Lancang-Mekong Cooperation Special Fund Projects

Research on Water Quality Monitoring Standards in Lancang-Mekong Countries

生态环境部对外合作与交流中心
Foreign Environmental Cooperation Center

澜沧江－湄公河环境合作中心
Lancang-Mekong Environmental Cooperation Center

中国－东盟环境保护合作中心
China-ASEAN Environmental Cooperation Center

Contents

Absract

The Lancang River originated in Qinghai Province, China. After exiting from Mengla County, Xishuangbanna Dai Autonomous Prefecture, Yunnan Province, China, the Lancang River became the boundary between Myanmar and Laos, and was originally called the Mekong River. The Mekong River flows through Myanmar, Laos, Thailand, and Cambodia, and flows into the South China Sea at Ho Chi Minh City, Vietnam. It is an important international river in Asia.

In order to better carry out the Lancang-Mekong environmental cooperation and provide data reference and technical support for the implementation of the Lancang-Mekong environmental cooperation project, this study comprehensively analyzed the current state of the water environment, water environment monitoring and management systems, water quality standards, and water environment management laws and regulations of the Mekong countries and explore the prospects of water quality monitoring cooperation in the Lancang-Mekong River Basin. The main conclusions are as follows:

Cambodia is a traditional agricultural country, where industrial backwardness is an important reason for low level of economic development. Therefore, environmental pollution is relatively light there, with water, soil and air not yet seriously polluted. However, due to an increasing population and the demand for economic development in recent years, environmental pollution and ecological destruction continue to be aggravated. Particularly in urban areas, pollution caused by wastewater and waste has become a major challenge in the improvement of urban environment. In Cambodia, central government agencies in charge of water environment management mainly include the Ministry of Environment (MOE), the Ministry of Water Resources and Meteorology (MWRM), the Ministry of Public Works and Transport (MPWT), the Ministry of Agriculture, Forestry and Fisheries (MAFF), the Ministry of Mines and Energy (MME) and Cambodia National Mekong Committee (CNMC). Among them, MOE, MWRM and CNMC are mainly in charge of water quality management. With economic development, Cambodia has realized the importance of sustainable utilization of water resources to national economic development, therefore it has enacted laws such as Water Pollution Control Law, Drinking Water Standards and Law on Water Resources Management, and established surface water quality standards which aim at biodiversity conservation and public health protection, with a view to enhancing the protection of water resources at home.

Laos boasts abundant water resources, but the water level is extremely low in Laos during the dry season due to great seasonal variation in the Mekong's flow, seriously affecting the life of local people. Meanwhile, despite generally good quality of water in the Mekong River, which can basically satisfy the living needs of people along the river, some segments of the river are seriously polluted with poor water quality. Set up on November 28, 2011, the Ministry of Nature Resources and Environment of the Lao PDR is an authority with functions and powers. Laos has integrated all solutions and plans with respect to environmental problems into the ministry and on this basis developed its environmental protection measures and plans, including a number of regulations such as the Second Five-Year National Environmental Action Plan (2011~2015), the National Environmental Education and Awareness Strategy to 2020 and Action Plan 2006~2010, the Regulations of the Lao PDR on Environmental Impact Assessment and the Decree on Compensation and Resettlement of the Residents Affected by Environmental Projects. As a large agricultural producer and a country with large reserves of Mekong water resources, Laos is faced with water pollution caused by agricultural production. To actively protect the security of water resources, Laos has developed and enacted a number of laws to protect water resources, for example, the Law on Water and Water Resources, Water and Water Resource Policy, Environmental Protection Law and National Environmental Standards Agreement. Moreover, apart from irrigation water and other agricultural water, Laos also wishes to develop international navigation on the mainstream of the Mekong River and abundant hydropower resources in tributaries. Laos' surface water quality standards contain 30 indicators, including two physical ones, two biological ones, two radioactive ones and 24 chemical ones which involve heavy metallic elements and toxic compounds.

