with turbidity variations between 4.5 and 5.7 FNU (Table 4.2). However, some of the inflowing rivers have higher turbidity (Table 4.3). The lake is a calcareous lake, with average calcium value at 49 mg Ca/l. With average colour values at 17 mg Pt/l it can be characterised as a clear lake. The nutrient content in Inlay Lake show mesotrophic-semi-eutrophic conditions (Salas and Martino 1991), however, see discussion in next chapter. Both phosphorous and nitrogen are generally higher in the investigated inlet rivers (Table 4.3 and 4.4). The inflowing rivers transport total suspended solids (TSS), which include inorganic and organic material into the lake. The ranges measured in this study varied between 149 g/m3 in Belu river and 48 g/m3 in Nay Gyar. The loads are a little bit lower than the transport of 200 g silt/m3 water described by IID (2012). MIN MAX and MEAN Values for Balu river + Inle lake + Outlet. Are given	A m In terms of Future Monitoring for Inle Lake, the authors describes that: hysico-chemical parameters should be included: oxygen, pH, conductivity, calcium, colour, turbidity, total phosphorous (TP), PO4, total nitrogen (TN), NO3, NH4, and total organic carbon (TOC). The original number of 14 sampling localities from 2014-2015 can be reduced to 6 localities for water chemistry and phytoplankton, while all localities should be maintained for aquatic macrophytes. To detect the effects from use of pesticides in the floating gardens, we suggest sampling once a month in the period when farmers spray with pesticides. To detect metal pollution from small industries, sampling close to the outlet and downstream the industries are needed. Sewage from villages will mainly refer to nutrient and bacteria impact. The map shows a profile like structure and suggest inlet and outlet to be monitored (not mapped) → it is necessary to be caution on to which extent this applies to Pekhon as the lake share such a different characteristics.
2017	Thinda Swe (MOECAF). Andreas Ballot, Marit Mjelde (NIVA)	Assessing Ecological Status of Inle Lake in Myanmar.	This is the support document for the NIVA Report (2017) – Similar data / info. Cf. NIVA report	Cf. NIVA report	Cf. NIVA report	Cf. NIVA report	Cf. NIVA report

2018 (2015)	Viviana Rea,⁎, Myat Mon Thinb, Massimo Settia, Sergio Comizzolia, Elisa Sacchia	Present status and future criticalities evidenced by an integrated assessment of water resources quality at catchment scale: The case of Inle Lake (Southern Shan state, Myanmar)	Assessing aquifer dynamics and groundwater interactions with surface waters are prerequisite for the correct management of water resources in the long-term, especially under the increasing pressure of climate change and the growing freshwater demand. This work presents the results of the first integrated assessment in the Inle Lake catchment aimed at understanding the surface and groundwater dynamics and the impact of agriculture and tourism on water quality. Results of an investigation performed in winter 2015, targeting the water chemical and isotopic (δ18OH2O and δ2HH2O) composition, and soil mineralogy, confirmed that Inle is an alkaline lake, where carbonate equilibria dominate its hydrochemistry. The high resilience of the lake to external perturbations is due to calcite precipitation, that represents an effective mechanism of P removal and, combined to the low residence time of water, prevents the accumulation of nutrients in lake waters. The investigation also permitted the first characterization of groundwater in the region, highlighting the dominance of Mg(Ca)-HCO3 facies. Two deep groundwater circulations could be evidenced: one of high temperature, Na-HCO3 type (Khaung Daing Hot Spring) and one in equilibrium with the dolomitic rocks of the basement, upwelling along a fault zone-oriented N-S in the Northern part of the basin. The latter groundwater contributes to Inle lake by mixing with local recharge in the aquifer and by feeding the network of artificial channels created for reclamation purposes. Evidencing recharge mechanisms of both surface and groundwater makes it possible to highlight the impact of seasonal fluctuations of the water levels, and the associated flooding of some sectors of the catchment, on the Inle Lake agroecosystems and to evaluate possible scenarios for the future sustainable development of the region.	Decmeber 2015. "uniform spatial coverage of lake" + all amjor rivers inflows. **+ pond water** and some rivers. + groundwater wells sampling (not detailed in this review). Probe: Electrical Conductivity (EC), pH and Eh With kit alkalinity Sampled and lab: EC, pH and alkalinity + main Ions. +stable isotopes.	 	Main results reagrding surface water are: - absence of clear stratification in the water body (no significant differences are observed for the main physical and chemical parameter) - EC ranges from 328 to 508 µS/cm, the alkaline pH varies between 7.65 and 8.66 (average 8.27). The redox potential is always high, in-dicating that waters are well oxygenated. The most abundant cations are Ca and Mg, whereas bicarbonate is the most abundant anion. - The Piper diagram (Fig. 1S in Supplementary Material) shows that surface and ground waters are of Mg(Ca)-HCO3 type, although surface waters present a higher variability in Ca and Mg relative abundances, Discussion points: -> Inle is an alkaline lake, where carbonate equilibria dominate the lake water hy-drochemistry. High HCO3 contents are a consequence of the dissolution of carbonates rocks in the catchment area and of biological activity in the lake. → refer to a preivous study claiming that […] demonstrated that during monsoon the lake water is fully flushed by inflow waters (and therefore the residence time is shorter than one year) → Inle is a highly resilient alkaline lake, where carbonate equilibria dominate → groundwater contributes to Inle inflow.	Table of results is available in supplemeary mateiral (paid acces).
2018 (2016-2018)	Seint Seint Win,1 Khin Maung Gyi,2 Mie Mie Sein3	Assessment on fishery sustainability in Inle wetland, Nyaung Shwe township, southern Shan state	The six indicators were used to analyze for sustainable fishery management in Inle wetland and grouped into four components categories–ecological, economic, community and institutional. A total of 41 fish species, among them 13 endemic and 16 ornamental fishes were found. The value of DO was slightly below the WHO standard in all study sites. The concentration of phosphate was relatively high, probably because of originated from domestic and agriculture uses. Inle water is under treated by contamination of fertilizers and pesticides used in floating cultivations in and around the Lake and also affected by other anthropogenic activities. The water of Inle Lake found to be hard water lake. Its high calcium can be attributed to the limestone of Shan Plateau. The fish species population abundance is currently low probably because of changes water quality and decreased clarity. Thus, there is an urgent need to uplift the status of the fishermen and also to safeguard the sustainability of array of indigenous, endemic and ornamental fish species that enjoy the ecofriendly nature of Inle water. Moreover, there is a need to maintain the Inle Lake to be environmentally friendly for the aquatic fauna and flora to thrive.	#4 sites. 'every season " march 2016 to Feb 2018. Sampling in mornning and sent to lab in Yangon.		■ >Site I (Innla`e) and Site II (Kay La Village) were the highest level of phosphate that indicated undergoing eutrophication. In the Kay La Village and unregulated and increased using fertilizers in floating island cultivation, sedimentation results in increasing the nutrient uploading leading to Eutrophication in Inle Lake. Concerns for Low DO with more than half of samples below the recommended (DO 5.0 – 9.0mg/L) for fisheries and aquatic life according to the EU criterion. 	→ Intersting paper that links directly quality with fisheries interest.
2019 (2017)	Phyu Phyu Aunga,b, Yao Maoa, Tianpeng Hua, Shihua Qia,⁎, Qian Tiana, Zhanle Chena, Xinli Xinga	Metal concentrations and pollution assessment in bottom sediments from Inle Lake, Myanmar	Heavy metal concentrations and assessment of pollution were carried out in the bottom sediments from Inle Lake, Myanmar analyzed by Inductively Coupled Plasma Mass Spectrometry (ICP- MS). Potential contamination of the sediments was assessed by geo-accumulation (Igeo) index and enrichment factors. The ranges of the metal enrichment in the lake bottom sediments are as follows: Mn > V > Cr > Zn > Ni > Pb > Cu > As > Co > Ga > Sb > Bi > Cd. Based on the results, it can be concluded that lake sediments may be minimal enrichment to moderate enrichment with metals such as Cd, Pb and Bi while moderate enrichment to signifying significant enrichment in sediments by As and Sb. The enrichment factor and geo-accumulation index, revealed that the concentrations of V, Cr, Mn, Co, Ni, Cu, Zn and Ga were mainly influenced by crustal materials or natural weathering processes, while that of metals As, Cd, Pb, Bi and Sb were impacted by the natural and anthropogenic processes. Concentration of As, Cd, Cr, Ni, Pb, Sb and Zn were comparison with Intrime Freshwater Sediment Quality Guidelines (ISQGs). The mean concentrations of elements viz.Cd, Cr, Ni, Pb, Sb and Zn were lower than the threshold effect level (TEL) of ISQGs values except for As. The concentration of As (arsenic) was higher than threshold effect concentration (TEL) value of ISQGs values.	Studies focues on heavy metals in sediment rather than water. July 2017. 38 samples in total		Main conlcusions: The results of the present study show that sediments from Inle Lake ranged from unpolluted to moderately polluted and, in some cases, strongly polluted. The data made available in this study can be used for comparison in future pollution studies. 1. According to the geo-accumulation indexes for the studied metals, Lake sediments have uncontaminated with V, Cr, Mn, Co, Ni, Cu, Zn Ga and Cd. Igeo values for Bi and Pb show very less degree of pol-lution level as compare to other metals. The Igeo values of As show a moderately polluted while Sb can be consider as moderately to strongly polluted degree at some sample sites (S14, S16, S21, S22, S23, S24, S33z, S34z and S39). 2. The ranges of the metal enrichment in the lake bottom sediments are as follows Mn > V > Cr > Zn > Ni > Pb > Cu > As > Co > Ga > Sb > Bi > Cd. The mean EF values of indicating that Inle lake has uncontaminated sediments with metals such as V, Cr, Co, Ni, Cu, Zn and Ga. The result of EF indicated that the study area may be minimal enrichment to moderate contaminated with metals such as Cd, Pb and Bi. **The EF values of As and Sb suggesting that sedi-ments of the Inle Lake may be significantly contamination with respect to As and Sb.** 3. The enrichment factor and geo-accumulation index, revealed that the concentrations of V, Cr and Mn Co, Ni, Cu, Zn and Ga are en-tirely from crustal materials or natural weathering processes, while that of metals As, Cd, Pb, Bi and Sb were impacted by the natural and anthropogenic sources. 4. The assessing results of enrichment factor and that of the index of geo-accumulation were similar, and the main pollutants and pol-luted sites were almost the same, were especially observed in Nanlet chuang, Nan Pilu chaung and near Ywa ma village.	→ Authors points out that Sediment quality is a good indicator of pollution in water column, where it tends to concentrate the heavy metals and other organic pollutants.. → Authors points to Sb and As problems, and suggest these elements might come not only form natural weathereing but from anthropogenic sources. It could be considered and worth noting that globally recognized source of arsenic include Metal separation and pesticides. Thus, activties around these main sources should be considered (mining, jewelry local factoreis, and pesticides content.).

2019 (2017-2018)	Takashi Yuasa, Gaku Manago, Kyoko, Ryo Matsumaru	Conference paper Current Water Quality of Inle Lake in Myanmar; A Potential Threat to the Lake Environment	Water quality survey was conducted in Inle Lake where various problems including water quality deterioration became obvious, and the current water quality of the lake was grasped. According to the surveys, it was revealed that COD was 5 to 20 mg/L, which were found to be of much higher levels compared with the representative lakes in Japan. On the other hand, turbidity was low and the lakes were found to be very clear. One of the reasons why the lake is transparent might be due to the purification effect generated by the aquatic plants, especially the submerged plants that grow abundantly in the lake. Considering the current water quality situation and pollution load, the authors are concerned that if the water quality of the lake were to drastically worsen, a "catastrophic shift" could take place. When lakes experience this "shift", like many shallow lakes have done so in Japan; they require much time and cost to improve their water quality. Therefore, it is desirable to promptly implement countermeasures before this "shift" occurs.	June 2017, August 2017, August 2018 Sampling. 32 locations selected (27 in lake and 5 in "intersting locations (inlet etc.). Boat was encored. Depth and temp taken – then sampling and immmediate testing on the boat. 		■ Authors have concerned about the high COD. And discuss the role of plants in mainting the lakes quality, with coparisons wihth cases in Japan of smiliar lakes where a "shift occurred" with death of plants and eutrophication. he submerged plants communities play an important role in maintaining and improving the water environment of the lake such as: (1) absorption and removal of nitrogen and phosphorus in the water, (2) providing refuge for zooplankton such as Daphnia, (3) reducing the growth of phytoplankton such as algae bloom due to allelopathic substance production, (4) prevention of waves and bottom mud resuspension, (5) providing a habitat for fish to spawn and grow (Ozaki et al., 2014). [...] Regarding the purification effect by aquatic plants, Scheffer et al. (2001) described the mechanism calling it a "catastrophic shift". With the aquatic plant condition, clarity of the lake can be preserved even when the nutrient load increases. However, if aquatic plants in the lake are lost because of an excessive nutrient over-load or aquatic plants dying because of herbicides, or the killing of Daphnia by pesticides, turbidity rapidly becomes a high level. They called this mechanism a "catastrophic shift"	➔ This study is interesting as: - ALL parameters were anaylized on the boat without samples being sent to the lab. This is low-cost and efficient. - It discusses the roles of the abundance of macrophytes and the role they might play in controling eutrophication, but also the risk of a major – rapid – shitf that could happen. However, one of the drawback is the absence of any P or N analysis –n a key point when looking at trophic status.
2019	Martin Michalon1, Yanni Gunnell2, Jérôme Lejot2, François Mialhe2, Toe Aung3	Accelerated Degradation Of Lake Inle (Myanmar): A Baseline Study For Environmentalists And Developers	This study takes stock of the confusion that exists around the environmental state of Lake Inle, a flagship destination of tourism in Myanmar. Reports on the dynamics of its iconic floating gardens and on the evolution of the lake's dimensions in response to land-use change in the watershed are inconsistent and provide a poor basis for policymaking. Here we (i) present a critical overview of the literature concerning land degradation around Lake Inle; (ii) provide an independent, quantitative re-examination of the lake's size; (iii) carry out a methodic assessment of the history of floating gardens based on written sources, interviews and high-resolution imagery from 1967, 1983, 2002 and 2014; and (iv) produce the first comprehensive and bi-seasonal bathymetric survey of the lake, thereby providing a baseline water-volume estimate fit for future monitoring purposes. Results challenge previous reports and show that floating agriculture boomed in the 1970s (11 km² in 1967, 29 km² in 1983), peaked in 2002 (35 km²), then declined slightly (33 km² in 2014). Our bathymetric survey reveals that the lake volume at the peak of the 2015 rainy season was 122.6·106 m3, with maximum water depths having diminished substantially from 6 m (as reported in 1918) to just 3 m today as a combined result of sediment aggradation and water level decline (–1 m in 25 years). Implications for the sustainability of floating agriculture, fishing and the local tourist economy are critical.	No Sampling for water quality. intersting for: - bathymetry measurments - Identification of Flaoting Gardemns and other features through google earth pro.		bathymetric survey reveals that the lake volume at the peak of the 2015 rainy season was 122.6·106 m3, with maximum water depths having diminished substantially from 6 m (as reported in 1918) to just 3 m today as a combined result of sediment aggradation and water level decline (–1 m in 25 years).   Intersting point: Ye-chan (flaoting gardens) has declined from 34.9 km² in 2002 to 33.1 km² in 2014. Although modest, this decline contrasts with the claim from some development agencies that ye-chan is still increasing dramatically (IID, 2012, MoECAF, 2014)	➔ Intersting point is the identificaiton of floating garden And differencating active and abandonned ones. ➔ Method used to identify floating gardens can be use to assess wether such gardens exist in Pekhon.
2020	Myat Mon Thin 1 , Elisa Sacchi 2 , Massimo Setti 2 and Viviana Re 2 , 3, *	A Dual Source of Phosphorus to Lake Sediments Indicated by Distribution, Content, and Speciation: Inle Lake (Southern Shan State, Myanmar)	Abstract: In this study, grab and core sediments from Inle lake were collected and analyzed for their water and organic matter (O.M.) contents. Total phosphorus (TPSMT) and P fractions, namely inorganic-P (IP), organic-P (OP), P bound to Al, Fe and Mn oxy-hydroxides (Fe-P), and calcium-bound P (Ca-P) were determined by a sequential extraction procedure. TPSMT varied considerably (152–1980 mg/kg), with minimum concentrations detected at sites away from the main inflow rivers and maximum concentrations in the floating gardens area. In core sediments, TPSMT concentrations tended to decrease with depth, reaching values of <100 mg/kg. Concerning P forms, the overall abundance sequence in grab sediments was IP >> OP and Ca-P OP > Fe-P, whereas in core sediments it showed marked divergences with depth and between sites. The relative abundance of the inorganic species (Ca-P, Fe-P) was controlled by the mineralogy of the sediments. While the TPSMT distribution pointed to an increased anthropogenic input, the relative abundance of P species provided information on the P origin, incorporation processes, and evolution over time. This information, combined with chemical and mineralogical data, permitted to identify two divergent P sources: the agricultural input in the floating gardens area and the detrital input related to soil erosion.	No wtaer sample. Grab and Core sediemtn samples. March 2014.		Looked at OM content and P. shows that P in sediement is increasde to to athropgenic activities. Two sources: - **the floating gardens** in this case <u>the dominant anthropogenic P form identified here was Ca-P, a relatively stable and non-bioavailable form. (due to Calcite).</u> **- sediment carried by rivers.** "In this case, the dominant anthropogenic P form was OP, which is more labile and can easily be released during O.M. degradation. Moreover, this process could lead to the establishment of anoxic conditions in the future, which may promote the reduction of Fe oxy-hydroxides and trigger a positive feedback mechanism, further increasing the internal P load. At present, oxygenated conditions are maintained in the water column throughout the year, as a combined e ect of the low depth and fast circulation [33]. Nevertheless, the changing climatic conditions and the anthropogenic disturbances are a ecting sedimentation and are progressively reducing the open water surface and the depth of this shallow lake".	➔ Shows that most worrying source of P is the one from Sediment inputs rather than gardens and in case of anoxic condition could be very worrying. ➔ highlights the need to check P near input rivers in Pekhon and also theck the D.O conditions carefully.

Annex 4: Monitoring / Sampling plan

Water resources are strategic to sustainable development of small-scale aquaculture. It requires understanding both what is the quality and availability of water resources to support aquaculture and what assessing what are the possible impacts of development on the environment. In the region of Pekhon, small-scale aquaculture is growing. Earlier work showed there is likely a multitude of water sources used by farmers to support aquaculture. Literature review in upstream Inle lake showed that there is a high risk of eutrophication, due to anthropic nutrient inputs (mainly Nitrate and Phosphate).

This water quality monitoring and water management evaluation aims at:

- Understanding what the current water quality in the Saga-Pekhon lake system is as it represents the hydraulic outlet of the basin, and is of national conservation significance (part of the Inle protection area). Building a baseline on water quality and its seasonal variability will assess its sensitivity to pollutants sources including the development of aquaculture and release of aquaculture wastewater. it is believed this is the first water quality survey of its kind in this part of Pekhon lake.
- Understanding the water source diversity and quality used to support aquaculture development, highlighting possible constraints if any.
- Assessing the water quality in fishponds and its temporal variability, particularly towards the end of the fish growing cycle and release of wastewater into the environment and evaluation of release points.
- Understanding practices and perspective regarding water management at farmer level.

Given the current circumstances as of March 2021, the sampling campaign will be carried out with the assistance of local partner based in Pekhon Township (KMSS).

The following documents details:

1. The monitoring plan for water quality in the Saga-Pekhon lake

2. The strategy for assessing the water management practices in aquaculture ponds in Pekhon area.

3. The monitoring plan for water quality in aquaculture ponds in Pekhon lake area

Measurement method and sampling period:

- Sampling located based on:
  - Spatial coverage on of the entire system and particularly the Upstream-Downstream profile
  - Specific locations (i.e., near inlets form adjacent hills were aquaculture is developed, near Pekhon town etc.)
  - **15 locations** across the lake Saga – Pekhon lake.
- Time interval: 2 months (cf. table hereafter)
- Variables: Temp, EC, TDS, pH, DO, Nitrate, Phosphate, Depth
- Depth:
  - For Phosphate and Nitrate: integrated 2 m sample.
  - For Probe parameters: if depth <2m: 1 point at 1m below surface. Otherwise, every 1m
- Most parameters measured on-site + 1 L sample taken back to base in the cool box for N and P for analysis on same day when back to shore.

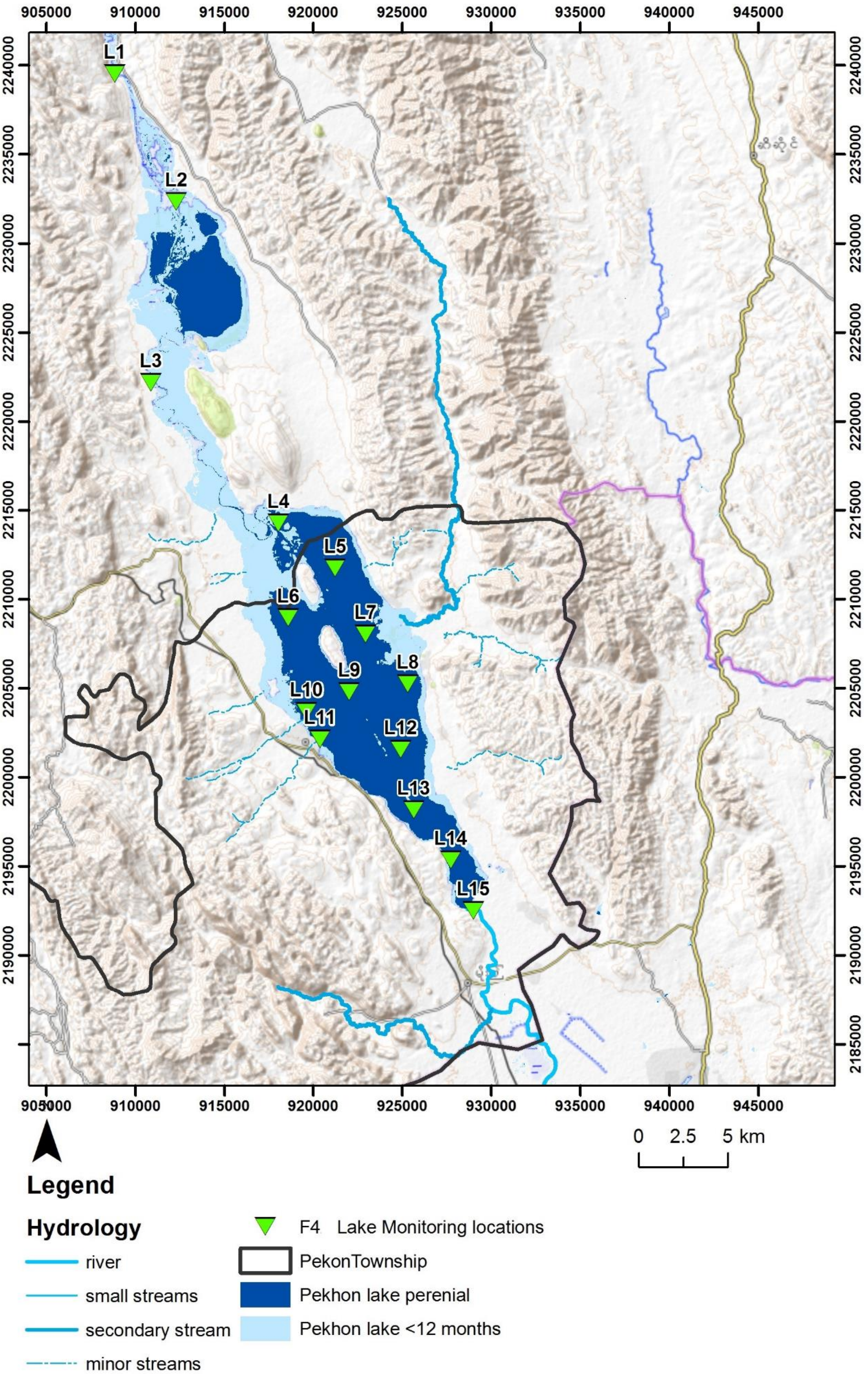
Table 1 Timetable of sampling in the lake

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	TOTAL	
Sampling in Lake				15		15		15		15			60	LAKE SAMPLES

Table 2 list of parameters, tools, and methods

parameter	Tool	Method
depth	Weighted rope / measuring tape	Approximation of lake depth
Temperature	Multimeter	Vertical profile at 1m interval.
EC	Multimeter	Vertical profile at 1m interval.
TDS	Multimeter	Vertical profile at 1m interval.
pH	Multimeter	Vertical profile at 1m interval.
DO	Multimeter	Vertical profile at 1m interval.
		Take a 1 L sample
Nitrate	Field Photometer	2 m integrated sample + analysis using reagents
Phosphate	Field Photometer	2 m integrated sample + analysis using reagents

Monitoring locations for Saga-Pekhon lake



Protocol for water quality analysis in LAKE

The protocol for water quality campaign around the region of Pekhon lake is produced by IWMI in collaboration with WorldFish to ensure quality control of water testing procedure and efficient process. The success and accuracy of water testing procedure depend primarily on the measures suggested in this protocol. The protocol is to be reviewed based on practical challenges faced during the sampling trip.

Any necessary changes or suggestions can be made to Aung Kyaw Kyaw (09777919902, a.kyawkyaw@cgiar.org), a project coordinator at IWMI Myanmar.

STEP-1 At base/ office Preparation and complete CHECKLIST

- Follow the calibration process carefully.
- Part of equipment (sensors, probe) shall be rinsed with clean water and wipe properly with appropriate clothes provided.
- Checking the number of items needed for the trip: use the CHECKLIST.
- Contact every time the project coordinator (Aung Kyaw Kyaw 09777919902) to confirm before departure and report any issue in preparatory phase.

STEP-2 transportation to location

- Choose transportation that allows transporting safely personnel and equipment accordingly.
- Before you start Turn on GPS on Phone and start Tracking your position (use any dedicated app), tracklog (.gpx or .kml) might be requested to assess distances and time and optimize future campaigns.
- Ensure of boat safety, presence of lifejackets and full agreement with a boatman.
- Use GPS coordinates on the phone to reach points or use the MAP provided.

STEP-3 when sampling point is reached – USE THE FORMS PROVIDED

  - Use an anchor for the boat to make sure you stay at the same location.
  - Fill the header of form. Take GPS Coordinates (and indicate accuracy)
  - Draw the schematic of the situation of the water, including flow and wind direction, boating or any other activity in sight.
  - Note anything that can clarify the water management situation.
- For all visits
  - Note time and outside temperature and weather.
  - Using a Measuring tape with weight, measure the Depth of water.
  - Immediately proceed to measure parameters ON-SITE with the probe and indicate results in the form.
  - If depth is >2m. Take 1 measurement every meter.
  - If depth is <2m take 1 measurement at depth of 1m below surface
  - Take a 1 L sample, and LABEL IT CAREFULLY using a permanent marker. Mark both bottle + cap. Make sure the marker is dry before putting it in a cool box.

- Make sure everything in the FORM is COMPLETE (aside from N and P values) and relieve anchor and move to next point.

STEP-4 Back to Shore / base

- On the SAME DAY, proceed to use the photometer to measure N and P and complete the form.
- Conserve the remaining water in the bottle until next trip – it might be used for quality checks if dubious results appear when reporting.

STEP -6 – Reporting

- Call / send a message to the project coordinator at the end of each day to confirm progress, number of samples taken and discuss issues.
- Provide scans of Forms (phone photos) as soon as possible after trip (48h)
- Send the GPS tracking file to project coordinator (.gpx; .kml etc.) (48h)
- Proceed to data entry as soon as possible after back to base (following days)

CHECKLIST FOR STUDY SITE SAMPLING

This document is provided as a measure to ensure an efficient process of water quality campaign in the region of Pekhon lake. It might be revised to accurately reflect practical challenges encountered during ground expeditions and to identify specific protocol requirements. If you have any questions and suggestions, please contact a.kyawkyaw@cgiar.org.

	ITEMS AND ACCESSORIES
☐	HANNA HI98194/10 Multiparameter pH/ORP/EC/DO/Pressure/ Temperature Waterproof Meter (10m cable + Reader + Probe + threes sensors + two sensor housings + maintenance kit and toolbox)
☐	HANNA HI97728 Nitrate Portable Photometer with two cuvettes.
☐	HANNA HI93728-03 Nitrate Reagents
☐	HANNA HI97708 Nitrite High-Range Portable Photometer with two cuvettes.
☐	HANNA HI93708-03 Nitrite High Range Reagents
☐	HANNA HI97717 Phosphate High Range Portable Photometer with two cuvettes.
☐	HANNA HI93717-03 Phosphate HR Reagents
☐	HANNA HI97713 Phosphate Low Range Portable Photometer with two cuvettes.
☐	HANNA HI93713-03 Phosphate Low Range Reagents
☐	HANNA HI97728-11 Nitrate CAL Check™ Standards
☐	HANNA HI97717-11 Phosphate High Range CAL Check™ Standards
☐	Check battery pack for each relevant equipment
☐	5 extra sets of 4-battery packs.
☐	Set of wiping cloths
☐	20 1-litre bottles with stickers indicating GPS-location of a particular sampling point.
☐	10-metre rope with a heavy ball for water depth measurement.
☐	For LAKE SAMPLING : Water-column-profiling PVC pipe + a cork/plug for lifting
☐	For POND Sampling; long PVC Pipe with marks (every 50cm, for depth measure) and a hole at the end to attach sampling device
☐	4 Cool boxes filled with ice cubes.
☐	Glove sets.
☐	If available GPS unit. Otherwise use a phone only if sufficient battery and knowledge on usage of phone GPS.
☐	POWER BANK +CHARGERS and CABLES FOR PHONES
☐	PROTECTIVE GEAR FOR SUN/RAIN FOR LONG HOURS (hat, jackets etc.)
☐	SUFFICIENT DRINKING WATER SUPPLY

☐	DRYBAG for Belongings/ equipment (if rainy weather)
☐	TRANSPARENT TAPE
☐	PERMANENT MARKER
☐	A4 SIZE FIELD WRITING PAD
☐	PENCILS (not pens if rainy weather / wet)
☐	LIFEJACKETS in the BOAT
☐	MAP and GPS Points are loaded into the phone
☐	MAPS are Printed out in A3 size.
☐	ALL Forms PRINT OUT A4 size
Comments: Need to add:	

Field Sheet

PEKHON Lake Sampling Sheet

Date and time		LOCATION ID (GRID)	
Officers Name		GPS X Y	
Officers phone		Gps Accuracy	_____m
		Gps device (phone?)	

Comments on location (presence of habitations, boating activity, alguae, any activity and distance

Depth of lake at point ______m

Multi-meter readings					
Depth profile	Temp (oC)	EC (uS.cm2)	TDS	pH	DO
0m					
-1m					
-2m					
-3m					
-4m					
-5m					
-6m					
-7m					
-8m					
-9m					
-10m					

Photometer readings (with Unit !)		
Phosphate		
Nitrate		

1L Sample Taken and in Cool box	Yes / No	Sample Label	
1 Geo-referenced photograh (GPS tag) taken	Yes/No		

Sketch of the area (habitations, distance to shore, activities)

Understanding potential water quality constraints to pond-based aquaculture in function of water source.

1. **Pond water management for aquaculture development and water management strategies by farmers.**
   - Using the farmers database created by WorldFish.
   - **Phone interviews** of farmers across Pekhon landscape to understand water source use and management practices. Using a database of WorldFish.
   - Semi-open interviews with farmers on water management practices, water quality issues and/or concerns.
   - First tested on 5 Farmers
   - Following test-phase and approval of the procedure, the 15 pond owners selected for field-surveys of water quality sampling will be interviewed in priority.
   - Another 10 farmers might be interviewed with a total aim of 30 interviews.

3/18/2021 F4L: Fish Ponds Water Management Practice Questionnaire

F4L: Fish Ponds Water Management Practice Questionnaire

1. Farmer's ID

   ____

2. Farmer's Name

   ____

3. Farmer's Phone Number

   ____

4. Pond's Location (Lat, Long)

   ____

5. Pond's Size (Length x Width x Depth) (ft) or Area (Acre)

   ____

6. **Pond's Construction Year

   ____

7. Type of Ponds (Structure & Lining)

Check all that apply.

	Earth	Concrete	Brick	Tarpaulin
Excavated	☐	☐	☐	☐
Dam	☐	☐	☐	☐
Above Ground	☐	☐	☐	☐
Other	☐	☐	☐	☐

Water Resources for Fish Ponds

8. What is the source of water for your ponds?

Check all that apply.

	Collect in Fish Ponds	seepage through embakement /soil	Pumping	Water Remain in Ponds when lake's water level is high, Pumping, Gravity))	Water from Canal
Rainwater	☐	☐	☐	☐	☐
Groundwater	☐	☐	☐	☐	☐
Borehole	☐	☐	☐	☐	☐
Pekhon Lake (Inn)	☐	☐	☐	☐	☐
Canal	☐	☐	☐	☐	☐

9. How far is the water source from the pond?

____

10. How do you channel the water (canal, pipe)?

____

11. Do you need to pump water or by gravity?

Check all that apply.

- [ ] Pump
- [ ] Gravity

12. How is the quality of water for your pond?

Mark only one oval.

	1	2	3	4	5	
very good	◯	◯	◯	◯	◯	problematic

13. Did the quality of your water source change over the last years? How and Why?

Check all that apply.

- [ ] Yes
- [ ] No
- [ ] Not Sure

Other: [ ] ____________________

14. How do you judge the Reliability of your water source ?

Mark only one oval.

	1	2	3	4	5	
unreliable	◯	◯	◯	◯	◯	reliable

15. Did the reliability / availability of your water source change over the last years? How? Why?

Check all that apply.

- [ ] Yes
- [ ] No

Other: [ ] ________________

16. Do you use the same water resource of fish ponds for other purposes? (e.g, irrigation/ domestic purposes)

Check all that apply.

- [ ] Yes
- [ ] No
- [ ] Irrigation
- [ ] Domestic Purposes

Other: [ ] ________________

17. Level of competitiveness for use of water sources with other users

Mark only one oval.

	1	2	3	4	5	
Very Low	◯	◯	◯	◯	◯	Very High

Fish Pond's Water Management and Quality

18. How often do you recycle/refill pond's water? In which month?

Check all that apply.

- [ ] Once a Year
- [ ] Twice a Year

Other: [ ] ________________

19. Do you have any water quality issues in your fish ponds?

Check all that apply.

- [ ] Yes
- [ ] No

20. If yes, what are the problems? How do you fix them?

____
____
____
____
____

21. Incident of fish death related to water? If yes, what is the reason?

Check all that apply.

- [ ] Yes
- [ ] No

Other: [ ] ________________________

Fish Pond's Waste Management

22. Where do you discharge pond waste water?

____

23. What do you do discharge the mud?

____

24. Is the discharge place connected to Pekhon Lake through stream?

Check all that apply.

- [ ] Yes
- [ ] No
- [ ] Maybe
- [ ] Don't Know

Other: [ ] ____________________

25. Reuse of Pond's waste water. Specify.

Check all that apply.

- [ ] Yes
- [ ] No

Other: [ ] ____________________

26. Reuse of Pond's muds. Specify.

Check all that apply.

- [ ] Yes
- [ ] No

Other: [ ] ____________________

27. Do you think the discharge of upstream fish ponds influence the quality of your water resources? How?

Check all that apply.

- [ ] Yes
- [ ] No
- [ ] Maybe
- [ ] Don't Know

Other: [ ] ____________________

28. Do you think the discharge of your fish ponds influence the quality of water resources for downstream ponds? How?

Check all that apply.

- [ ] Yes
- [ ] No
- [ ] Maybe
- [ ] Don't Know

Other: [ ] ______________________

29. Usage of chemicals to treat ponds ? Specify.

Check all that apply.

- [ ] Yes
- [ ] No

Other: [ ] ______________________

Other Questions

30. Do you have chicken farms above your fish ponds?

Check all that apply.

- [ ] Yes
- [ ] No

Other: [ ] ______________________

31. Are you/your family fishing in Pekhon lake apart from your ponds?

Mark only one oval.

- ( ) Yes
- ( ) No
- ( ) Other: ______________________

3/18/2021 F4L: Fish Ponds Water Management Practice Questionnaire

32. Main Species of Fish that are caught in Pekhon Lake (if you know)

____

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Google Forms

https://docs.google.com/forms/d/1pYyrt0f1WceE069lumD6RO2R_Xo8fbiqTglLAzmO8Vo/edit 8/8

List of Interviewees

Farmers Interviewees List

Sr	FarmIDfull	Farmers_Name	Mobile_Number	Pond size			Pond type (Perineal, seasonal)	Average depth of the pond (ft)	Pond Age	Source of water	Latitude	Longitude
				Length	Width (ft)	Acre						
1	MMR014010,02005	U Luigy	09-899066535	30	20	0.01	Perineal	3'	2Year	Inn,Rainwater,Reservoir	19.80416	97.10164
2	MMR014010,02006	U Lawrence	09-452694057	70	70	0.11	Perineal	3'		Inn,Rainwater,Reservoir	19.8058	97.095962
3	MMR014010,02018	Mg Khone	09-445208118	440	80	0.81	Perineal	3'	2	Inn,Rainwater,Reservoir	19.7687	97.11863
4	MMR014010,02022	U Da	09-250783315	150	50	0.17	Perineal	3'		Rainwater,Fount	19.70712	97.082231
5	MMR014010,02055	U Kalawreh	09-689070032	558	60	0.77	Perineal	5'		Inn,Rainwater,fount	19.5727	96.5845
6	MMR014010,02060	U Phe Bu	09-780452351	70	35	0.06	Perineal	8'		Inn,Rainwater,fount	19.5521	96.5156
7	MMR014010,02062	Fr. Petru Hlaing	09-252442865	220	160	0.81	Perineal	2.5'	15	Inn,Rainwater,Fount	19.84866	97.032418
8	MMR014010,02065	Aung Hein	09-667140689	426	127	1.24	Perineal	4'	5	Inn,Rainwater,Fount	19.98102	96.984327
9	MMR014010,02070	U Joseph	09-669022385	12	6	0.002	Perineal	3'		Well,YCDC	19.84555	97.032686
10	MMR014010,02073	U Mateo	09-402441556	456	156	1.63	Perineal	3'		Inn,Rainwater,Reservoir	19.72651	97.114941
11	MMR014010,02079	U Nyo	09-253309860	150	150	0.52	Perineal	3'	5	Rainwater,fount,cistern	19.80126	97.07718
12	MMR014010,02081	U Sai Lu	09-692649139	70	35	0.06	Perineal	7'	4	Rainwater,fount,cistern	19.5651	97.53700
13	MMR014009,02062	U Hla Moe	09-252105655	48	30	0.03	Perineal	6'		Inn,Rainwater,fount,cistern	19.96814	96.954905
14	MMR014009,02063	U Tee Lon	09-252105655	66	36	0.05	Perineal	6'		Inn,Rainwater,fount,cistern	19.96279	96.95604
15	MMR014009,02066	U Soe Reh	09-252105655	60	30	0.04	Perineal	6'		Inn,Rainwater,fount,cistern	19.9472	96.954468
16	MMR014009,02067	U Chel	09-252105655	105	30	0.07	Perineal	10'		Inn,Rainwater,fount,cistern	19.578	96.5825
17	MMR014010,02076	U Lwici	09-688056799	362	96	0.80	Perineal	3'		Inn,Rainwater,Reservoir	19.72806	97.114918
18	MMR014010,02077	U Yu	09-440191058	473	141	1.53	Perineal	3'		Inn,Rainwater,Reservoir	19.7279	97.114877
19	MMR014010,02078	John	09-428005666	100	80	0.18	Perineal	2.5'		Inn,Rainwater,Reservoir	19.485	97.438
20	MMR014010,02007	U Marko	09-787344807	105	75	0.18	Perineal	3'	12	Inn,Rainwater,Reservoir	19.76866	97.118885
21	MMR014010,02008	U Moe Zet	09-788060907	244	220	1.23	Perineal	3'	5Year	Inn,Rainwater,Reservoir	19.7754	97.1155
22	MMR014010,02009	V Noe	09-428001827	255	170	1.00	Perineal	3'	4	Inn,Rainwater,Reservoir	19.76965	97.118915
23	MMR014010,02023	U Aye Mg	09-250783315	150	100	0.34	Perineal	3'		Rainwater,Fount	19.70859	97.081217
24	MMR014010,02057	U Koreh	09-663172814	340	81	0.63	Perineal	8'		Inn,Rainwater,fount	19.554	96.5642
25	MMR014010,02058	U Phyareh	09-251152798	45	23	0.02	Perineal	8'		Inn,Rainwater,fount	19.5529	96.5758
26	MMR014010,02063	Jovanni	09-428360467	256	228	1.34	Perineal	4'		Inn,Rainwater,Fount	19.536	96.59430
27	MMR014010,02068	Fr. Robert	09-428330551	6	13	0.002	Perineal	3'		Well,YCDC	19.8645	97.006784
28	MMR014010,02027	U Thant Zin	09-250783315			1.8	Perineal	3'		Inn,Rainwater,Reservoir	19.72196	97.082964
29	MMR014010,02031	Fr. Paul Lwe	09-446066364	100	150	0.34	Perineal	3'		Inn,Rainwater	19.5153	97.547
30	MMR014010,02039	Fr.Beh	09-442098019	127	27	0.08	Perineal	3'		Plughole,Rainwater		

Monitoring network of water quality in Pond water and water sources used for aquaculture.