Myanmar possesses abundant surface water resources and as an agricultural country, it consumes far more water for agricultural use than the sum of that for industrial and domestic use. The authority in charge of water environment management in Myanmar is the Ministry of Agriculture and Irrigation. Following the enactment of the Law on Protection of Water Resources and Rivers of Myanmar, the Myanmar Government has gradually normalized the development of water resources at home by studying the development of water resources according to the law and developing plans for the development of water resources and relevant investment and other policies. In order to meet the demand of economic development, Myanmar has formulated mid- and long-term plans for the development of hydropower resources in the light of its economic development plan and actual national conditions. So far,

Myanmar has no technological or economic conditions required by independent development of large hydropower projects, nor can it completely consume the electric power generated by large hydropower stations in the short run. After studies, Myanmar has selected neighboring countries that not only have economic and technological strength, but also can consume huge electric power generated, such as India, China and Thailand, to jointly develop hydropower resources, thus allowing rivers in Myanmar to provide energy and foreign exchange for its economic development. Myanmar has no national surface water quality standards, so it borrows international standards. List again wastewater, rainfall runoff, sewage and sanitary discharge quality standards of Myanmar and water quality standards of Yangon. Myanmar mainly uses water resources in the Mekong River for irrigation, so pollution caused by the country to the Mekong River is mainly from chemical fertilizers and pesticides. Hence, Myanmar has also developed and promulgated laws such as the Pesticide Law and the Law on Protection of Water Resources and Rivers to protect waters.

Thailand has plentiful water resources, and the runoff in summer and fall is much greater than that in spring and winter, indicating great seasonal variation in water quantity. North Thailand enjoys better water quality than other areas and water quality in Central Thailand is more seriously aggravated, with most water quality problems coming from pollution caused by community and agricultural activities. The quality of water resources in North Thailand lies between average and very good, and parameters that do not meet the Type III surface water quality standards are BOD, DO and FCB, which are mainly caused by community and agricultural pollution; water quality in Central Thailand lies between bad and good, and parameters that do not meet the Type III surface water quality standards are DO, BOD, TCB, FCB and NH_3-N, with water pollution there mainly coming from communities and livestock farms without a waste management system; in the Chao Phraya River and Tha Chin River with bad water quality, water pollution is mainly caused by wastewater discharged from industrial workshops and factories; water of average quality dominates the water resources in East Thailand and parameters that do not meet the Type III surface water quality standards are BOD, DO, TCB and FCB, resulting mainly from wastewater discharged from community and agricultural activities; water quality in South Thailand lies between average and very good, and parameters that do not meet relevant standards are BOD, DO, FCB and TCB, mainly caused by wastewater from community and agricultural activities. Based on the intended use, Thailand's surface water quality standards are divided into 5 categories. In Thailand, there are 26 rivers, which are put under 4 geographic regions, involving the central part, the northeast part, the south part and the east part. The rivers are subject to the quality standards based on 5 water bodies which specify the water quality classification and its parameters at different segments of the main rivers. In order to reduce the impacts of water resources development and utilization on water environment, Thailand has enacted a number of laws and regulations, such as the Groundwater Act and the Enhancement and Conservation of the National Environmental Quality Act, to supervise the development of water resources and protect water environment quality.

Vietnam is rich in water resources, but water resources are extremely unevenly distributed as rainfall is mainly observed in three to four months throughout a year due to the climate there. Vietnam established an environmental monitoring network at the end of 1994 to monitor water quality and other environmental factors. Monitoring points are distributed in major river basins and are subject to regular sampling analysis (generally once a month), which mainly monitor temperature, pH value, turbidity and the contents of some metallic elements (Fe, Mg, Ca, Na, Ka, etc.). In short, water quality of the Mekong River in Vietnam is good, but total suspended solids (TSS) exceed the Class A2 surface water standards of Vietnam. In addition, pollutant indicators rise sharply in My Tho, which requires strict

inspection and control of discharge sources in that city, so as to prevent gradual deterioration of water quality. Urban and rural water supply and sanitation are separately managed in Vietnam, with the Ministry of Construction taking charge of urban water supply and sanitation management and the Ministry of Agriculture and Rural Development responsible for rural water supply and sanitation management. Vietnam has its own surface water quality standards with Vietnamese characteristics. For example, surface water quality standards of Vietnam contain a large number of pesticide- and herbicide-related indicators, which is related to its history. Besides, Vietnam has established stricter standards for nitrate nitrogen and nitrite nitrogen than other countries. Located on the lower Mekong River, Vietnam is faced with relatively serious water environment problems and is still challenged by serious pollution of water resources though it has enacted laws and regulations such as the Water Resources Law, the National Water Resources Strategy and the Environmental Protection Law.