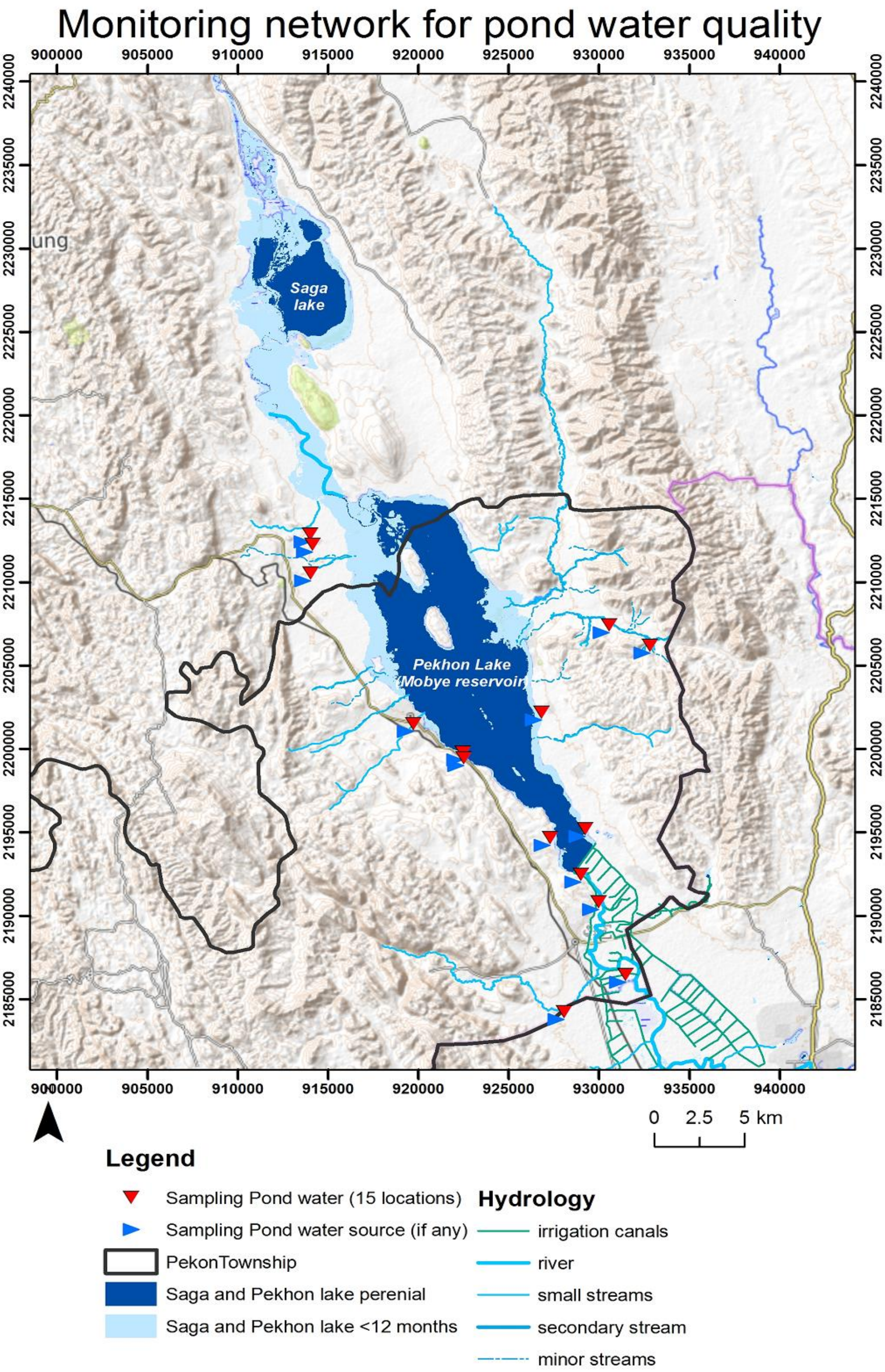
- 15 selected Ponds likely corresponding to various water sources.
- 15 associated “pond water source” for selected ponds
- Time interval: Monthly
- Variables measured: Temp, EC, TDS, pH, DO, Nitrate, Phosphate, Depth
- Mode of analysis:
    - Multi probe: Temp, EC, TDS, pH, DO, Depth
    - Photometer: nitrate and phosphate
- Note: due to budget constraints, Chlorophyll and Pesticides residues will not be monitored

Table 2 timeline for water sampling in ponds

	Jan	feb	mar	apr	may	jun	jul	aug	sep	oct	nov	dec	TOTAL
Fishpond periods					Stocking								
							Raising Fish						
	harvest fish												
			Empty /drying ponds										
#ponds W. source				15	15	?	15	15	15	15	[...]		90
#ponds W.				15	15	?	15	15	15	15	[...]		90
													180

Table 3 List of parameters, tools, and methods

parameter	Tool	Method
depth	Rigid pipe	Rigid pipe /or/ discussion with owner
T°C	Multimeter	Sample below surface at middle of pond
EC	Multimeter	Sample below surface at middle of pond.
TDS	Multimeter	Sample below surface at middle of pond
pH	Multimeter	Sample below surface at middle of pond.
DO	Multimeter	Sample below surface at middle of pond
Nitrate	Field Photometer	Sample below surface at middle of pond
Phosphate	Field Photometer	Sample below surface at middle of pond


Monitoring network for pond water quality
900000
905000
910000
915000
920000
925000
930000
935000
940000
2240000
2235000
2230000
2225000
2220000
2215000
2210000
2205000
2200000
2195000
2190000
2185000
Saga lake
Pekhon Lake (Mobye reservoir)
0 2.5 5 km
Legend
Sampling Pond water (15 locations)
Sampling Pond water source (if any)
PekonTownship
Saga and Pekhon lake perenial
Saga and Pekhon lake <12 months
Hydrology
irrigation canals
river
small streams
secondary stream
minor streams

PROTOCOL for WATER QUALITY

in PONDS

The protocol for water quality campaign around the region of Pekhon lake is produced by IWMI in collaboration with WorldFish to ensure quality control of water testing procedure and efficient process. The success and accuracy of water testing procedure depend primarily on the measures suggested in this protocol. The protocol is to be reviewed based on practical challenges faced during the sampling trip.

Any necessary changes or suggestions can be made to Aung Kyaw Kyaw (09777919902, a.kyawkyaw@cgiar.org), a project coordinator at IWMI Myanmar.

STEP-1 At base/ office Preparation and complete CHECKLIST

- Follow the calibration process carefully.
- Part of equipment (sensors, probe) shall be rinsed with clean water and wipe properly with appropriate clothes provided.
- Checking the number of items needed for the trip (use the checklist)
- Contact by phone the owners to ask if they are on site or nearby on visit day.
- Contact every time the project coordinator (Aung Kyaw Kyaw 09777919902) to confirm before departure and report any issue in preparatory phase.

STEP-2 transportation to location

- Choose transportation that allows transporting safely personnel and equipment accordingly.
- Before you start Turn on GPS on Phone and start Tracking (use any dedicated app), tracklog (.gpx or .kml) might be requested to assess distances and time and optimize future campaigns

STEP-3 Arrival at the Pond – USE THE FORMS PROVIDED

For the FIRST visit

- Fill the header of form. Take GPS Coordinates (and indicate accuracy)
- Draw the schematic of the situation of the farm, including FLOW-LINES of water source(s) and discharge points.
- Note anything that can clarify the water management situation.

For all visits

- Note time and outside temperature and weather.
- Using a Measured tape or a long PVC/bamboo perch with marks, measure the Depth of water in the center of pond.
- Using the same perch, or using a rope and bucket take a sample in the middle of the pond, if possible, below the surface.
- Immediately proceed to measure parameters ON-SITE with the probe and indicate results in the form.
- Use the water for Photometer measurements of N and P also ON-SITE
- Only if strange / dubious results, Sample the water in a 0.5L bottle with Label.

STEP-4 water sources

- Check for WATER SOURCE(s) for the Pond (observations / asking owner)

- Take the GPS coordinates of the source point.
- Proceed for sampling and analysis according to the Form.

STEP-5 Clean site and CLOSE any Gate etc.

STEP -6 – Reporting

- Call / send a message to the project coordinator at the end of each day to confirm progress, number of samples taken and discuss issues.
- Provide scans of Forms (phone photos) as soon as possible after trip (48h)
- Send the GPS tracking file to project coordinator (.gpx; .kml etc.) (48h)
- Proceed to data entry as soon as possible after back to base (following days)

- **CHECKLIST FOR STUDY SITE SAMPLING**

This document is provided as a measure to ensure an efficient process of water quality campaign in the region of Pekhon lake. It might be revised to accurately reflect practical challenges encountered during ground expeditions and to identify specific protocol requirements. If you have any questions and suggestions, please contact a.kyawkyaw@cgiar.org.

	ITEMS AND ACCESSORIES
☐	HANNA HI98194/10 Multiparameter pH/ORP/EC/DO/Pressure/ Temperature Waterproof Meter (10m cable + Reader + Probe + threes sensors + two sensor housings + maintenance kit and toolbox)
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☐	HANNA HI97717-11 Phosphate High Range CAL Check™ Standards
☐	Check battery pack for each relevant equipment
☐	5 extra sets of 4-battery packs.
☐	Set of wiping cloths
☐	20 1-litre bottles with stickers indicating GPS-location of a particular sampling point.
☐	10-metre rope with a heavy ball for water depth measurement.
☐	For LAKE SAMPLING : Water-column-profiling PVC pipe + a cork/plug for lifting
☐	For POND Sampling; long PVC Pipe with marks (every 50cm, for depth measure) and a hole at the end to attach sampling device
☐	4 Cool boxes filled with ice cubes.
☐	Glove sets.

☐	If available GPS unit. Otherwise use a phone only if sufficient battery and knowledge on usage of phone GPS.
☐	POWER BANK +CHARGERS and CABLES FOR PHONES
☐	PROTECTIVE GEAR FOR SUN/RAIN FOR LONG HOURS (hat, jackets etc.)
☐	SUFFICIENT DRINKING WATER SUPPLY
☐	DRYBAG for Belongings/ equipment (if rainy weather)
☐	TRANSPARENT TAPE
☐	PERMANENT MARKER
☐	A4 SIZE FIELD WRITING PAD
☐	PENCILS (not pens if rainy weather / wet)
☐	LIFEJACKETS in the BOAT
☐	MAP and GPS Points are loaded into the phone
☐	MAPS are Printed out in A3 size.
☐	ALL Forms PRINT OUT A4 size
Comments: Need to add:	

Field sheet for Ponds

Pond Sampling Sheet							
Date and time						LOCATION ID (GRID)	
Officers Name						GPS X Y	
Officers phone						Gps Accuracy	____m
						Gps device (phone?)	

Comments on location (presence of habitations, algae, any activity and distance)

Depth of pond at point	_____m

	Multi-meter readings				
Depth profile	Temp (oC)	EC (uS.cm2)	TDS	pH	DO
0m					
-1m					
-2m					
-3m					
-4m					
-5m					

Photometer readings (with Unit !)		
Phosphate		
Nitrate		

1L Sample Taken and in Cool box	Yes / No	Sample Label	
1 Geo-referenced photograph (GPS tag) taken	Yes/No		

Sketch of the area (habitations, distance to shore, activities)

Annex 5: Modelling of climate variability and water resource development (e.g., irrigation and hydropower) as well as expansion of ponds to assess impacts on water resource availability and timing and to predict water availability under different scenarios including climate change.

Objective

The main objective of Activity 2 is to set up a hydrological model (SWAT) to assess water resources availability for the current as well as the future periods. In order to expand fishponds, it is very important to check the bio-physical constraints in terms of water availability. Therefore, a hydrological model for the Upper Ayeyarwady basin was set up. Furthermore, climate change analysis was also done to assess the impact of climate change on future water resources availability. The modeling task was started in Year 1 and the following activities were completed:

1. Description of the study area and data preparation and formatting for setting up a SWAT model.
2. A literature review on hydrological models in the context of Myanmar and assessment of their respective performance.
3. Initial steps for the SWAT model setup.

The description of the SWAT model, the workplan and steps completed so far in year 2 are described in the following sections.

Overview of workflow for SWAT model

The methodological framework for this study is illustrated in Figure 2. Spatial and temporal data necessary for the SWAT model set-up were collected from the Hydro Informatics Center - Myanmar, IWMI archives and other sources. After the preliminary set-up, a sensitivity analysis was conducted using the Sequential Uncertainty Fitting (SUFI-2) algorithm in SWAT Calibration and Uncertainty Program (SWAT CUP) to determine the most sensitive parameters in the basin. The calibration and validation of the model was completed by using observed flow data from four stations in the study area and different criteria, namely coefficient of determination (R^2), Nash-Sutcliffe Efficiency and percent bias. For the final part, the consequent model results will be analyzed in terms of water balance at daily scales in the entire study area and will be compared to model runs using climate change projection data to evaluate the possible impacts from modeled climate change. Furthermore, scenario analysis that includes scenarios with changes in landuse, extension of aquaculture ponds will also be evaluated.

Soil Water Assessment Tool (SWAT)

SWAT is a continuous physically based distributed river basin model used in simulating the water quality and quantity of surface as well as groundwater (Lévesque, et al., 2008). The model can predict the impacts of land use, land management practices and climate change on water availability. The major components of the model include climate, hydrology, soil temperature and properties, plant growth, nutrients, pesticides, bacteria and pathogens, land management, and channel and reservoir routing (Bharati, et al., 2019) Arnold et al. 2012).

The model divides a basin into sub-basins, each connected by a stream channel. The model further divides sub-basins into Hydrological Response Units (HRUs), the smallest spatial unit of the model, based on a homogeneous combination of soil, land use and slope. The model simulates hydrology, vegetation growth and management practices at the HRU level. As plant growth and the movement of sediments, nutrients, etc., is significantly impacted by water balance, all the processes in SWAT are driven by it (Arnold, et al., 12). SWAT simulates the hydrological cycle based on the following water balance equation:

$$SW_t = SW_o + \sum_{i=1}^{n}(R_{day} - Q_{surf} - E_a - w_{seep} - Q_{gw})$$

where,

SW_t	: final soil water content (mm)
SW_o	: initial soil water content (mm)
t	: time (days)
R_{day}	: precipitation amount on day i (mm)
Q_{surf}	: amount of surface runoff on day i (mm)
E_a	: amount of evapotranspiration on day i (mm)
w_{seep}	: amount of percolation on day i (mm)
Q_{gw}	: amount of return flow on day i (mm)

The disaggregation of the basin into sub-basins facilitates the model to reflect variations in evapotranspiration for various soils and crops as the model maintains a continuous water balance. Therefore, the model predicts runoff for each sub-basin, which are later combined to generate the total runoff for the entire basin. This also increases the accuracy of the model and subsequently provides a more detailed physical description of the water balance. More information on the model and its processes can be found in Arnold et al. (2012).

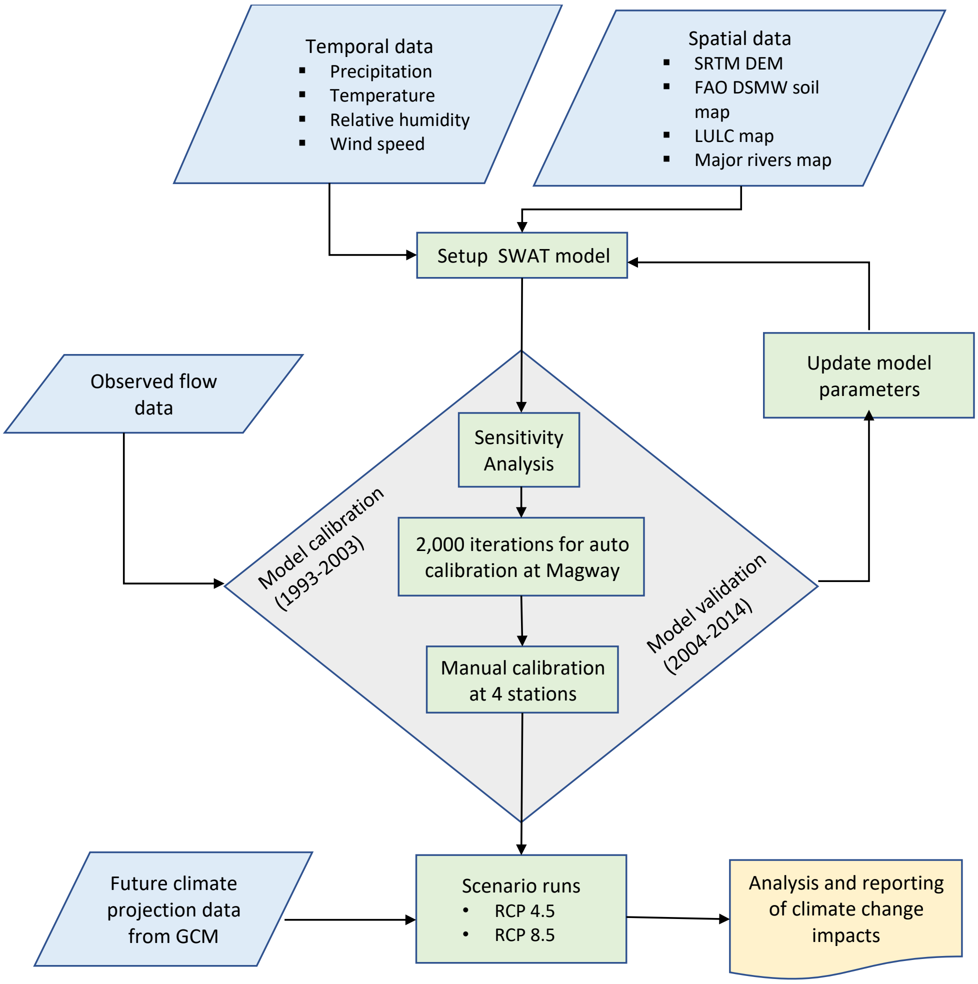


Figure 2. Methodological framework for this study.

Sensitivity analysis

After setting up the model (Year 1), the most sensitive parameters were identified. The SWAT Calibration and Uncertainty Program (SWAT-CUP) developed by the Swiss Federal Institute of Aquatic Science and Technology was used for sensitivity analysis. SWAT-CUP is a widely used tool for sensitivity analysis of parameters and automatic calibration of the model (Ghimire, et al., 2020). In total, 25 parameters were selected for the sensitivity analysis based on expert knowledge and results from similar studies. The most sensitive parameters with p-value less than 0.2 are shown Table 2. The model was run for 1,000 iterations using observed data from gauging station at Katha (outlet of 7th subbasin).

Table 2 The ranking of sensitive parameters.

Rank	Parameter	Description
1	GW_DELAY	Groundwater delay time (days)
2	CN2	Initial SCS runoff curve number for moisture condition II.
3	CH_K2	Effective hydraulic conductivity in the main channel alluvium (mm/hr)
4	OV_N	Manning's roughness coefficient for overland flow.
5	SURLAG	Surface runoff lag coefficient.
6	ALPHA_BF	Deep aquifer percolation fraction
7	GWQMN	Threshold depth of water in the shallow aquifer required for return flow to occur (mm H_2O)

Model calibration

The model is calibrated for the period 1994 to 2000 and validated for the period 2002 to 2008. This period was selected because flow data for this period was more complete and it matched the land cover map chosen for the basin. More importantly, these periods also represent the pristine condition of the river basin where human interventions in the forms of dams and reservoirs have not resulted in considerable alterations in the hydrology of the basin. Four stations namely Katha, Monywa, Sagaing and Magway are used for the calibration and validation process whose location is depicted in Figure 3.

The results from initial model run depicted that the model is satisfactorily predicting the low flows but overestimating the high flows. This is considered to be the effects of dams and reservoirs constructed in the river basin over the analysis period. To remedy this effect, the number of dams, their capacity to retain water and the flows they regulated were considered and introduced into the model. Reservoirs were added in the sub-basins 1, 7, 9, 12, 13, 15, 17, 18, 19 and 20. The model was fine-tuned using auto calibration in SWAT CUP while providing a reasonable value range for all the sensitive parameters and other parameters identified from previous studies. However, given the large size of the basin and the difficulties in fitting the parameters for the entire basin based on discharge from one gauging station, the simulated and observed hydrographs were not similar for all the outlets after auto calibration. This was followed up by manual calibration. The calibration process was based on three criteria: Nash-Sutcliffe Efficiency (NSE), the coefficient of determination (R2) and percent bias (PBIAS).

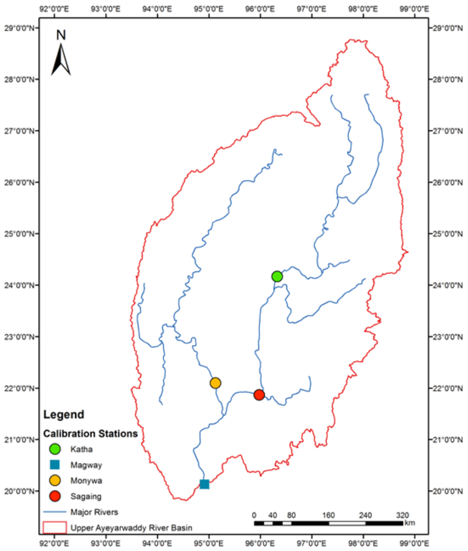


Figure 3 Location of calibration and validation stations.

Manual calibration was done using the daily flow data from four stations: Katha, Sagaing, Monywa and Magway. To include the spatial heterogeneity of the river basin in the model, it was found rational to calibrate the major tributaries of the Ayeyarwaddy river independently. In the manual calibration process, firstly, parameters identified in the sensitivity analysis for Magway as the most sensitive parameters, as described above, were adjusted and subsequently changes were made to least sensitive parameters. For some stations, additional hydrological parameters not identified in the sensitivity analysis were adjusted for better model performance. Table 3 highlights the selected parameters for this study along with their initial value/range and fitted value/range for two stations.

Table 3 List of parameters, their initial value and final value for Katha and Monywa

Station	Parameter	Initial value	Final value
Katha	A_CN2.mgt	73 – 89	30 – 36.6
	V_ALPHA_BF.gw	0.048	0.41
	V_GW_DELAY.gw	31	78.8
	V_GWQMN.gw	1000	549.7
	V_GW_REVAP.gw	0.02	0.14
	V_REVAPMN.gw	750	349.4
	V_CH_N2.rte	0.014	0.16
	V_CH_K2.rte	0	136.9
	R_SOL_AWC.sol	0.01 – 0.17	0.01 – 0.18
	V_SURLAG.bsn	4	8.7
	V_CANMX.hru	0	0.71
	R_OV_N.hru	0.01 – 0.15	0.10-0.20
Monywa	A_CN2.mgt	73 – 89	83 - 96
	V_ALPHA_BF.gw	0.048	0.14
	V_GW_DELAY.gw	31	14.55
	V_GWQMN.gw	1000	741
	V_GW_REVAP.gw	0.02	0.15
	V_REVAPMN.gw	750	807
	V_CH_N2.rte	0.014	0.061
	V_CH_K2.rte	0	82.1
	R_SOL_AWC.sol	0.06 – 0.18	0.07 – 0.20
	V_CANMX.hru	0	0.4
	R_OV_N.hru	0.01 – 0.15	0.15 – 0.22

Because the use of initial SWAT-estimated parameters mostly overestimated the high flows in all cases, the curve number CN_2 was majorly responsible for decreasing the peak flows. The soil available water (SOL_AWC) and soil evaporation compensation factor (ESCO) parameters were also responsible to decrease the peak flows, although the latter was not very sensitive. This was further complemented by adjusting the baseflow parameters. It is to be noted that, in Myanmar, the majority of rainfall precipitates in the rainy season between May to October owing to Southwest monsoon. In the remaining months, the baseflow is sustained by groundwater recharge during the monsoon period. The baseflow alpha factor (ALPHA_BF), groundwater delay time (GW_DELAY), threshold depth of water in the shallow aquifer required for return flow to occur (GWQMN), groundwater “revap” or percolation coefficient (GW_REVAP) and the threshold depth of water in the shallow aquifer for percolation to the deep aquifer to occur (REVAPMN) were all adjusted to match the simulated values with the observed flows. Subsequently, the Manning’s roughness coefficient for the main channel (CH_N2) along with effective hydraulic conductivity in main channel alluvium (CH_K2) were adjusted for better performance of the model. Meanwhile, the plant uptake compensation factor (EPCO) and Manning’s roughness coefficient for overland flow (OV_N) were also adjusted. As elevation bands were used in the model in sub-basins where the elevation difference exceeded 500 meters, precipitation lapse rate (PLAPS) and temperature lapse rate (TLAPS) had a significant role to play in those sub-basins. The value of PLAPS and TLAPS was estimated empirically and set to -470 mm/km and -5.8 oC/km based on the precipitation and temperature data from observed stations.

After the model was deemed to be performing satisfactorily in the calibration period, the model was validated for a different period, i.e., 2002 to 2008, using the same sets of parameters obtained during calibration. The primary aim of the validation was to measure the robustness of the model. Table 4 shows the daily statistics of calibration and validation, respectively, and Figure 4 shows the observed and simulated hydrographs at the five gauging stations. Overall, the model performed satisfactorily. The NSE values are above 0.60 for all stations except for the calibration period in Monywa. The model simulation improves in the lower part of the basin as can be seen from the figure and statistics obtained at Magway.

Table 4 Daily calibration and validation statistics assessing the model performance at five hydrologic stations.

Station	**Index**	**Calibration**	**Validation**
Katha	NSE	0.65	0.63
	R^2	0.54	0.56
	PBIAS	-4.16	-4.51
Sagaing	NSE	0.74	0.61
	R^2	0.74	0.50
	PBIAS	3.74	-22.21
Monywa	NSE	0.59	0.72
	R^2	0.57	0.53
	PBIAS	31.57	16.62
Magway	NSE	0.78	0.79
	R^2	0.78	0.80
	PBIAS	6.56	1.89

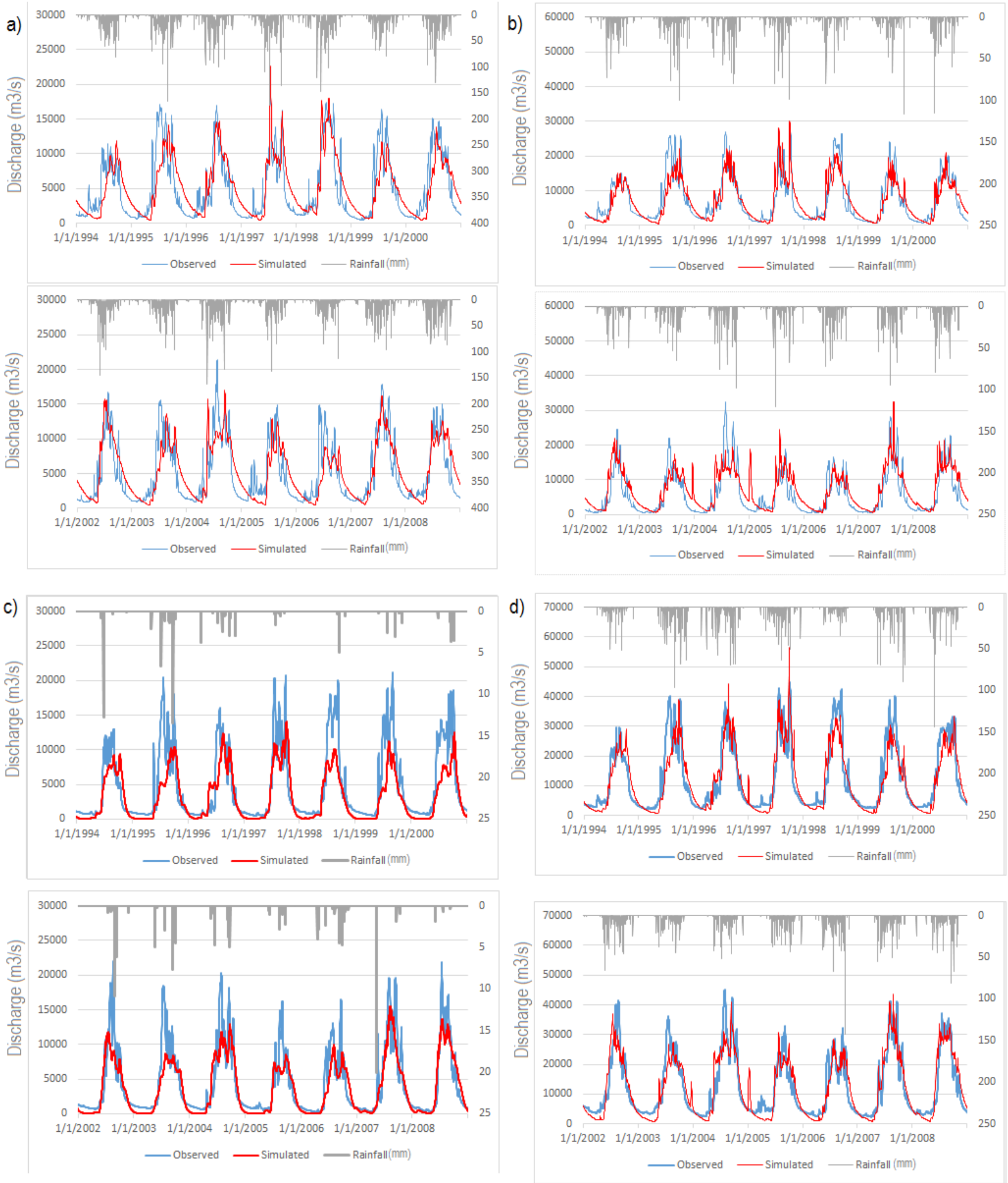


Figure 4 Observed and simulated flows at: a) Katha, b) Sagaing, c) Monywa and d) Magway

Water Balance Results

Temporal Distribution of Water Balance Components

After the calibration and validation process, the model was run from 1986 to 2015 with the first two years (1986 – 1987) set up as warm-up period. Four hydrological components were considered for the analysis: precipitation, actual evapotranspiration (ET), net water yield and the change in storage (Δ storage). Net water yield is determined collectively by snowmelt, surface runoff, baseflow and lateral flow. Hence, it does not always follow the pattern of precipitation and is also affected by various other elements like rainfall intensity, soil properties, and land cover characteristics. Likewise, the change in storage is a collective term that takes into account groundwater recharge, change in soil moisture storage in the vadose zone and model inaccuracies.

For the 28 years of simulation (1988 – 2015), the average annual precipitation for the entire basin was 1,249.7 mm. Likewise, actual ET and net water yield of the entire basin for the simulation were 186.2 mm and 1,037.8 mm respectively. However, huge variations exist in these components when analysed temporally (Figure 5) and spatially (Figure 8). The monthly water balance in Figure 5 highlights the prevalence of a strong monsoon (May to October) season that contains over 90% of the precipitation and flow. In line with expectations, actual ET is also high in this period and low during the winter (November to February) and summer seasons (March to April). Water yield follows similar trend as actual ET with high values in the monsoon season, moderate in November to December and low in the remaining period. High values of Δ storage from May to August suggests high groundwater recharge during the monsoon which ultimately contributes in the groundwater flow and in the baseflow during the dry periods. Likewise, a decreasing trend of Δ storage in the remaining months is evidently illustrated in the graph. The driest month is December with an average monthly precipitation of 4.08 mm. In contrast, July is the wettest month with average monthly rainfall of 265.88 mm. The mean seasonal distribution of rainfall is 1,178.91 mm, 34.85 mm and 35.85 mm for monsoon (May to October), winter (November to February) and summer (March to April) seasons respectively. Similarly, the mean seasonal distribution of actual ET is 126.73 mm, 29.78 mm and 29.63 mm for monsoon, winter and summer seasons respectively. Similarly, water yield varies from 857.67 mm, 149.34 mm and 30.7 for monsoon, winter and summer seasons respectively.

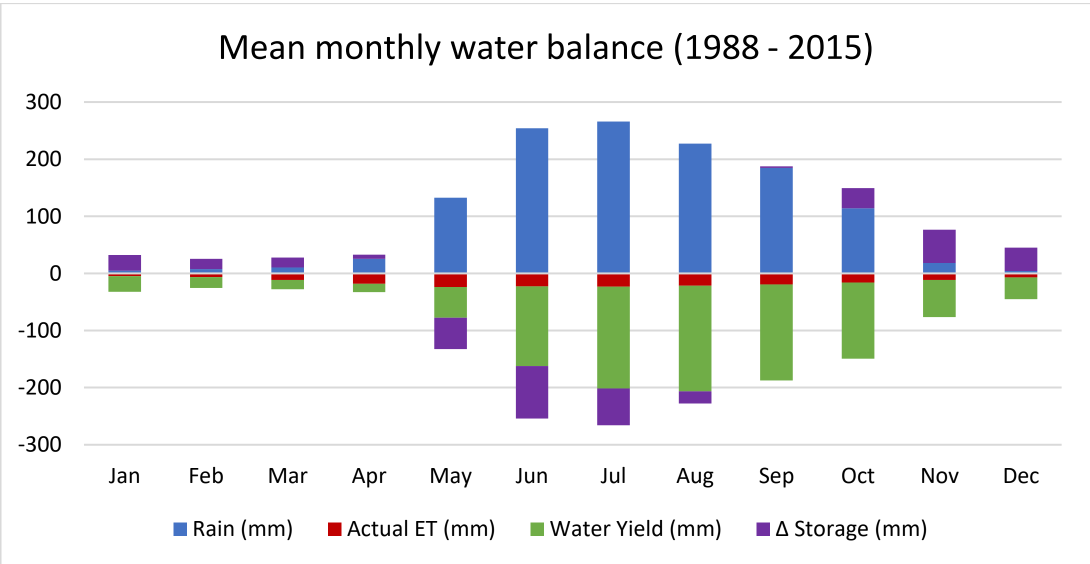


Figure 5 Mean monthly water balance (1988 – 2015).

Spatial Distribution of Water Balance Components

Figures 6, 7 and 8 illustrates the spatial variation of precipitation, actual ET and total water yield over the entire basin for the reference period 1988 – 2015. The precipitation and net water yield are highest in the mountainous region in the North and gradually decrease downstream. The lowermost sub-basins with average annual precipitation of 13 – 500 mm represent the Central Dry Zone of Myanmar, which is also the most water-stressed region in Myanmar. The actual ET values depend largely on rainfall, land cover and temperature, and were found to be on the higher side in the northern region with forest cover and also in some agriculture zones. As expected, these regions also witness high rainfall compared to other downstream regions. The maximum precipitation (2,322 mm) was seen in the Northernmost mountainous region which borders China, and the minimum precipitation (13 mm) was observed in Monywa which lies in the Central Dry Zone. Actual ET was highest in the Southeastern region (516 mm) and lowest (12 mm) in the central region. Water yield was found to be the highest (2,040 mm) in the Northernmost region which also had the highest precipitation, and the lowest (0.5 mm) in the central region which also had the lowest mean annual precipitation.

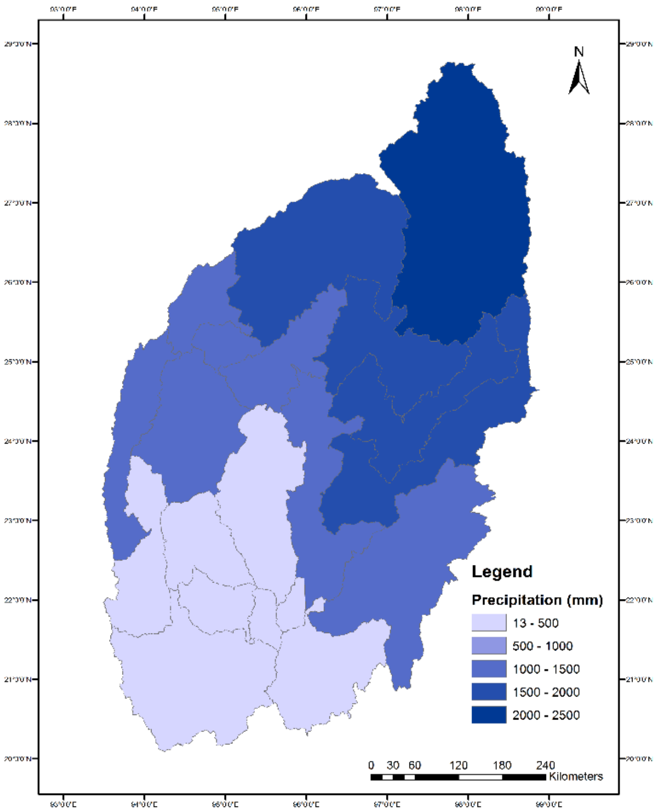
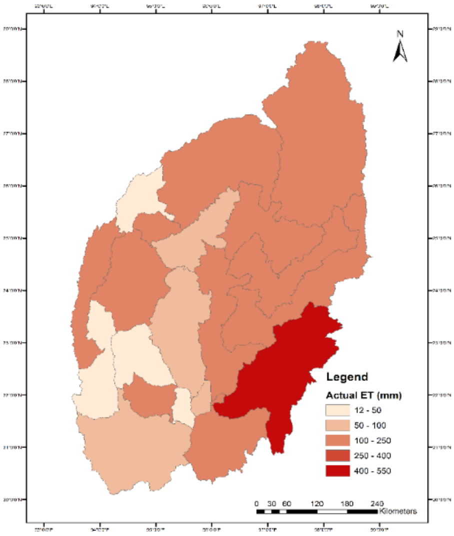


Figure 6 Spatial distribution of annual average precipitation.



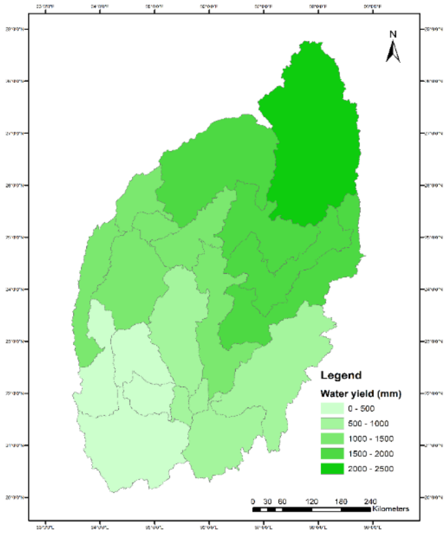


Figure 7 Spatial distribution of annual average actual evapotranspiration

Figure 8 Spatial distribution of annual average net water yield.

Annex 6: Climate change analysis—assess the impact on water resource availability and timing, and predict water availability.

Climate variables such as precipitation, minimum and maximum temperature have severe impacts on ecosystem and infrastructure related to aquaculture. Therefore, assessment on climate change was conducted to determine expected extreme conditions of temperature and duration of precipitation in the future. Future scenarios namely RCP4.5 and RCP8.5 were selected for analysis. The following tasks were completed:

1. Statistical downscaling of climate data from 11 RCM projections followed by building an ensemble mean of project data for climate variables namely precipitation, minimum and maximum temperature.
2. Changes in precipitation and temperature values are assessed for three timeframes such as near future (2030s), mid-future (2050s) and far future (2080s) under both RCP scenarios.
3. Trend analysis is undertaken for various climate indices.

Statistical downscaling

Station-based downscaling was applied using quantile mapping method (Thrasher, et al., 2012) using the observed data from HIC for precipitation, minimum and maximum temperatures. Figure 9 shows the locations of stations with observed data (28 stations for precipitation and 18 stations for temperature). Figure 10 and Table 5Table *5 Locations of stations used in the study in central dryzone, north east hilly region and delta region.* show the regional segregation of the stations into central dryzone, north east hilly region and delta region. Table 6 lists 11 RCM projections used in this study. The downscaled datasets are re-assessed using metrics such as Pearson's correlation coefficients, standard deviation, centred root mean square error as shown in the Taylor diagram (Figure 11). RCM results namely MOHC_EAS, NIMR, SMHI_SEA and IPSL_SEA were disregarded as they were outliers. An ensemble was built by averaging timeseries data of precipitation, minimum and maximum temperatures for the historical period, and both RCP4.5 and RCP8.5 scenarios. In Figure 12, a 20-day moving average is applied to the aerially averaged monthly precipitation, across the historical period of 1986-2006 for all chosen RMCs and compared with observed data (Figure 12). The ensemble precipitation mean encompasses the seasonal characteristics of pre-monsoon, monsoon, and post-monsoon adequately. Therefore, the ensemble mean from chosen RMCs has a close resemblance with the observed data from the historical period.

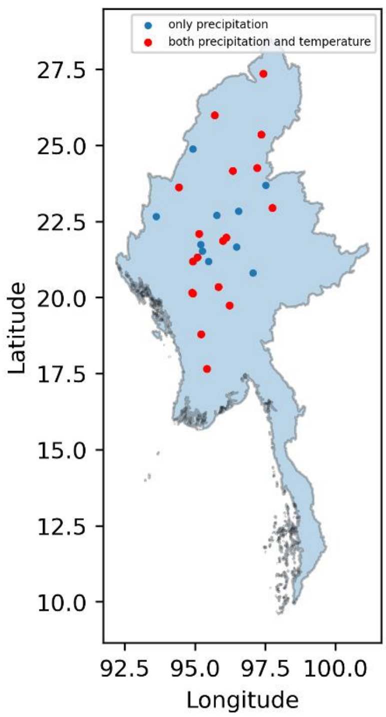


Figure 9 Map of stations used in the study.

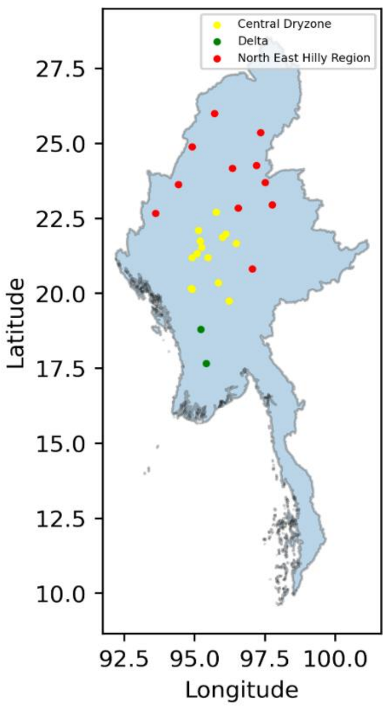


Figure 10 Regional segregation of stations into central dryzone (yellow), north east hilly region (red) and delta region (green).

Table 5 Locations of stations used in the study in central dryzone, north east hilly region and delta region.

Region	Stations	Lat	Long
Central Dryzone	Ywatha	22.714581	95.764069
	Mandalay	21.983000	96.100000
	Sagaing	21.867000	95.983000
	Yeywa Hydropower station	21.674325	96.474425
	Monywa	22.100000	95.133000
	Mahu	21.745119	95.197510
	Chit Thu	21.533000	95.250000
	Ayartaw	21.199539	95.469940
	Nyaung Oo	21.200000	94.917000
	Pakokku	21.333000	95.083000
	Meitktila	20.359720	95.833330
	Pyinmana	19.743330	96.216670
	Minbu	20.167000	94.883000
	Magway	20.133000	94.917000
Northern and Eastern hilly region	Mawlaik	23.633000	94.417000
	Hkha	22.675830	93.616670
	Hkamti	26.000000	95.700000
	Homalin	24.892780	94.916670

Region	Stations	Lat	Long
	Myitkyina	25.367000	97.350000
	Katha	24.167000	96.333000
	Bhamo	24.267000	97.200000
	Shweli 1 Hydropower Station	23.698133	97.506472
	Lashio	22.960000	97.750000
	Kyauk Talone	22.841190	96.548721
	Taunggyi	20.810280	97.050000
Delta region	Pyay	18.800000	95.217000
	Hinthada	17.667000	95.417000

Table 6 List of RCMs used (SEA = South East Asian, EAS = East Asian)

No.	GCM	RCM	Institute	Domain	Abbreviation
1	ICHEC-EC-EARTH	RegCM4-3	RU-CORE	SEA	ICHEC_SEA
2	IPSL-IPSL-CM5A-LR	RegCM4-4	RU-CORE	SEA	IPSL_SEA
3	MOHC-HadGEM2-ES	RegCM4-5	RU-CORE	SEA	MOHC_SEA
4	MPI-M-MPI-ESM-MR	RegCM4-6	RU-CORE	SEA	MPI_SEA
5	NOAA-GFDL-GFDL-ESM2M	RegCM4-7	RU-CORE	SEA	NOAA_SEA
6	MOHC-HadGEM2-ES	RCA4	SMHI	SEA	SMHI_SEA
7	ICHEC-EC-EARTH	HIRHAM5	DMI	EAS	DMI_ICHEC_EA
8	CNRM-CERFACS-CNRM-CM5	CCLM5-0-2	CLMcom	EAS	CNRM_EAS
9	MOHC-HadGEM2-ES	CCLM5-0-4	CLMcom	EAS	MOHC_EAS
10	MPI-M-MPI-ESM-LR	CCLM5-0-5	CLMcom	EAS	MPI_EAS
11	HadGEM3-AO	RMP	NIMR	EAS	NIMR

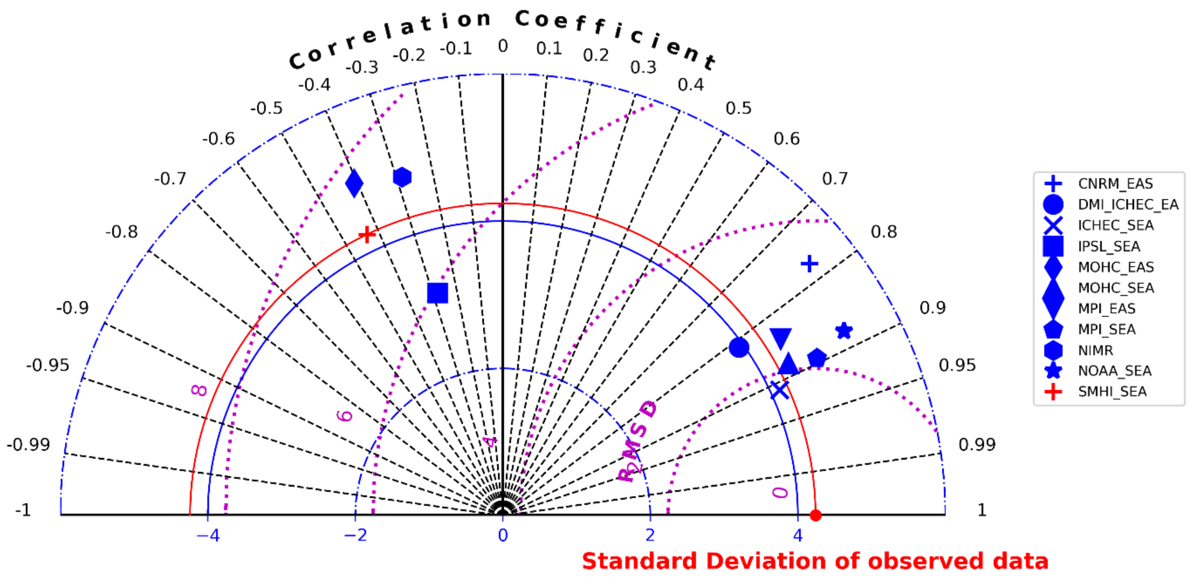


Figure 11 Taylor diagram showing the performance of RCM models based on centred root mean square error (RMSD), standard deviation, and correlation coefficient.