In general, comparison of hydrological conditions in the Lancang-Mekong River Basin is as follows: along the Mekong River Basin, the water quantity increases first and then starts to decrease near Phnom Penh, which might be a result of an increase in water consumption due to a dense population there. Mekong countries have set up water quality management agencies according to their respective needs and these agencies are located in central and local government agencies in charge of environmental protection and water resources management. Four countries, including China, Thailand, Cambodia and Vietnam, in the Lancang Mekong River Basin have promulgated further detailed provisions on types of surface water sources, while Myanmar and Laos have not. All Lancang-Mekong countries have formulated relevant laws and regulations for water environment management, only in varying degrees of perfection. Common concerns about the water environment and water resources require the six countries to enhance water quality monitoring and exchanges and cooperation in water environment governance and promote the gradual perfection of their respective water environment management systems and methods, so as to maintain sustainable economic, social and water environment development in the river basin.

Chapter 1 Overview of the Lancang-Mekong River Basin

The Lancang River originated in Qinghai Province, China. After exiting from Mengla County, Xishuangbanna Dai Autonomous Prefecture, Yunnan Province, China, the Lancang River became the boundary between Myanmar and Laos, and was originally called the Mekong River. The Mekong River flows through Myanmar, Laos, Thailand, and Cambodia, and flows into the South China Sea at Ho Chi Minh City, Vietnam. It is the largest international river in Southeast Asia. The main stream of the Lancang River and the Mekong River is 4880 km long, with a total catchment area of 81×104 km^2.

Table 1-1 Main conditions of the Lancang-Mekong River

River segment	Length/km (The proportion in the total length)	Basin area/10^4 km^2 (The proportion in the total basin)	Annual runoff/10^9 m^3 (The proportion in the total basin)	Water yield m^3/s (The proportion in the total basin)
Lancang River	2161（44.3%）	16.44（20.2%）	761（16%）	2140（16%）
Mekong River	2719（55.7%）	64.66（79.8%）	4004（84%）	12650（84%）
Lancang-Mekong River Basin	4880（100%）	81.10（100%）	4765（100%）	15060（100%）

Table 1-2 Water resources owned by each country in the Lancang-Mekong River Basin

Country	Runoff/ km	Water yield m^3/s (The proportion in the total basin)	Area of the Mekong River Basin/10^4 km^2	The proportion in the total basin area	The proportion of the basin area in the national territory area
Myanmar	265	300（2%）	2.40	3.80	3.60
Laos	1987	5270（35%）	20.20	31.24	85.34
Thailand	976	2560（18%）	18.40	28.45	35.87
Cambodia	501	2860（18%）	16.17	25.00	89.34
Vietnam	229	1660（21%）	6.50	10.05	19.70

Chapter 2 Water Environment Status in Lancang-Mekong Countries

Monitored items for water quality of the Mekong River mainly include biochemical oxygen demand (BOD), dissolved oxygen (DO), pH value, temperature, TSS and total coliform.

Table 2-1 lists the specific locations of the 22 routine monitoring stations set up by the Mekong River Commission (MRC) along the Mekong River. These monitoring stations are basic stations which provide very detailed historical and real-time data.