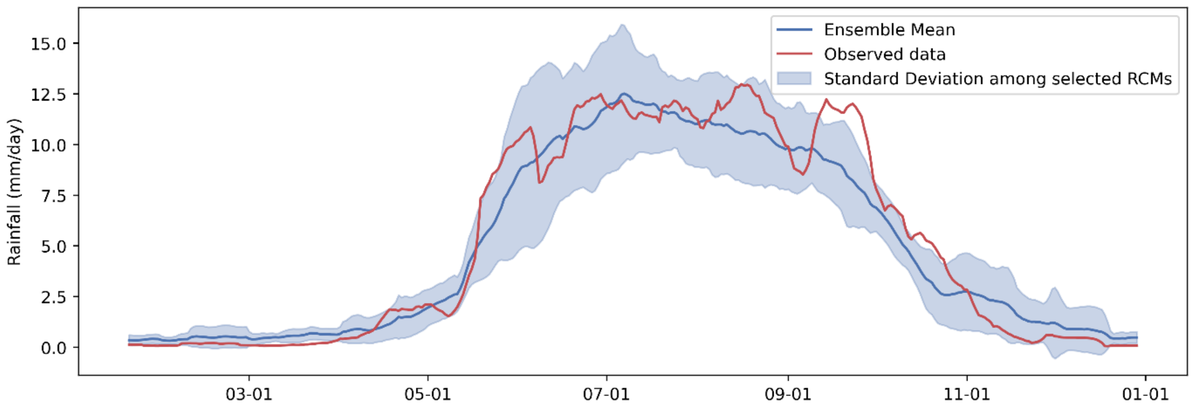


Figure 12 Similarity of seasonal characteristics of 7 RCMs.

Assessment of changes in precipitation and temperature

Changes in seasonal characteristics derived from aerially averaged monthly precipitation derived for the period of 2020-2097 for the whole country, central dryzone, North East hilly region and Delta were assessed for both RCP4.5 and RCP8.5 scenarios against historical precipitation (Figure 13). Both RCP4.5 and RCP8.5 shows less rainfall for pre-monsoon (i.e., around May) and post-monsoon (i.e., around September) for all regions. The central dryzone is projected to have significantly less rainfall than the historical period during mid-monsoon season (i.e., from July to September) for both RCP4.5 and RCP8.5 scenarios. Changes in precipitation against changes in both maximum and minimum temperatures were assessed (Figure 14). Each point represents the average change against historical mean for a particular timeframe. The colors represent three different timeframes namely 2030s (2020-2045), 2050s (2046-2070) and 2080s (2071-2097). In general, all the regions are projected to experience an increase in both minimum and maximum temperature. Most of the projections show decreasing rainfall for central dryzone while the opposite phenomena is observed for the north east hilly region.

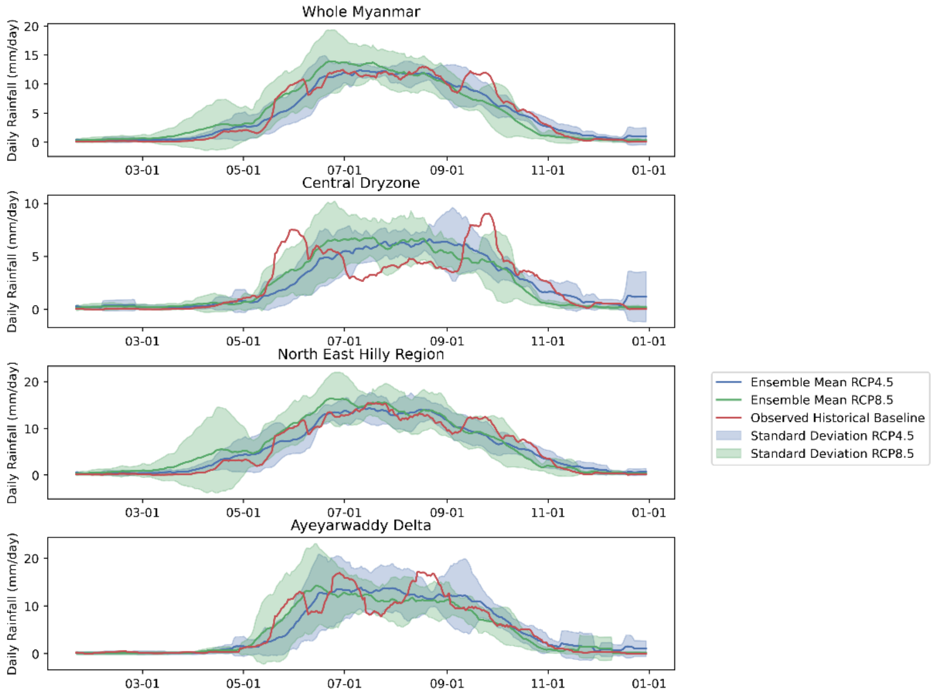


Figure 13 Changes in seasonal characteristics of precipitation for each region.

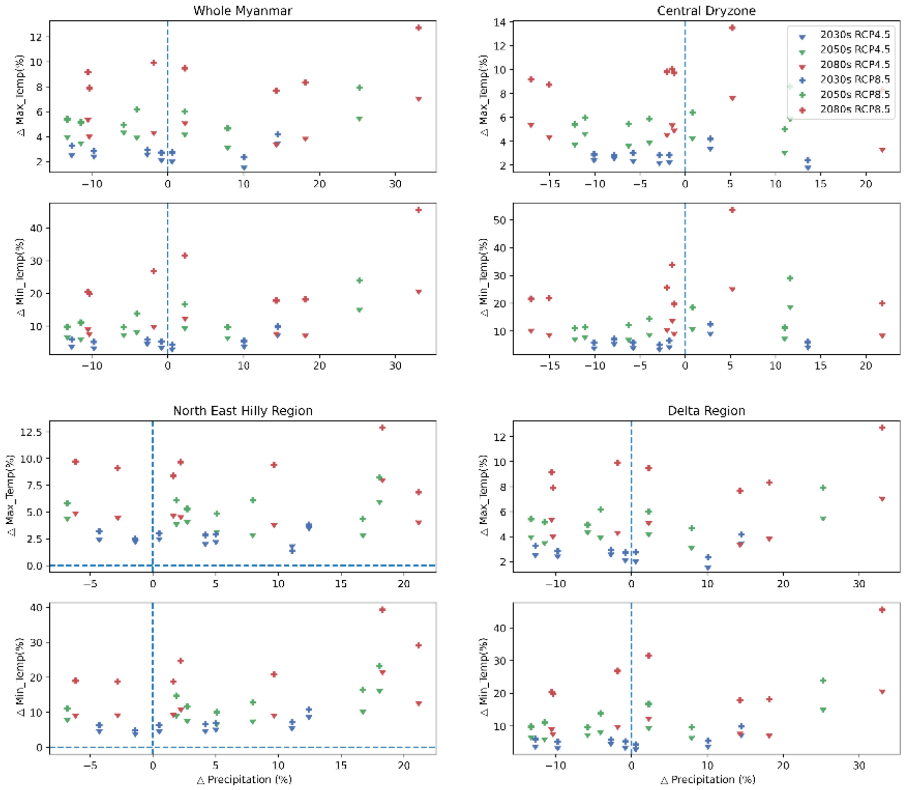


Figure 14 Percentage change in temperature vs precipitation.

Climate indices

Precipitation

Typical climate indices (Alexander & Herold, 2016) were assessed for all regions for both RCP4.5 and RCP8.5 projections against historical data shown in Table 7. Monthly indices such as cdd, cwd, sdii, txx and tnn were averaged across the projection period (2020-2097) for each month and compared against historical data.

Changes in precipitation-related indices

All regions are projected to have more continuous dry days under future RCP4.5 and RCP8.5 scenarios (Figure 15). Only the North East hilly region has increasing projections of monthly mean precipitation across the period of 2020-2097 compared to historical monthly mean precipitation (Figure 17). Furthermore, the simple precipitation intensity index is higher than in the historical period for all regions, indicating the increasing intensity of rainfall (Figure 18).

Table 7 Explanation of climate indices assessed in this study.

Index	Meaning
R1mm	Annual count of days when PRCP ≥ 1mm (Annual counts of wet days)
R5mm	Annual count of days when PRCP ≥ 5mm
R10mm	Annual count of days when PRCP ≥ 10mm
R20mm	Annual count of days when PRCP ≥ 20mm
cwd	Maximum length of wet spell: maximum number of consecutive days with RR ≥ 1mm
cdd	Maximum length of dry spell: maximum number of consecutive days with RR < 1mm
sdii	Simple precipitation intensity index (Ratio of total precipitation of period to the number of wet days)
txx	Monthly maximum value of daily maximum temperature
tnn	Monthly minimum value of daily minimum temperature
SU (Hot days)	Number of summer days (days with temperature greater than 30 ℃)
TR (Warm night)	Number of tropical nights (night time temperature greater than 25 ℃)

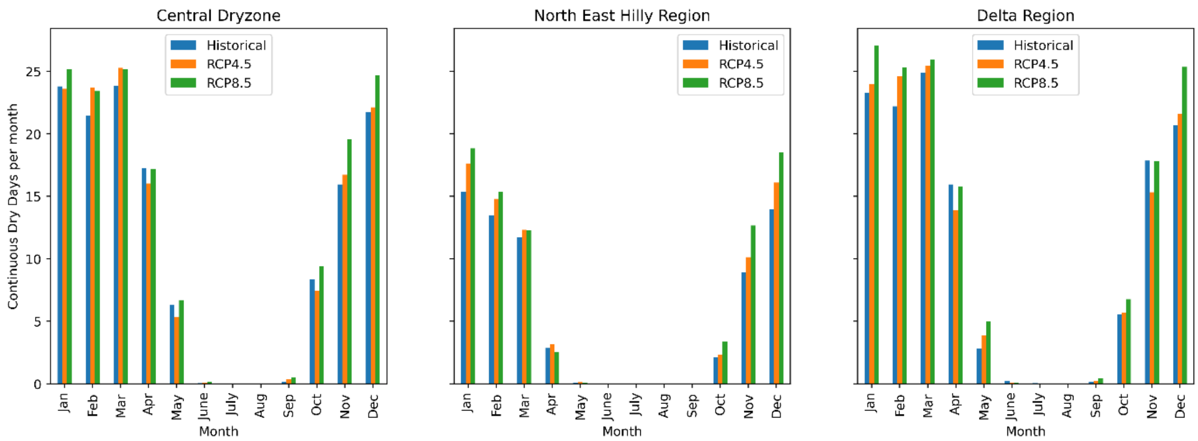


Figure 15 Continuous dry days for each month for each region.

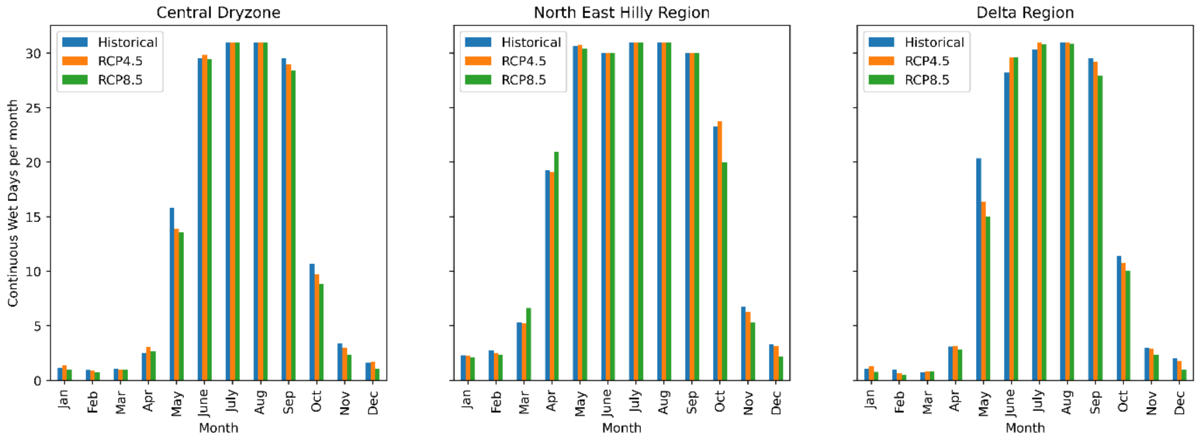


Figure 16 Continuous wet days for each month for each region.

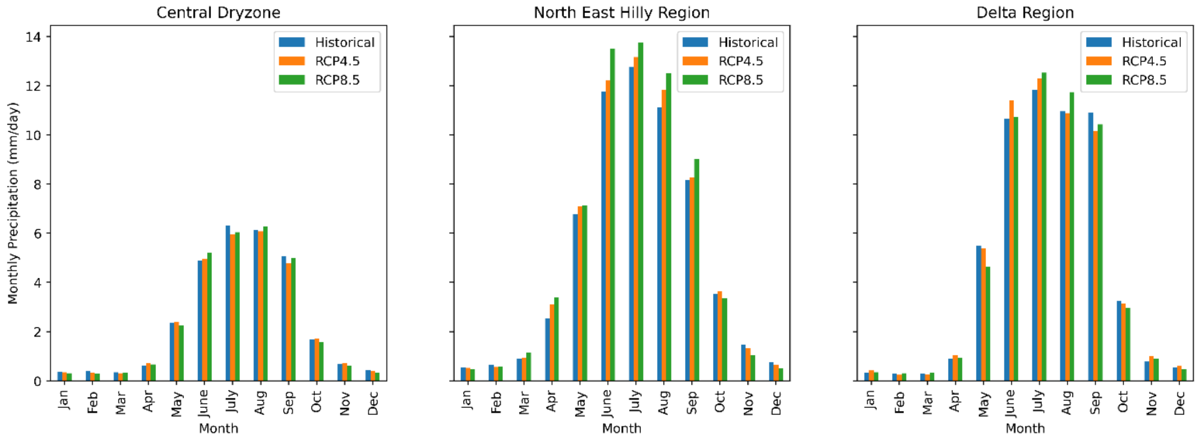


Figure 17 Monthly precipitation for each month for each region.

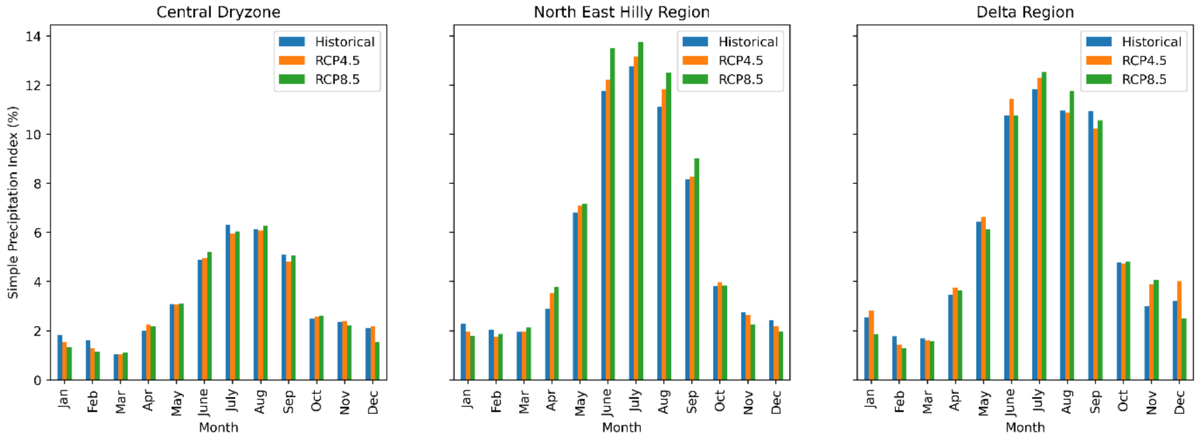


Figure 18 Simple precipitation intensity index

Temperature

Climate indices related to temperature such as monthly maximum temperature (txx) and monthly minimum temperature (tnn) were assessed for all regions (Figure 19 and Figure 20). Central dryzone generally has the highest values of both txx and tnn while the north east hilly region has the lowest values for each month. For both RCP scenarios, all the regions have higher txx and tnn than the historical data for every month.

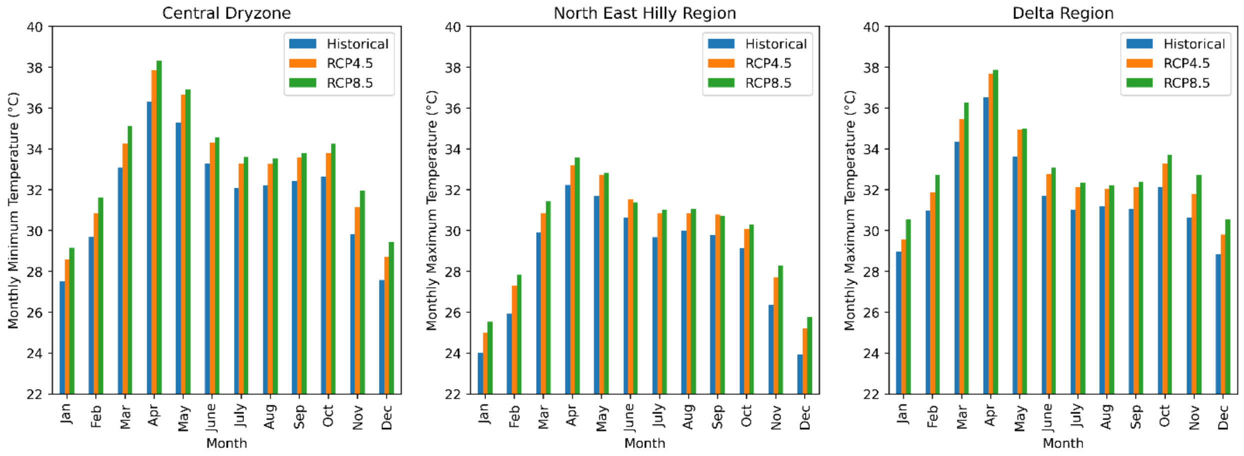


Figure 19 Changes in minimum values of daily minimum temperature in a month for each region.

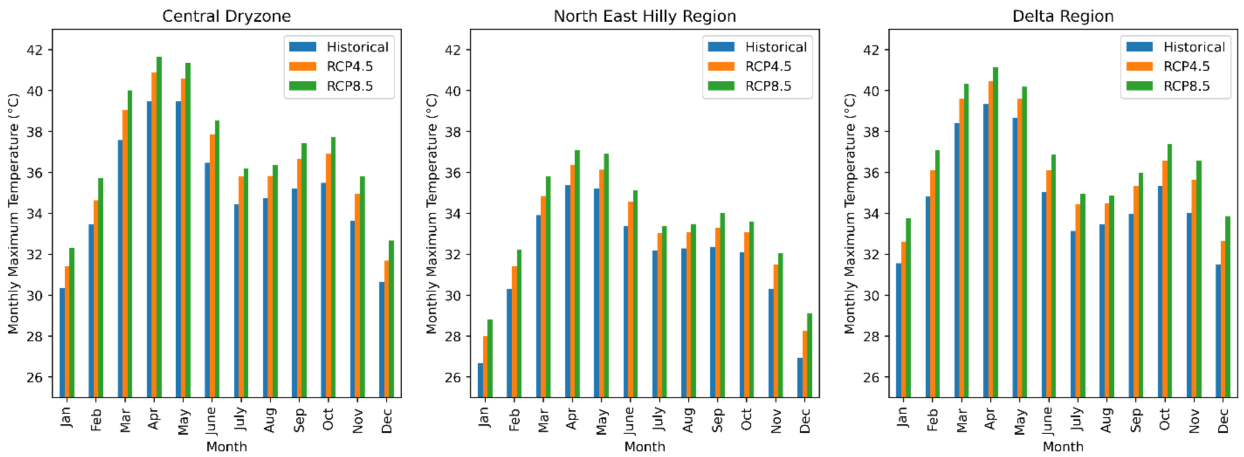


Figure 20 Changes in minimum values of daily minimum temperature in a month for each region.

Other indices

Figure 21 shows the changes in remaining year-based indices related to both precipitation and temperature in comparison with historical data. Such year-based indices are averaged across the period of 2020-2097 for the future period and 1986-2006 for the historical period. The north east hilly region has larger number of wet days with all levels of rainfall (i.e., R1mm, R5mm, R10mm, R20mm) while the central dryzone has the least number of wet days for both RCPs. The north east hilly region also has larger count of days with heavy rainfall (i.e. R10mm and R20mm). The central dryzone has the highest number of warm nights and hot days in a year. All the regions show increased number of warm nights an hot days under both future RCP scenarios.

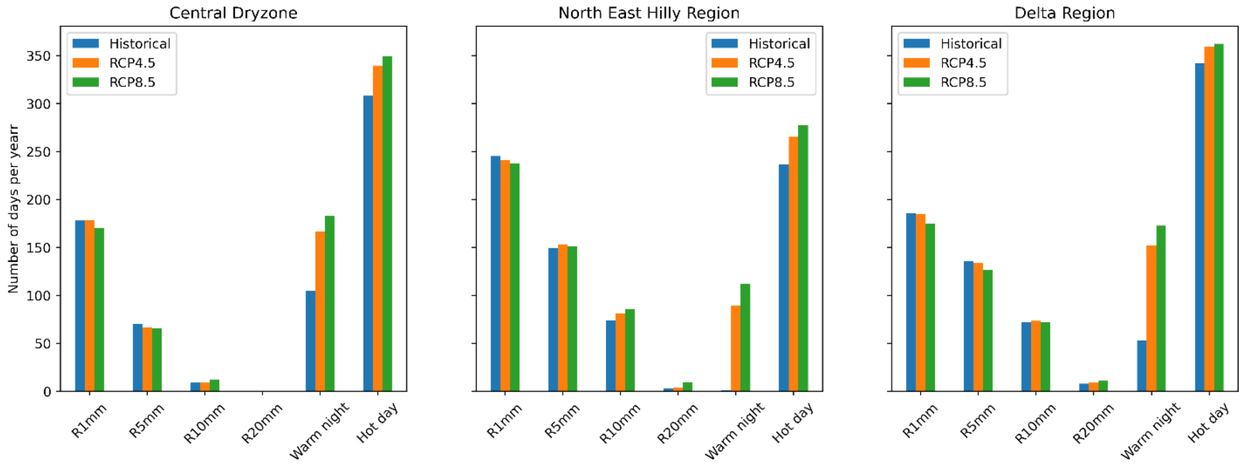


Figure 21 Changes in year-based climate indices related to both precipitation and temperature for each region.

Trend analysis

Precipitation

Modified Mann-Kendall test (Hamed & Rao, 1998) was applied to the timeseries of the annual total precipitation for the period of 2006-2097 under both RCP scenarios with 95% confidence. The resulting linear regression equations were assessed in each sub-figure with associated Sen's slope. Double asterisks indicate that the trend for a particular rainfall timeseries is significantly increasing or decreasing. Overall, the central dryzone has the least annual total precipitation while the north east hilly region has the highest precipitation among the regions. Although RCP8.5 projection shows decreasing precipitation (negative slope), the significance test fails to hypothesize that there is such trend at the level of 95% confidence (Figure 22). The remaining regions show increasing trend in precipitation by Hamed test for both RCP scenarios. The highest rate of increase in precipitation was observed under RCP8.5 in the north east hilly region.

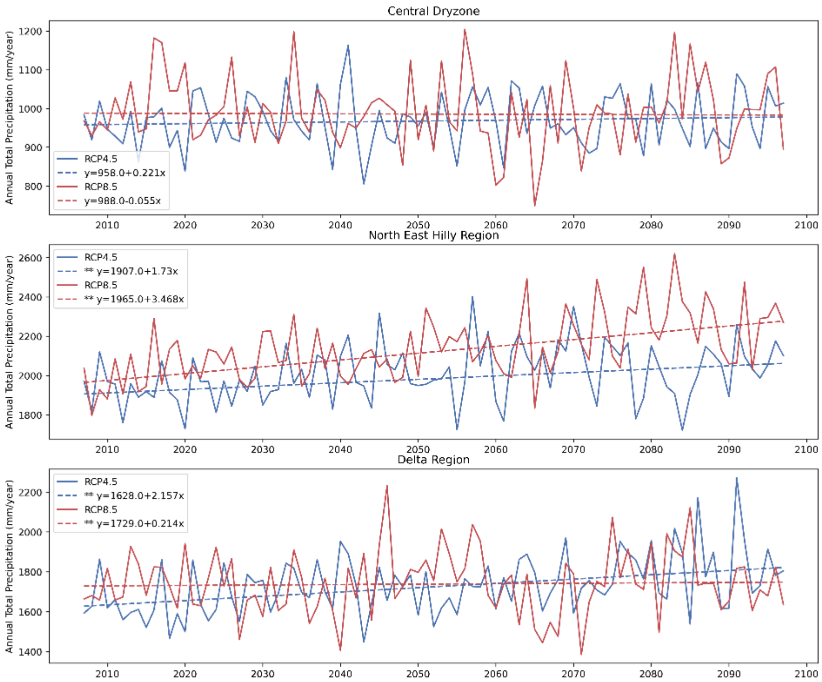


Figure 22 Trend in annual total precipitation for RCP4.5 and RCP8.5 for each region.

Temperature

The Modified Mann-Kendall test (Hamed & Rao, 1998) was applied to the annual mean timeseries of minimum and maximum temperatures for all regions. Both RCP scenarios show increasing trend of minimum and maximum temperatures at the significant level. The central dryzone has the highest rate of increase in minimum temperature at 0.075 ℃ per year for RCP8.5 and at 0.03 ℃ per year for RCP4.5 (Figure 23). The same phenomenon is observed for maximum temperature with the central dryzone having the highest rate of increase at 0.018 ℃ per year for RCP4.5 and at 0.042 ℃ per year for RCP8.5 (Figure 24). In addition to the regions, significant tests were applied for each station. Under RCP4.5, most of the stations show no significant trend in precipitation while all the stations show significant trends for minimum and maximum temperature. Under RCP8.5, the number of stations with increasing trend in precipitation increases especially in the north east hilly region although most of stations show no significant trend. All the stations show increasing trend for both minimum and maximum temperature under RCP8.5 scenario, as shown in Figure 25.

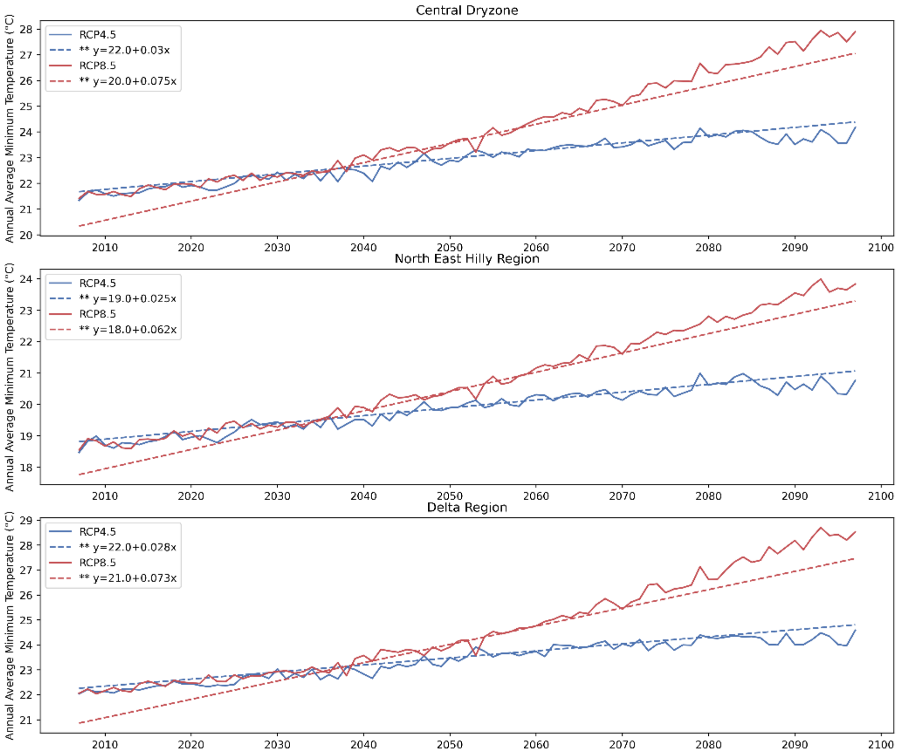


Figure 23 Trend in annual minimum temperature for RCP4.5 and RCP8.5 for each region.

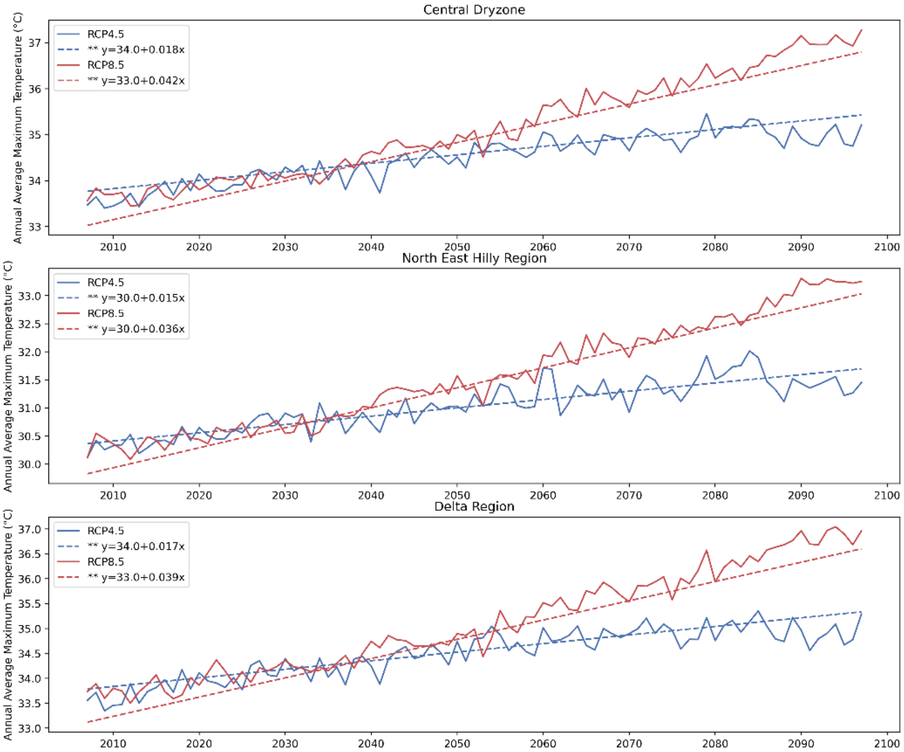


Figure 24 Trend in annual maximum temperature for RCP4.5 and RCP8.5 for each region.

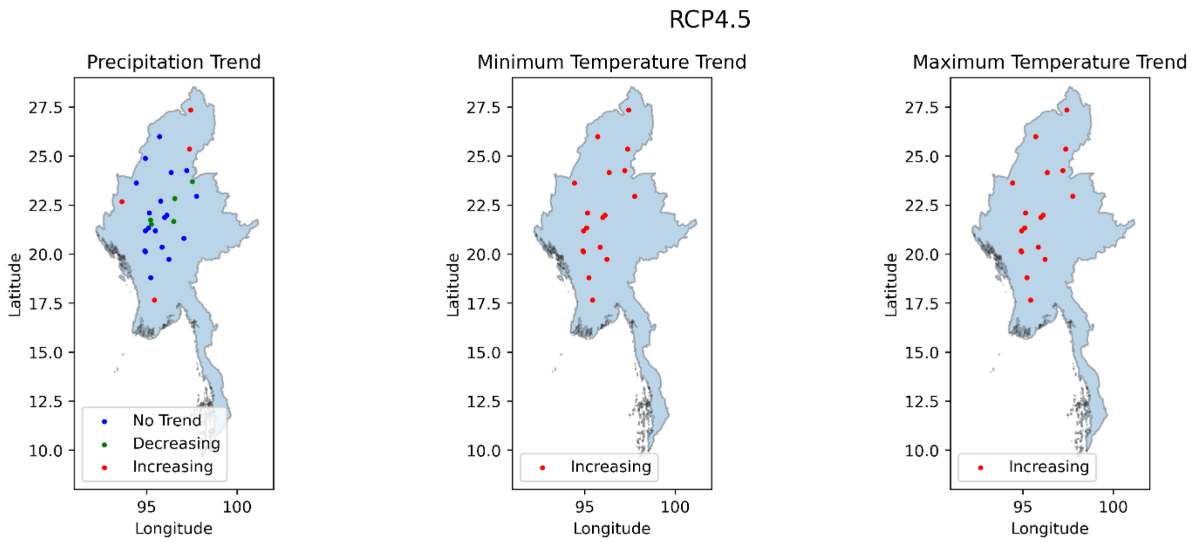


Figure 25 Spatial representation of results of trend tests for annual precipitation, minimum and maximum temperature for each station.

Annex 7: An evaluation of the policy and regulatory landscape in Myanmar in terms of the interface between water-land and fisheries (including small-scale aquaculture).

Objectives

This literature-based evaluation of the policy and regulatory landscape in Myanmar focusses on the interface between water-land and fisheries (including small-scale aquaculture), seeking to understand key challenges and opportunities for supporting Myanmar achieve its policy objectives around building more diverse, integrated and nutritious food systems for rural food security, poverty reduction and improved health through nutrition.

Methodology

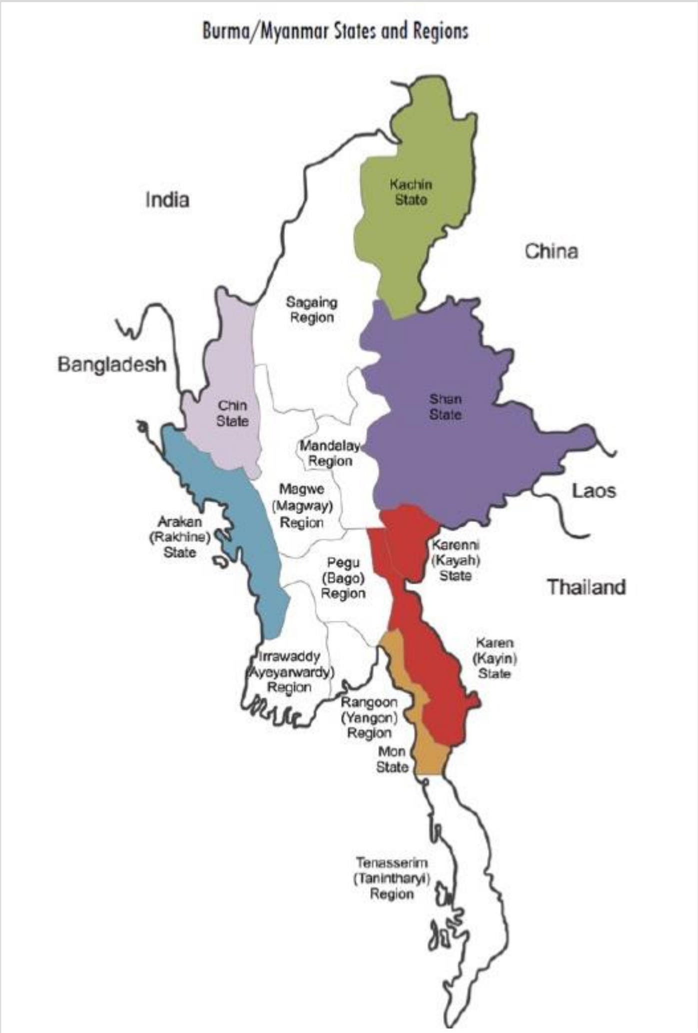
This review is based solely on a reading of relevant policies, strategies, legislation and secondary literature sourced through bibliographic searches; Google and Google Scholar, and the professional networks of IWMI and WorldFish.

The organization of the review, and hence structure of the report, begins with the overall governance structure in Myanmar, as defined by the country's constitution, with particular attention to the distribution of decision making and administrative authority between the Union level (center) and the States/Provinces as part of Myanmar's partial decentralization. This helps situate decision making regarding fisheries and land and water management at their respective levels of authority. This is followed by an analysis of the policy and regulatory landscapes in terms of how fish (freshwater capture and aquaculture) is positioned within overarching development goals, and within a range of sectors intersecting with water and land management. These include agriculture more broadly; water resources management (including irrigation); land management; energy and transport, with the important inclusion of health, given its links to nutrition and hence food systems. Section 5 deals with the critical issue of cross-sectoral coordination, because even where fish, water and land are well reflected sectorally, mechanisms are needed to ensure that these sectoral visions mesh through holistic decision making.

Division of powers under the 2008 Constitution

The Republic of the Union of Myanmar comprises seven States and seven Regions (Figure 26), six self-administered zones and divisions, and one Union territory containing the capital Nay Pyi Taw and surrounding townships. States and Regions are the same entities under the Constitution, the difference in terms only reflecting the distinction between areas where non-Burmese ethnic groups are the majority (e.g., Shan State) and majority Burmese Regions.

States and regions are governed by a partially elected *hluttaw*, an executive body led by a Chief Minister, a Cabinet of Ministers, and judicial institutions. Hluttaws are empowered to enact laws on topics specified by the Constitution in Schedule Two of the Region/State Hluttaw Legislative List. These include agriculture and freshwater fisheries, but does not include water resources or irrigation more specifically. Hluttaws are required to prepare a regional development plan outlining local priorities (Nixon, et al., 2013).



Source: The Border Consortium

Figure 26 Burma/Myanmar States and Regions

Hluttaws are empowered to establish administrative organizations and appoint personnel[1]; can submit a Region/State Budget Bill to Union (central) government based on the annual Union Budget[2], and collect taxes and revenue listed in Schedule Five[3]. These include land revenue; water tax and embankment tax based on dams and reservoirs managed by the Region or State. These sub-national governments can therefore participate in and influence the preparation of the national budget. Beginning with the 2012-13 fiscal year, regions and states have had separate budgets from the Union, though these budgets continue to rely heavily on significant budget transfers from the Union budget (Nixon et al. 2013).

Since agriculture and freshwater fisheries come under the purview of states/provinces, auctions of licenses to raise fish in natural ponds; tenders for fishing rights in inland waterways; fees collection for freshwater fishing equipment, and licensing of existing artificial fishing ponds are all managed by the state/province. Licenses for freshwater fisheries need to be approved only by the Region/State government. In fact, license fees from auctions are the single largest revenue source in some Regions/States (Stokke and Aung. 2019). This has important implications for how inland fisheries are structured, managed and accessed by rural households, as reflected in current leasable fishery practices, where rent seeking precludes small-scale fishers from competing with wealthy operators (Khin, et al., 2020). In addition to being out-bidded by wealthy operators, that fact that for most auction licenses, the fee must be paid in advance before any income is earned, is a challenge for many small fisheries operators businesses in credit-poor rural conditions.

The autonomy states/regions enjoy however is limited by the fact that the Chief Minister of each Region/State is appointed by the President of Myanmar, and the appointment of Region/State ministers is largely in the hands of the Chief Minister (Nixon et al. 2013;). Although the 2008 Constitution, creates state/region parliaments/governments, real decision-making power vests with the Chief Minister (Stokke and Aung. 2019) who is responsible for signing laws submitted by the state/region Hluttaw and

[1] Article 257 of the Constitution
[2] Article 252 of the Constitution
[3] Article 254 of the Constitution

takes a leading role in determining policy across cabinet portfolios (Nixon et al. 2013). Furthermore, state/region Chief Justices are nominated by the president, in consultation with the Chief Justice of the Union, while all courts are subordinate to the national Supreme Court, which has final appellate authority over other levels.

Consequently, even though sates/regions may have legislative autonomy over some subjects including freshwater fisheries and agriculture, disputes over interpretations of these rules will be finally adjudicated on at the Union level (Nixon et al. 2013). This is important given the possibility of deviations between Union and states/regions on agricultural and inland fishery policy. It is for example conceivable that some states/regions may embrace the progressive agriculture sector policies, whilst such change may be slower to emerge at the Union level. In other words, the powers and responsibilities granted to state/region are limited, and the executive responsible for implementing them is ultimately accountable to the President, not to the state/region Hluttaw. Moreover, even where state/region level functions are concerned, because the heads of ministry offices at the state/region level are still part of a Union ministry hierarchy, Union ministers still see themselves as having control over their whole ministry. This is particularly the case with agencies not listed in Schedule Two in the Constitution, which remain directed by, and accountable to, their corresponding Union ministry (Nixon et al. 2013). The limited nature of devolution of powers is further evident through the position and powers of the General Administration Division (GAD), which controls Myanmar's vertical subnational state structure below the state/region level. The District Administrator who supervises the townships is a GAD officer. It is at the township level that many key functions of government take place including land registration, and most forms of tax collection – they are the building blocks of administration in Myanmar. The GAD collects most of the taxes at the township level (Nixon et al. 2013), and convenes weekly township-level interdepartmental meetings.

As noted by Stokke and Aung (2019), this partial decentralisation has especially important natural resource management (NRM) implications, in particular for many ethnic states that are resource rich but remain under centralized administration. Policy making in Myanmar therefore remains typically centralized and top-down, reflecting a long legacy of military decision-making structures.

Many departments linked to NRM such as the Department for Rural Development (DRD), Department of Agriculture (DoA), and Department of Forestry (DoF), are linked closely to Union level, and the degree to which these are involved at sub-national levels varies. For example, in the Ayeyarwaddy Region, the DoF has an important township-level role because of the importance of fishing in that region (Stokke and Aung. 2019). This Department governs fishery activities, including offshore fishing, inland fishing, and aquaculture. It oversees a licensing regime that requires separate permissions and payments for numerous different aspects of the fishing process. This licensing regime is the source of most revenue for the Department, and its administration is the Department's primary responsibility (Stokke and Aung. 2019). This therefore requires coordination within each state/region which have authority over fisheries under Schedule 2 of the Constitution. For these responsibilities, the DoF offices at state/region level can establish their own rules and regulations for licensing and auctions, which some have done – see the Ayeyarwaddy Freshwater Fisheries Law 2018 in Section 3.

Fish, Water and Land in the policy and regulatory environments

Food system diversification emerges as a key pillar in especially rural development policy with strong alignment between overarching development and food sector policies and strategies.

Natural resources are the property of the state according to the Constitution of 2008. Their governance is nested within several overarching development policies and strategies. According to the Rural Development Strategic Framework (RDSF, 2014), ensuring households are able to meet their food and nutrition needs, and increase incomes by 30% - 50% are central in overall development policy. Similarly, the National Comprehensive Development Plan (NCDP, 2011), which consists of four five-year plans and guides all national development planning including long-term reforms, seeks to increase incomes and living standards of rural households who have inadequate access to food, nutrition and essential non-food items, and suffer from micronutrient deficiencies.

The agriculture sector as a whole is considered a primary driver of poverty reduction, in addition to its role in assuring food security. The Framework for Economic and Social Reform (FESR, 2012) for example, emphasizes the development of rural small-scale productivity, while according to the Myanmar Agriculture Development Strategy and Action Pan (ADS, 2018-19 - 2022-23), inclusion, nutrition and sustainability form part of the overall vision for the agriculture sector, with agricultural growth representing the best way out of poverty. The National Economic Strategy (NES, 2016) meanwhile calls for an economic model that balances agriculture and industry, and supports the holistic development of the agriculture, livestock and industrial sectors, to enable rounded development, food security, and increased exports.

The ADS explicitly envisages an agricultural system contributing to the socio-economic wellbeing of farmers and rural people, with higher and more equitable income for rural households and strengthened farmers' rights. It thus aims to increase landless households' income by 40-45%, and smallholder farmers' income by 50-60%, viewing them as core drivers of growth, and acknowledges that smallholder farmers' rights to land, food, information, and voice in planning, decision making, and implementation should be recognized formally by law. Fisheries is seen as an important element in diversification away from an excessive focus on rice, to rice-based farming systems that will encompass a range of non-paddy options depending on location. It further notes that land titling independent of the conditional growing of specific crops, especially those land classified as paddy lands is of particular relevance if such a transition to mixed food systems is to occur. A more flexible land classification/use approach would also ensure that seasonal loans from the Myanmar Agricultural Development Bank (MADB) can be accessed for cropping, livestock or fisheries. The ADS proposes further steps including Agro-ecological Zoning based on specific production/farming systems suitability analysis for combinations of crops, livestock, fresh water fish ponds and shrimps farming.

Specific actions in the fisheries sector include Development of a new Fisheries Law; the identification, inventory and fishery resource conservation of adaptable fish species, and the provision of fishing infrastructure. In the aquaculture sub-sector, initiatives are to include the integration of land development and cage and pen technology with existing ponds or reservoirs under appropriate legal frameworks, and the restructuring and expansion of aquaculture seedling infrastructure for the production and distribution of fish and shrimp seed, including its privatization where appropriate. These provisions appear to align with the National Sustainable Development Strategy (NSDS, 2019), which recognises the nutritional and ecological importance of the resource, observing that as a national commodity, fish are largely untapped and calls for rice-fish integrated cultivation to double outputs.

The emergence of nutrition more squarely into the framing of development priorities is notable, intensifying the impetus for expanding historically rice-centric food strategies. The Myanmar Sustainable Development Plan (MSDP, 2018)recognizes the need to enhance household-level food security by tackling the root causes of food insecurity and under-nutrition through increased and diversified domestic food production. The Multi-Sectoral National Plan of Action on Nutrition (MS-NPAN, 2018) articulates the links between several health issues afflicting especially rural women and young children (malnutrition, stunting, anemia) to micronutrient deficiencies, noting also that maternal and child undernutrition is most prevalent among the poor. To have the greatest impact, the MS-NPAN focuses on improving the nutritional well-being of the most vulnerable groups, identifying diversified food production and supply of nutrient-dense crops, fish and animal-based foods by integrating these into mixed farming systems as a key need. It specifically identifies the need to demonstrate the feasibility of small-scale aquaculture models for the increased local production of fish. Like the ADS, the MS-NPAN also calls for increased productivity and for a land use framework that supports more flexible and diversified land use. Not surprisingly given this alignment between the ADS and NS-NPAN, the later sees the ADS as a key vehicle for meeting national nutritional goals.

Agricultural diversification focusing on smallholder households is also a key adaptive strategy under the Myanmar Climate Change Strategy and Action Plan (MCCSAP) 2016–2030 (MoNREC, 2017), linking diversification to the need to adopt climate-smart agriculture, fisheries and livestock for rural food security by 2030. It considers this sector as a high priority for Myanmar to reach Sustainable

Development Goals (SDGs) 1 (end poverty), and 2 (end hunger, achieve food security and improved nutrition and promote sustainable agriculture). Outcomes in the agriculture sector are also linked to SDG 5 (gender equality), while sustainable natural resources management is mapped to SDG 6 (sustainable water management). Meanwhile, the National Wetland Policy and Strategic Actions (2019) recognizes that inland wetlands are important breeding sites for freshwater fish, and that if such wetland ecosystems are lost, fish production, food security, and export earnings would also decrease significantly.

The bent towards commercial food systems in pursuit of productivity and export revenue may relegate the focus on smallholders to rhetoric.

A central tension in the policy landscape appears to be the desire to use agriculture to alleviate rural (especially small-holder and landless) poverty and food insecurity on the one hand, while also supporting export-oriented growth. This dichotomy is perhaps best illustrated where the ADS, which seeks a 50% increase in land productivity[4], proposes that accelerated agricultural growth involving a transition from subsistence to commercial farming represents the best way out of poverty. This tension is explicitly recognized by the FESR which notes that of particular importance will be how to allocate and ensure equitable and sustainable use of land resources among stakeholders including smallholders and large private companies, while maintaining agriculture (including livestock and fisheries) as a means of poverty reduction. The FESR thus calls for a balance between small-scale producers and larger enterprises in how these sectors are developed. This attempt to balance smallholder interests with raising productivity in the food sector is also evident in the MSDP, which envisages private sector led growth in the agriculture sector including aquaculture, while also seeking to empower rural communities to initiate locally-generated and inclusive development initiatives, calling for strengthening rural households' land tenure and, property rights - a key obstacle to small-holder investments as will be explained below.

This dissonance assumes a more concrete form in the NSDS, which promotes the granting of virgin, fallow and vacant land under the Vacant, Fallow and Vacant Land Act to private entrepreneurs to undertake fish culture on a commercial scale to promote the expansion of aquaculture in marine and freshwater environments. Similarly, private entrepreneurs are to be allowed to operate some leasable fisheries in three-year cycles, which is currently the case. Although these measures are in addition to introducing freshwater fingerlings into reservoirs, rivers, lakes, streams, etc., to support capture fisheries, the NSDS specifically recommends that "(*f)ishery production from fish and prawn cultivation should be paid more attention than fishing from the natural sources*" (Forestry, 2009). Further evidence for a bias towards commercial fisheries include performance indicators focusing on total fish production and fishery exports, while none exist to monitor household fish consumption. However, an important consideration shaping this smallholder-commercial tension is the consideration that capture fisheries in fact cannot be sustainable, and in fact needs to be supplemented with production from aquaculture. As such, this could be seen as a pragmatic strategy on the part of the State. This does not however negate the risks for smallholders inherent in this strategy, where prime land (and water) resources will be diverted to commercial operations. Moreover, one may also argue that the need for commercial operations has less to do with alleviating rural poverty, being aligned to generating export revenues. Such concerns have been voices for example by Tsamenyi (2011) who believes that the Freshwater Fisheries Law (1991) appears to be designed primarily to provide a framework for commercial exploitation of fisheries, with few responsible fisheries principles such as conservation and social considerations as its objectives. Overall therefore, the central question remains how land and water resources will be identified for commercial activities, given the common pool resource characteristics of inland fisheries, and the critical role of these resources in smallholder-based food system diversification. Failure to resolve this question will mean that actions on the ground are unlikely to address the distributary aspect within fisheries (and agriculture at large), and will thus undermine the roles fisheries is expected to play in rural poverty reduction and food and nutrition security.

Climate change adaptation and a focus on rice exports may exacerbate irrigation-fish trade-offs unless irrigation is re-imagined.

[4] The Government is acutely aware that productivity remains below regional averages.

The ADS notes, most public investment in agriculture has focused on irrigation infrastructure, particularly the construction of dams, reservoirs, and main canal systems to provide surface irrigation for rice production, although water supply remains uncertain for many farmers. In the Ayeyarwady Delta in particular where rice and fish make major contributions to national diets, poldering to simultaneously minimize flood damage and make more land available for cropping have also contributed to the alteration of freshwater flows and hence the productivity of freshwater fisheries (e.g. Arulingam et al. In prep). Investments in irrigation are set to continue if not increase, given it is a key adaptive strategy under the MCCSAP in reducing production risks in an increasingly variable climate environment, and will need to fuel the ADS's focus on rice exports. In fact, according to the ADS, 53.84% of the total donor investments between 2016 and 2022 to be channeled for rehabilitating existing irrigation infrastructure and new irrigation[5], while the share to the fisheries sub-sector is only 13.53%. Given that the MS-NPAN views the ADS as a key vehicle for delivering more nutrient rich food systems, this balance between rice and diversification assumes even greater significance. What is of concern from a fisheries and smallholder and landless household perspective, is the lack of recognition of the trade-offs this will involve within the food sector itself.

Since this trend is likely to continue beyond 2022, it appears paramount that the irrigation sector is engaged to explore opportunities for not merely minimizing trade-offs, but exploring the feasibility of promoting more multi-functional infrastructure by including fish as a legitimate water user within irrigation systems, and maintaining water and habitat connectivity (McCartney, et al., 2019).

Despite this dichotomy between increasing irrigation and potential impacts on fisheries, the overall policy landscape sets the scene for a shift to more diverse food systems, through the focus on increased productivity and the emphasis on more nutrient dense food. The importance of this shift in terms of the opportunities it creates for engaging decision makers and planners to address long-standing cross-sectoral conflicts should not be under-estimated.

A closer look at fisheries

Agriculture, livestock and fisheries account for nearly 30% of Myanmar's Gross National Product (GDP) and about 56% of employment. By volume, fish is second to rice in its contribution to the Myanmar diet and may be the most important source of protein (ADS). This sector is regulated primarily under the Freshwater Fisheries Law (FFL) of 1991, complemented by the Law Relating to Aquaculture of 1989 (Aquaculture Law). The FFL is applicable to freshwater fisheries waters, which include the waters, ponds, courses, rivers, streams and lakes of permanent or temporary nature. The FFL defines "Fish" as "all aquatic organisms living the whole or a part of their life cycles in the water, their spawns, larvae fry's and seeds. Under the FFL, freshwater fisheries is administered through two systems: i) leases (to be purchased through a system of competitive bidding during an auction) and ii) licenses, both to be issued at the township level.

According to Tsamenyi (2011), many of its provisions simply carry forward the philosophy from the 1905 and earlier fisheries legislation, and consequently, many of the objectives and provisions of the law are out of date. The Department of Fisheries is responsible for administering the FFL, including fishing licenses and leases. From the operation of Schedules One and Two of the 2008 Constitution, the Aquaculture Law comes under the legislative competence of the Union legislature, meaning the states and regions unable to draft their own arrangements in this regard, whilst the FFL has been devolved to the regions (World Bank, 2019b). The FFL on the other hand, comes under the legislative competence of the states and regions. However, the States and regions generally lack the expertise and resources to effectively manage fisheries on their own (Tsamenyi 2011).

MS-NPAN calls for considering the feasibility of small-scale aquaculture models that would serve local needs. The MCCSAP recognizes that particularly small-scale fisheries are a crucial source of livelihood and income for millions of people, and promotes capacity building for community aquaculture as an adaptive strategy to broaden production options. Under the Aquaculture Law, a lease is required from DoF to carry out aquaculture on aquaculture land, fisheries waters[6], or in reserved fisheries waters. According to the Aquaculture law, the DoF has the authority to demarcate and reserve land for

[5] New irrigation infrastructure accounts for 5.6% of the total allocation for irrigation.
[6] Waters in which fishing is permitted with restrictions.

aquaculture from agricultural and waste lands, in accordance with the existing Land Law. The Director General of the DoF may lease such land, for a period of not more than 10 years, so long as at least 75 percent of the leased land will be developed into pond surface area. While this may appear geared to large-scale operations, it is not clear whether it is possible to also apportion smaller parcels of land to landless households in particular. In fact, under the Aquaculture Law, any person who has obtained a lease to carry out aquaculture on land designated for that purpose, or in fisheries waters, can apply to the DoF for an aquaculture license.

Aquaculture in one pond with a water surface area of 25 ft. x 50 ft. (1,250 sq. feet) operated by a family for family consumption is exempted from the requirement to obtain a license, although not from the land use restrictions under the Farmland Law as described in section 4.3. Use of this provision to promote rice-fish (RF) or pond culture by smallholders is also limited by the seeming prohibition to sell any part of the produce, although it will promote improved household nutrition. Moreover, small-scale aquaculture is constrained by restrictive land use rules under the farmland Law, which prevents the small-scale conversion of paddy land to fish culture.

Land use rules remain prohibitive to diversified and integrated food production, and is thus a fundamental constraint.

The government is the ultimate owner of all natural resources including land in the country under Article 37 of the 2008 Constitution. This means that only land use property rights may be granted, and that the government reserves the power to rescind these rights. The remit of those rights has increased, particularly in recent years as the rights became officially transferrable and eligible for mortgaging in 2011 (Raitzer, et al., 2015). Four land use categories currently operate in Myanmar: i) agricultural land (e.g. paddy, other crops, gardens, seasonally flooded land, etc.); ii) non-agricultural land (mining, pasture land, roads and railways, etc.); iii) forest land, and iv) virgin, fallow, and vacant land. The land use category determines what government body is responsible for the management of that land (World Fish, 2018)

Land use in Myanmar is governed mainly through the Farmland Law (2012) and the Vacant, Fallow and Virgin Lands Management Law (VFVLML) of 2012[7], and from a rice-fish and small-scale aquaculture perspective, the former remains a significant obstacle by restricting the freedom households have over land use decisions. This situation is embedded in the need for a Land Use Certificate (LUC) under the farmland Law, which only gives farmers permission to grow specific crops, with unauthorized changes potentially resulting in land confiscation[8] – a serious deterrent to farmers who wish to either convert to another crop, fish or a combination thereof. This is compounded by considerable uncertainty regarding tenure in the past due to poor documentation of rights, leaving room for rights to be revoked by the authorities at any time with little compensation to farmers. While the Farmland Law now provides farmers land use rights certificates which can be mortgaged, sold and transferred, Raitzer et al. (2015) believe that poor implementation continues tenure insecurity. Part of this uncertainty arises from unclear definitions of land classifications as well as outdated mapping of such lands. This can result in the alienation of land from customary rights holders who do not qualify to secure their land under the Farmland Law. Moreover, the Land Acquisition Act (1894) provides for land to be legally confiscated in the ‘national interest’ and seized without due process or compensation.

This situation also undermines adaptation to climatic and other drivers of agro-ecological change – a key meta narrative shaping food systems. Moreover, the Farmland Law defines “farmer” as a person who is involved in agriculture or livestock breeding or both by using the land as his main livelihood, but does not mention fish production/aquaculture. Non-agricultural uses are prohibited, and because the definition appears to exclude fisheries, this would appear to prohibit any fishery/culture activities without permission (this needs to be verified).

Furthermore, the Farmland Law explicitly describes paddy as “the staple crop of the State” (s.28), and where self-sufficiency of rice is the dominant agricultural concern of the State. The majority of farmland

[7] Along with the Law Amending the Vacant, Fallow and Virgin Lands Management Law (2018) and the Vacant, Fallow and Virgin Lands Management Rules (2012).

[8] If found guilty of violation, the penalties include a monetary fine, reverting to the land use/crop type that is mentioned on the land use certificate, land confiscation. Violators can be sentenced to 6 months up to 2 years in prison and a fine ranging from MKK 300,000 to 500,000.

is thus devoted to paddy cultivation, and land allocated for rice culture must be used for that purpose, and although the law includes administrative mechanisms to request crop and land use changes, these are cumbersome, and the authorization of such requests is strongly centralized, especially for lands classified as paddy fields. Landholders wishing to convert agricultural land into fish ponds can only do so after acquiring the necessary certificates under Article 30 of the Farmland Law. Currently, it is estimated that only 31% of aquaculture ponds that have been established on agricultural lands have the required documentation (World Fish 2018)[9]. However, under the decentralized government arrangements, state/region authorities can decree land use change as long as such modification leads to improved productivity and profitability for those farming the land, though this proviso needs to be verified.

The VFVLML is a mechanism by which citizens, private sector investors, government entities and NGOs may lease vacant, fallow and virgin (VFV) lands. "Vacant land and Fallow land" means land that was used for agriculture or livestock breeding in the past and abandoned by the farmer. "Virgin land" includes forest reserves, grazing grounds and fishery lakes and ponds which have been legally revoked in line with this law and is not currently in use. Under this Law, agriculture, livestock breeding and aquaculture are permitted on vacant, fallow and virgin (VFV) lands. In such cases, these lands will be re-classified as farmland and be subject to the Farmland Law (s.34). This is somewhat confusing since the Farmland Law does not appear to entertain aquaculture, while the VFVLML allows for up to 1,000 acres of VFV land can be allocated for aquaculture ponds (noting also the emphasis on large-scale enterprise). VFV land can also be used for mining and any other purpose the government sees fit, which suggests that such land use can either support fishery or impede it, depending on the use allowed, and especially depending on the degree to which the land is altered from its natural state (especially with virgin land). This is recognized in the Law, which therefore requires the body reviewing applications to use such lands to coordinate with MoNREC and other concerned Ministries to conserve natural lands, watershed areas, natural lakes, ponds, etc. Nevertheless, the fact that decisions over the use of these lands need the agreement of the Myanmar Investment Commission for foreign investment, it appears that the primary use of such lands is for large scale commercial purposes, rather than by rural households. Section 10 further emphasizes the Law's focus on facilitating large scale commercial projects by indicating the possibility of using such land for commercial cultivation of perennial crops over between 300 and 3,000 acres, for a period of 30 years. A critique of this Law is that it fails to prioritize land allocation to those in rural areas with no land for livelihood purposes, but rather continues the market-oriented "Wasteland Instructions" of 1991, which enabled domestic and foreign investment in large-scale commercial agricultural enterprises, often with no recognition of customary law or actual user-rights (Oberndorf 2012). Similarly, (Franco, et al., 2015) notes that under the VFV Law, land that is not currently titled and being used is seen as a 'wasted asset'. The central government can confiscate untitled farmland as well as waterways and fishponds and reallocate them to domestic and foreign investors. As such, although the Farmland Law and the VFVLM Law were ostensibly introduced to improve tenure security for farmers, in many respects they have had the opposite effect, partly because of the onerous and poorly specified processes involved. This includes the onus on farmers to obtain the Land Use Certificates from their local Farmland Administration Body and have their land registered by the Settlement and Lands Record Department. The process of securing LUCs however remains unclear. Moreover, as noted by McCarthy (2018), even land certification may not protect land from state confiscation because the Land Acquisition Act (1894) remains in effect and the state remains the ultimate owner of all land.

It should however be noted that Section 8 in the Amendment to the Law in 2018 does recognize that landless citizens and smallholder farmers may apply to the relevant management committee in conformity with the criteria seeking a permit to carry out agricultural, livestock breeding and affiliated economic enterprises on such land. Yet again, aquaculture appears to be missing, and the extent to which this provision is practical for smallholders is unclear.

In sum, the Farmland Law and VFV Law do not appear to be line with the seemingly pro-poor, pro-smallholder and pro-diversified food systems directions on current national development policies for two key reasons. The first is the significant centralised control the state exercises over what a household can grow on their land under the farmland Law, and secondly, a seeming preference for commercial

[9] De Wit (2018) estimates that most land currently under fishponds in the Ayeyarwady were established under the 1991 Wasteland act – the predecessor of the 2012 VFV law as a FIRST FAO-EU Partnership Programme Policy Assistance Facility, and now coming under the VFV land legislation. However, an estimated 80% of the total aquaculture and rice-fish area of 500,000 acres is estimated to contravene existing land use classifications/rights and hence technically illegal, with many also therefore not obtaining the aquaculture license from DoF.

scale production especially under the VFV law, both in terms of the scale of land assigned and the definitions that could ignore traditional land uses. Also noteworthy is the seeming exclusion of aquaculture under the Farmland Law, while the VFV Law appears to provide considerable scope for aquaculture, be it at commercial scale. As such, these laws appear to add to the smallholder-commercial tension evident in the policy landscape discussed in section 4.1. This problem is moreover recognised at policy level, since the ADS and MS-NPAN both call for making land titling and land use independent of the conditional growing of specific crops, especially those land classified as paddy lands.

These two Laws also appear to fall short of the objectives and principles of the National Land Use Policy (NLUP) of 2016, which includes recognizing and protect customary land tenure rights of ethnic nationalities, and to promote people centered development, participatory decision making, responsible investment in land resources and accountable land use administration in order to support the equitable economic development. In fact, another objective of this policy is to develop an umbrella national Land Law to implement this Policy.

The Naypyitaw Integrated Rice-Fish Agreement: a first step to re-interpreting the existing Farmland Law.

This emerged out of the Rice-Fish Systems Symposium organised in August 2018 by World Fish and ACIAR. The key element of this Agreement was the encouragement by His Excellency Dr. Aung Thu, Minister MoALI, of the Departmental Directors to actively promote integrated agriculture (rice-fish-vegetables), incorporating best management practices for both rice and fish with no pesticide application. To enable this, noting the current restrictions under the Farmland Law, the Minister recommended that farmers be allowed to convert up to 15% of their rice field to a fishpond, based on the encouraging results of rice-fish field trial undertaken by WorldFish-Myanmar. Reflecting this, the Agreement also recognised that scientific research results in Myanmar and experience from neighbouring countries show that improved integrated rice-fish management practices require minimum paddy modifications and yield the same amount of rice/ha as rice-only practices, and that these production systems will maintain the national rice production targets while increasing the livelihoods of farmers and gender equitable employment opportunities, especially in marginal rice producing areas. In other words, the Agreement seems to recognize that these rice-fish systems offer a solution to the smallholder-commercial tension by both meeting gross rice production targets while enhancing smallholder incomes and food security.

To create an enabling regulatory and planning environment for rice-fish scaling, the Agreement also calls for a MoALI land use policy and legal reform working group to be established, and for the promotion of integrated rice-fish practices through their inclusion in key strategic planning documents like the MS-NPAN and contributions to achieving the Sustainable Development Goal targets in Myanmar. (De Wit, 2018) is of the view that if fully implemented, the Naypyitaw Agreement could partially overcome the need to acquire rights over land (to undertake aquaculture), although how this Agreement is to be operationalised (i.e. incorporated into the current permission system) involving the Department of Agriculture Land Management and Statistics (DALMS) is not clear, especially since integrated land use classifications do not currently exist. If the land in question is farmland, the land use right (or re-classification) is managed by the Central or Regional/State Farmland Management Committees (MoALI/DALMS) under the Farmland Law. If this land is on Vacant or Fallow land, the Central VFV Land Management Committee (MoALI/DALMS) is responsible for issuing 30-year permits (De Wit 2018). Farmers would also need to obtain an aquaculture license under the Aquaculture Law - a process administered by the Department of Fisheries at the region/state level. Consequently, farmers wishing to adopt aquaculture need to deal first with DALMS to reclassify the permitted land use, and then obtain the aquaculture license from DoF. Annex 3 to this report reproduces a table in De Wit (2018) which further details the legal issues and suggests potential remedial pathways. However, while the table in Annex 3 further explains the complexity of changing land use rights, it does so base on a rather binary agriculture or aquaculture perspective. This either/or approach may not be the most desirable for rice-fish systems such as those trialled by WorldFish, that seek to combine rice and fish, rather than replace one by the other.

Water Resources policy recognizes multiple use, but the lack of a comprehensive legal framework means default sectoral frameworks remain dominant.

According to the National Water Policy (NWP, 2014) (NWRC, 2014) Myanmar possesses 12% of Asia's freshwater resources. The MCCSAP estimates that about 90% cent of water use is agricultural, and predicts that increases in demand for water, combined with lower replenishment rates in reservoirs, rivers and groundwater sources due to a changing climate, will lead to regular freshwater shortages, especially in the CDZ, raising concerns over the impacts of climate change on food systems. Given the continued emphasis on paddy production including surpluses for export, irrigation and water storage infrastructure will continue to dominate investments in the water sector, perpetuating the dichotomy between irrigation and fisheries.

The policy and regulatory framework for the water sector consists largely of the National Water Policy; the Myanmar National Water Framework Directive (MNWFD), both developed in 2014, and mutually supportive, and the Irrigation Law enacted in 2017. The MNWFD is an umbrella statement of general principles governing the exercise of legislative and/or executive powers by the Union, the states and regions, and local governing bodies. It, along with the NWP, provides a holistic policy framework adopted by the National Water Resources Council (NWRC), which is expected to be the basis for a new holistic water law, a development for which the NWRC is responsible. The MNWFD emphasizes the principle of River Basin Management and the development of River Basin Management Plans – a departure from administrative or political boundaries, framed by Integrated Water Resources Management (IWRM) practices, also espoused by the NWP (and the ADS). This adoption of IWRM prompts the MNWFP to recognize the need for a National Water Budget to balance priorities in relation to a water-energy-food-ecosystem nexus (also highlighted by the MCCSAP), shaped also by the impacts of climate change. It also emphasizes ecological health of rivers and other aquatic ecosystems, including maintaining environmental flows and good surface and groundwater quality, assessed according to the suitability for fish, benthic invertebrates and aquatic flora.

The focus on IWRM is re-iterated in the NWP, which acknowledges the absence of a single institution responsible for the management of water resources, and that water resources projects are being planned and implemented in a fragmented manner without giving due consideration to environment sustainability and holistic benefits to people. IWRM is thus expected to usher in a holistic, inter-disciplinary and socially inclusive approach so that solving water related problems will also contribute to poverty alleviation and sustainable development. Thus, as with the MNWFD, the NWP encourages the fair, transparent and inclusive allocation of water to the many competing functions such as agriculture, forestry, mining, manufacturing, power generation, recreation, tourism, informed by equity, social justice and minimum ecological needs. Fisheries is noticeable by its absence in this list. However, rather contradictorily, the NWP goes on to provide the following priority list of water demands: Drinking Water, domestic use, water for people; urban and rural sanitation; food security and other uses (industries, hydro-power, beautifications, firefighting, etc.), followed by the rather vague statement that such allocation “shall be based on economic, social and environmental values of the water determinants” (Section 2.6(ix), p.17). Although not in the list of priorities, the NWP also requires ecological needs of rivers to be determined, and a portion of river flows kept aside to meet these needs. This is to include the needs of aquatic eco-systems, wetlands and flood plains in planning. Also noteworthy is that the Policy encourages local investments such as small bunds, field ponds and other small-scale strategies for augmenting irrigation.

These broad principles in the NWP are to be applied at project level through inter-disciplinary planning accounting for social and environmental aspects in addition to techno-economic considerations. All water resources projects moreover, including hydropower projects, should be planned to the extent feasible as multi-purpose projects. In contrast, while the Irrigation Law applies to all forms of surface irrigations and to tube well, it does not explicitly acknowledge impacts arising from irrigation infrastructure. Also worth noting in the context of fisheries is that access to canal water appears to be limited to crop cultivation, and the Law expressly prohibits fishing inside the canal or drainage areas.

In addition to the above instruments, there is also the Conservation of Water Resources and Rivers Law (2006), which is limited in scope to protecting water resources especially river systems from pollution and affording safe navigation. A reading of the text however indicates that the primary concern is with navigation, with the exception of prescribing terms and conditions to prevent water pollution and monitoring implementation. As such, the implementing authority appears to be the Ministry of Transport, whose duties under this Law are predominantly related to ensuring safe navigation.

With respect to water pollution, prior to 1989, no governmental agency had responsibility for controlling the impacts of pollution discharge or water abstraction, and thus managing environmental impacts were the responsibility of each sector authority until the Ministry of Foreign Affairs (MOFA) first took some responsibility over environmental matters in 1989 (Nesheim et al. 2016). However, given the absence of a comprehensive water law[10], and Environmental Impact Assessment legislation until 2016, little effective measures have been taken to account for environmental impacts. This is despite the NSDS

[10] A draft Water Law (Bill) has been drafted by the National Water Resources Committee, though an English version could not be sourced even from the Secretary to the NWRC due to prevailing political conditions in Myanmar.

calling for a lowering chemical fertilizer and pesticide levels in 2009 – an objective difficult to achieve not only due to insufficient regulatory oversight, but also given the emphasis on increasing (by 50% according to the ADS) land-water productivity.

Along with an increased demand for irrigation driven by rice exports and climate change induced water scarcity, hydropower is likely to impose a significant imprint on freshwater flows. About 75% of Myanmar's electricity is generated through hydroelectricity although only about 30% of the population has access to electricity. The MCCSAP notes that there is still significant untapped potential in energy generation, mostly from hydropower, although it also states that large infrastructure at national, regional and local scale must take into account the impact on natural capital and ecosystem services. Ironically, while in-country energy supply is both low and erratic, energy exports constitute an important source of foreign revenue. The Myanmar Energy Master Plan (2015) on the other hand is silent on potential cross-sector impacts, although it targets 80% electrification by 2030 with 92 potential sites for hydropower development (over 10MW) and 210 sites for small and medium size plants. To be more precise, the Master Plan does consider that the environmental and social impacts of large dams remain the highest concern, hence so the focus on mid-sized to small hydropower generation projects. While this amounts to a tacit acknowledgement of potential trade-offs, it says little about what these may be, or how they could be minimized.

The issue of cross-sector impacts of water infrastructure appears to be addressed under the NSDS, the Environmental Conservation Law (2012) and the Environmental Impact Assessment procedures launched in January 2016. While the NSDS seeks to increase the cultivated area under irrigation by increasing storage capacity and building canals and other related infrastructure, it requires an EIA prior to construction of dams, agro-based industries and infrastructure, and the integration of environmental concerns in energy policies. The Environmental Conservation Law requires both an EIA and a Social Impact Assessment. It empowers MoNREC to set standards and require licences before industries and other activities damaging the environment can commence, and requires government agencies to conserve fisheries resources. The Environmental Conservation Rules (2014) add the need for Initial Environmental Examinations prior to EIAs. These rules apply to irrigation systems ≥ 100 ha but < 5,000 ha which require an IEE, while those over 5,000 ha require an EIA, although it is the quality of these reports that will influence decision making. In terms of groundwater, its use for industrial, agricultural or urban water supply requires an IEE if extraction is less than 4,500 m3/day, while an EIA is needed for extraction of equal or more than 4,500 m3/day.

The framework for managing groundwater is markedly sparse, consisting of a mere two-page Underground Water Act passed as long ago as 1930, which is limited to simply requiring that all groundwater extraction obtain a permit that can be accompanied by conditions regulating access. A more comprehensive management framework is likely in the current Groundwater Bill is passed. This will supersede the 1930 Act, will requires the establishment of a Central Committee for Groundwater Management (CCGM) to be chaired by MONREC. This is interesting and promising given it widens control over decision making at Union level away from IWUMD, and appears to reflect a multi-function approach to groundwater management, although the full list of Committee members is not disclosed.

The CCGM will be empowered to make policies for groundwater management; to require related data collection and database creation to help monitor groundwater use; to monitor compliance with prescribed standards in groundwater extraction, and to raise public awareness. Although centralised by name, this Committee will be able to form state/region working groups with the state's/region's Chief Minister as the chair. These decentralised governance arrangements extend to township working groups where the township GAD administrator is to be the chairperson. These township groups will also include representatives from DRD, MONREC, IWUMD, DOA, DOLF, Tsp development committee, etc. While the state/region committees will be able to make regulations, such powers are not specified for township committees.

The primary regulatory tool will remain drilling permits and groundwater use permits (issued after testing water quality), applications have to be submitted to relevant working groups. Tubewells drilled before this Bill (assuming it passes into law) must also be registered. Permits are to be used for "domestic" and "businesses" purposes, with the latter including agriculture and livestock, and seemingly excluding fish culture (in the very least, it is not explicitly mentioned). The permissible extraction rates for businesses is more than 3,000 gallons per day, while no figure is stipulated for domestic use. In the case of extraction for business, failure to stipulate an upper ceiling implies that there is in fact no limit to what can be extracted per day. Nevertheless, the Bill will also require the installation of water meters to measure the amount of water used, although it does not specify whether this applies to wells used for both domestic and business purposes. Unlike other forms of aquifers, the Bill stipulates that only the Central Committee can manage artesian wells and artesian zones.

Inter-sectoral coordination
The sustainable management of natural resources is prioritised by the National Sustainable Development Strategy (NSDS, 2009), which views sustainable land management as attaining a significant rise in land productivity, along with the modest expansion of cultivated area. The Myanmar Sustainable Development Plan is more specific in calling for an enabling environment which supports a diverse and productive economy through inclusive agricultural, aquacultural and polycultural practices as a foundation for poverty reduction in rural areas.

MNWFD: As Myanmar's main rivers cross many administrative boundaries, i.e. States and Regional Administrative Boundaries, the Local Governments have to cooperate and work together for the management of the river basin

An important development in the NSDS is its call for the protection of fisheries in sustainable development, and calls for an Environmental Impact Assessment (EIA) prior to construction of dams and agro-based industries and infrastructure. This is repeated under Sustainable Energy Production and Consumption, which calls for integrating environmental concerns in the formulation of energy policies and conducting an EIA prior to constructing hydropower dams. However, in a bid to increase the cultivated area under irrigation, the NSDS also calls for the construction of new reservoirs and dams; the renovation of existing reservoirs to increase storage capacity; infrastructure for efficient delivery of irrigation water; the diversion of water from streams and rivulets during high water levels into adjacent ponds or depressions for storage with sluice gates, and the lifting of water from rivers and streams through pump irrigation and the efficient use of ground water. The MSDS similarly requires the enhancing of irrigation and drainage services, as does the Myanmar Climate Change Strategy and Action Plan (MCCSAP) 2016–2030. While increasing irrigation is wholly understandable, the real question is how the inevitable intensification of trade-offs between irrigation infrastructure and freshwater capture fisheries are to be addressed. This is not clear, despite the recent introduction of EIAs into planning processes, given the continuing sector-based approach to planning.
Much less content on water resources as a key resource for the agriculture sector, with no explicit recognition of trade-offs, though the new EIA law maybe seen as a tacit recognition. Whether these will have an impact however will depend on how they are implemented in practice.
NSDS - Percent of population with access to an improved water source
Inter-sector coordination mechanisms or the lack of and implications. ADS - regional planning - the coordination between local plans and national plans become more important, within an emerging process of decentralization.
Myanmar launched its new Environmental Impact Assessment procedures in January 2016. This is considered as an important step forward.
In 2016 three previously separate Ministries (Agriculture and Irrigation; Livestock Fisheries and Rural Development; and Cooperatives) were merged into one Ministry of Agriculture, Livestock and Irrigation (MOALI) to address the sector development in a more integrated and holistic approach.
The previous three separate ministries are emerged into one unified Ministry of Agriculture, Livestock and Irrigation (MOALI). In other words, its role has evolved from a crop agriculture focus, to one of diversification
The grouping of the previously separate agencies dealing with agriculture, livestock, irrigation and fisheries are merged into one unified Ministry of Agriculture, Livestock and Irrigation (MOALI), though Fisheries does not form part of the Ministry name. This offers significant potential for more integrated planning if embedded cultures of silos can be overcome. Data can be an important tool to this end, and its dearth and the absence of associated decision support tools remains a central challenge.

Environmental Conservation Law 2012
Provides for carrying out an environmental impact assessment and a social impact assessment as to whether or not a project or activity to be undertaken by any Government department, organization or person may cause a significant impact on the environment.
suitable surface water quality standards in the usage in rivers in rivers, streams, canals, springs, marshes, swamps, lakes, reservoirs and other inland water sources of the public. But does not define whether these standards take into account the needs of species other than humans.

Requires government agencies to conserve fisheries resources and ecosystems, and cooperation between these agencies and MoNREC. MoNREC can also set standards and require licences before industries and other activities damaging the environment can commence.
Environmental Conservation Rules 2014 and Environmental Impact Assessment (EIA) Procedure 2015 Activities covered include any commercial, economic, agricultural, social or other activity that is deemed to have an adverse impact. Where an EIA is required, these are required to include EIAs must have an environmental management plan. These include activities that are characterized by a high risk of significant, adverse environmental or social impact.
IEE: a Project judged by the Ministry to have some Adverse Impacts, but of lesser degree
Potential impacts on conservation and protection of biodiversity is one criteria that can trigger the need for an EIA/IEE.
For EIAs, in addition to identifying Impact and Risk Assessment and Mitigation Measures, an EIA is required to also identify Cumulative Impacts.
Requires a Strategic Environmental Assessment to facilitate the prompt and effective integration of relevant environmental and social considerations into public policy and planning, the Ministry may require that policies, strategies, development plans, frameworks and programs that are prepared or contemplated by Union 31 Ministries, the governments and authorities of Regions, States. Where such Screening indicates that any such policy, strategy, development plan, framework or program may have a significant environmental or social impact, the Ministry may require the authority responsible for such policy, strategy, development plan, framework or program to undertake a properly scoped study to identify and assess the potential environmental and social impacts, and to prepare and incorporate into such policy, strategy, development plan, framework or program an environmental and social management and monitoring framework comprehensively addressing such impacts.

Other Considerations

- Structural and capacity issues e.g. lack of special data for cross-sector dialog
- the lack of reliable data and statistics is a major constraint to effective policy analysis, strategy development, and planning that requires urgent attention. The ADS sees reorientation and strengthening of the policy and planning system for agriculture and the rural sector is clearly a priority area where extensive capacity development and resource allocation is needed.

The Institutional Framework

National Water Resources Committee (NWRC)

The committee will draw up and implement an integrated water management system, and develop a national integrated water management strategy, a national water resources policy, a water framework directive and a water law. It is seeking ways to earn revenue by utilizing water resources, set up a water resources decision support system and databank, promote international collaboration on water sectors and establish a water resources trust fund.
To take responsibility for the overall management of national water resources and to facilitate for a more coordinated approach, in 2013, the Myanmar National Water Resources Committee (NWRC) was established by a presidential degree. The overall mandate of the NWRC is institutional strengthening including formulation of proper national water policy, law, a national water framework directive, and capacity building to related stakeholders. An important decision made by the NWRC in 2014 was to transform governance of water resources, going from a sectoral approach to integrated river basin management. (Nesheim et al. 2016)

Sector	Agency	Mandate	Coordination Mechanisms
Fisheries	Department of Fisheries (Under the Ministry of Agriculture, Livestock and Irrigation, MoALI)	Management of the fisheries resources of Myanmar. Guided by six policy objectives: • Conservation and rehabilitation of the fishery resources; • Promotion of fisheries research and surveys;	no institutional structure built into the Freshwater Fisheries Law to support mangrove management. Article 83 of the Freshwater Fisheries Procedure requires that where the Department of Fisheries grants a lease, tender or

		• Collection and compilation of fishery statistics and information; • Provision of fisheries extension services; • Supervision of the fishery sector; and • Ensuring sustainability of fishery resources.	fishing implement license for fresh water fisheries in an area also under the jurisdiction of another Government Department or organization, the DoF must obtain the remarks from the Government Department or organization concerned, and incorporate the conditions set out by this entity.
Forestry			
Environment			The Environmental Conservation Committee can advise other Government department on environmental conservation and call for information from any government or non-government entity . It can also require government agencies to take remedial action (Environmental Conservation Rules 2014).
Agriculture			Forestry law has similar provisions to seek views of other agencies, and to understand the affected rights of the public prior to designating a reserved forest.
Water			
Energy			

Discussion

- Cohesion or fragmentation
  - Link to on-ground connectivity issues and fragmented planning
  - Opportunities for small-scale aquaculture

The outline of Myanmar and Cambodia's national contexts highlights the intersectoral nature of inland fisheries management, driven by multiple potential water uses characterised by the water-food-energy nexus.

o Clear recognition in overarching development policy of three key roles of food production systems: food security, rural and especially smallholder poverty reduction and nutrition. The major positive development is the more central positioning of nutrition, that provides a compelling rationale for diverse and integrated food systems.

o The agriculture sector follows this rationale, but fisheries specifically loses focus on smallholders, shifting instead to a commercial footing. The proposed land use changes to support this create additional concerns for capture fisheries if currently open access land and water resources are to be commercialised.

o While commercialisation could minimize undue pressure on wild stocks, the evaluation of key capture fishery systems in the next section suggest that the poor are marginalised from these systems as well. Together, this risks squeezing the poor marginal households out of capture fisheries altogether, as local and commercial elites control the fisheries .

o While policies broadly now provide the rationale for diversification and integration, a major obstacle remains in the prohibition of land conversion (especially from rice to other production systems) under the Farmland Law of 2012.

o Focus on fisheries diminishes in terms of proposed investments and with respect to addressing cross-sector trade-offs when planning water and other infrastructure – a dearth of recognition in these sectors. The recent introduction of EIA procedure offer the potential to address this.

The influence and focus on irrigation as a vehicle for national development, including poverty and hunger alleviation is demonstrated in both Myanmar and Cambodia by the proportion of Ministerial budget allocated to that department relative to other sectors within agriculture and natural resource management. For example, in 2017 Myanmar's Irrigation Department received almost 35% of the Ministry for Agriculture and Livestock (MOALI)'s budget, in contrast to Fisheries, which, sitting within the same Ministry, received 0.2% (Conallin et al., 2019). As Gregory et al. (2018) note, integrated approaches are often constrained by departmental budgets which amongst other things influences the skill sets of personnel who could be involved. The focus on irrigation, (and by proxy, rice), has similarly retarded the development of a thriving aquaculture industry in Myanmar, due to restrictive land use policy (Baran, Gareth & Tezzo, 2020; Belton et al., 2015; 2018).

Regulatory framework is weak in both countries, manifested in Myanmar by the outdated and incomplete FFL (Tsamenyi, 2011)

The recent history and political orientation of Myanmar is an important consideration when considering natural resource governance in the country. As Nesheim et al. (2016) point out, Myanmar's history of centralized governance, and a lack of transparency and data in decision making was an important obstacle for resource management planning. While political process are now in transformation, the lack of data for informed choices around natural resources remains a significant obstacle in shifting from a sector approach to an integrated resource management approach. This state of transition within Myanmar is therefore an overarching narrative shaping this discussion of inland fisheries in Myanmar NRM management and broader development frameworks.

- Opportunities and risks for small-scale aquaculture – key policy statements and legal provisions
- CC implications and how do other pols like irrigation, ADS and MS-NPAN link?

Opportunities
Recommendations by Paul De Wit: (World Fish 2018)

- Integrated agriculture promotion by DALMS - Central Administrative Body of the Farmland (CABF)-MoALI by means of an Administrative Order/Directive on the basis of the Farmland Law Instructions Article 42b. The suggested action would be to consider the classification of smallholder rice-fish-vegetable units as an integrated agriculture rice system for land use certification (Form 7) purposes as rice land; and
- Small-scale aquaculture involving action by the MoALI Cabinet to issue an amendment to the Farmland Law (Farmland Law Instructions Article 42a) to either: a) issue a specific and simplified instruction for paddy into pond conversion (up to 2 acres) or b) consider flexible Land Tenure regularisation for smallholders (up to 5 acres).
- These would also provide greater security of tenure for small-scale farmers who wish to adopt rice-based integrated farming options.
- Align with ADS (article 42) "… rather than an excessive focus on rice, there is a need to think in terms of rice-based farming systems that will encompass a range of non-paddy options depending on location"

Opportunities arising from the EIA legislation

- The coverage of irrigation infrastructure and several potentially polluting activities are covered under opens the medium-tong term opportunity to build in-country capacity to conduct high quality IEE and EIAs. However, these words on paper are only as effective as the capacities to implement them and the political economies attached to them. While EIA processes maybe seen as being highly political activities, ensuring government agencies and organization that conduct the studies are aware of what the cross-sector implications could be (especially in the case of irrigation), and how such studies should be conducted, is within the sphere of influence of development actors.

- A related need is the provision of data and open access databases to support IEE and EIA studies.
- It is therefore recommended that the CG centers in Myanmar collectively work with MoNREC, MoALI and other agencies to co-develop a training module on conducting IEEs and EIAs in the water sector, to bring out the multi-dimensional impacts of altering freshwater flows, and methods for impact assessment.

Key Findings/Messages

- Agriculture remains central to overall development policy, including rural poverty reduction and food security.
- The emphasis on productivity and nutrient content of food production increases the strategic relevance of fish within the food systems space.
- Fisheries not well represented within agriculture.
- Water resources and land sectors, critical for healthy inland fisheries, are not supportive, and do not follow the progressive path adopted by overall development and food sector policies, and this is a major obstacle.

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The section of references covers Appendices 1,3,4,5 and 6.

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Annex 8: Mapping Myanmar's water resources is key to developing sustainable aquaculture and improving nutrition

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Many people in Myanmar suffer from poor nutrition because they eat too many carbohydrates – primarily rice – and too little protein.

Photo: Majken Schmidt Søgaard / WorldfFish

One way to overcome poor nutrition is to expand small-scale aquaculture by increasing the number of fishponds and stocking existing water bodies with protein-rich fish. This is the ambition of the Fish for Livelihoods project, led by WorldFish and supported by USAID. The International Water Management Institute (IWMI) is supporting the project by identifying locations with sufficient and sustainable water resources to expand fish production.

IWMI's project team is modeling the Irrawaddy river basin that covers approximately 50% of Myanmar (337,400 km^2). The objective is to quantify available water sources and pinpoint potential areas for developing new fishponds while also monitoring water quality to understand where poor conditions may constrain development. Additionally, as sustainability of aquaculture development is a priority before building new ponds and other infrastructure, it is crucial that an assessment is made of the possible impacts on future water resources from climate change.

The findings of an IWMI analysis of historical weather-station data show that Myanmar's climate is already changing. Data recorded at 13 weather stations, located in various hydro-ecological zones, revealed a temperature rise of between 0.1°C and 0.3°C at 11 of the stations between 1986 and 2015. Extreme rainfall (more than 30mm a day) increased at three inland stations: Mandalay, Nyaung Oo and Pyay. Further analysis using regional climate model (RCM) projections (from the Coordinated Regional Climate Downscaling Project for South-East Asia) also showed that the number of days with temperatures above 30°C is forecast to increase in the future.

The IWMI project team is also researching the various types of ponds that exist in Myanmar. Pond typologies are differentiated by water source and include: springs; groundwater seepage from shallow aquifers; groundwater extracted from boreholes by pumping; surface water directed through dams or streams; surface water diverted from streams or rivers; and rainwater harvesting. So far, the team has mapped the different pond typologies, and assessed their quality and availability using remote sensing images and GIS.

Preliminary results show that Sagaing region (north-western part of Myanmar) has the largest area with potential for expanding aquaculture due to availability of diverse water sources. However, Kachin State (northernmost part of Myanmar), which has the smallest suitable area, has more diverse water sources, encompassing both surface and groundwater supplies. Having diversity of water sources reduces risks related to water availability and increases resilience to climatic shocks. So, it may be that expanding aquaculture in moderate-sized areas with greater diversity of water sources is the best option.

IWMI's work will help to ensure that future investments in aquaculture in Myanmar will be sustainable, and able to boost rural livelihoods and nutrition as climate change takes hold.