Table 2-1 The 22 main water quality monitoring stations in the Mekong River Basin

No.	Monitoring station name	River	Country	Latitude	Longitude
1	Houa Khong	Mekong River	Laos	21.5471	101.1598
2	Chiang Saen	Mekong River	Tailand	20.2674	100.0908
3	Luang Prabang	Mekong River	Laos	19.9000	102.0000
4	Vientiane	Mekong River	Laos	17.9281	102.6200
5	Nakhon Phanom	Mekong River	Tailand	17.4250	104.7744
6	Savannakhet	Mekong River	Laos	16.5583	104.7522
7	Khong Chiam	Mekong River	Tailand	15.3255	105.4937
8	Pakse	Mekong River	Laos	15.1206	105.7837
9	Stung Treng	Mekong River	Cambodia	13.5450	106.0164
10	Kratie	Mekong River	Cambodia	12.4777	106.0150
11	Kampong Cham	Mekong River	Cambodia	11.9942	105.4667
12	Chrouy Changvar	Mekong River	Cambodia	11.5861	104.9407
13	Neak Loung	Mekong River	Cambodia	11.2580	105.2793
14	Kaorm Samnor	Mekong River	Cambodia	11.0679	105.2086
15	Tan Chau	Mekong River	Vietnam	10.9079	105.1835
16	My Thuan	Mekong River	Vietnam	10.2725	105.9100
17	My Tho	Mekong River	Vietnam	10.3430	106.3505
18	Takhmao	Mekong River	Cambodia	11.4785	104.9530
19	Koh Khel	Mekong River	Cambodia	11.2676	105.0292
20	Koh Thom	Mekong River	Cambodia	11.1054	105.0678
21	Chau Doc	Mekong River	Vietnam	10.9552	105.0867
22	Can Tho	Mekong River	Vietnam	10.0580	105.7977

2.1 Water Environment Status in Cambodia

Cambodia is a traditional agricultural country, where industrial backwardness is an important reason for low level of economic development. Therefore, environmental pollution is relatively light there, with water, soil and air not yet seriously polluted. However, due to an increasing population and the demand for economic development in recent years, environmental pollution and ecological destruction continue to be aggravated.

The mean of the Mekong in Laos are listed in Figures 2-1. Mekong's flow in Cambodia exhibits a tendency of increasing first and then decreasing, with the turning point located near Phnom Penh. The runoff in summer and autumn is far higher than that in spring and winter, exhibiting great seasonal variation.

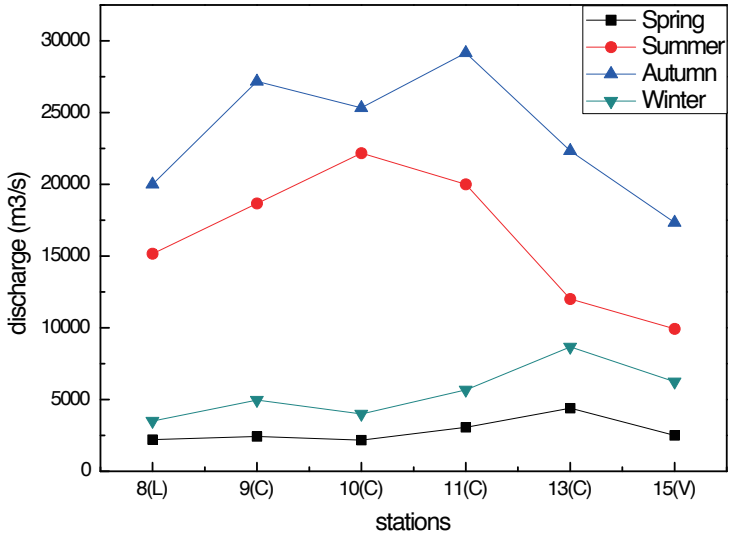


Fig.2-1 Seasonal variation in the mean runoff of the Mekong in Cambodia during 1960-2018

The total suspended solids (TSS) content of Mekong River in Cambodia, as shown in Figure 2-2 (a), presented a variation trend of first ascending, then descending, and ascending and descending again; the pH value of waters of Mekong River in Cambodia, as shown in Figure 2-2 (b), was basically alkaline, and the variation trend was relatively gentle; the dissolved oxygen (DO) changes, as shown in Figure 2-2 (c), presented a downward trend, indicating the water quality was gradually worsened; the chemical oxygen demand (COD_{Mn}), as shown in Figure 2-2 (d), gradually ascended, but presented a variation trend of sharply rising next to two monitoring stations, probably because that plenty of organic pollutants were discharged into the waters near Phom-Penh, leading to the deterioration of water quality.

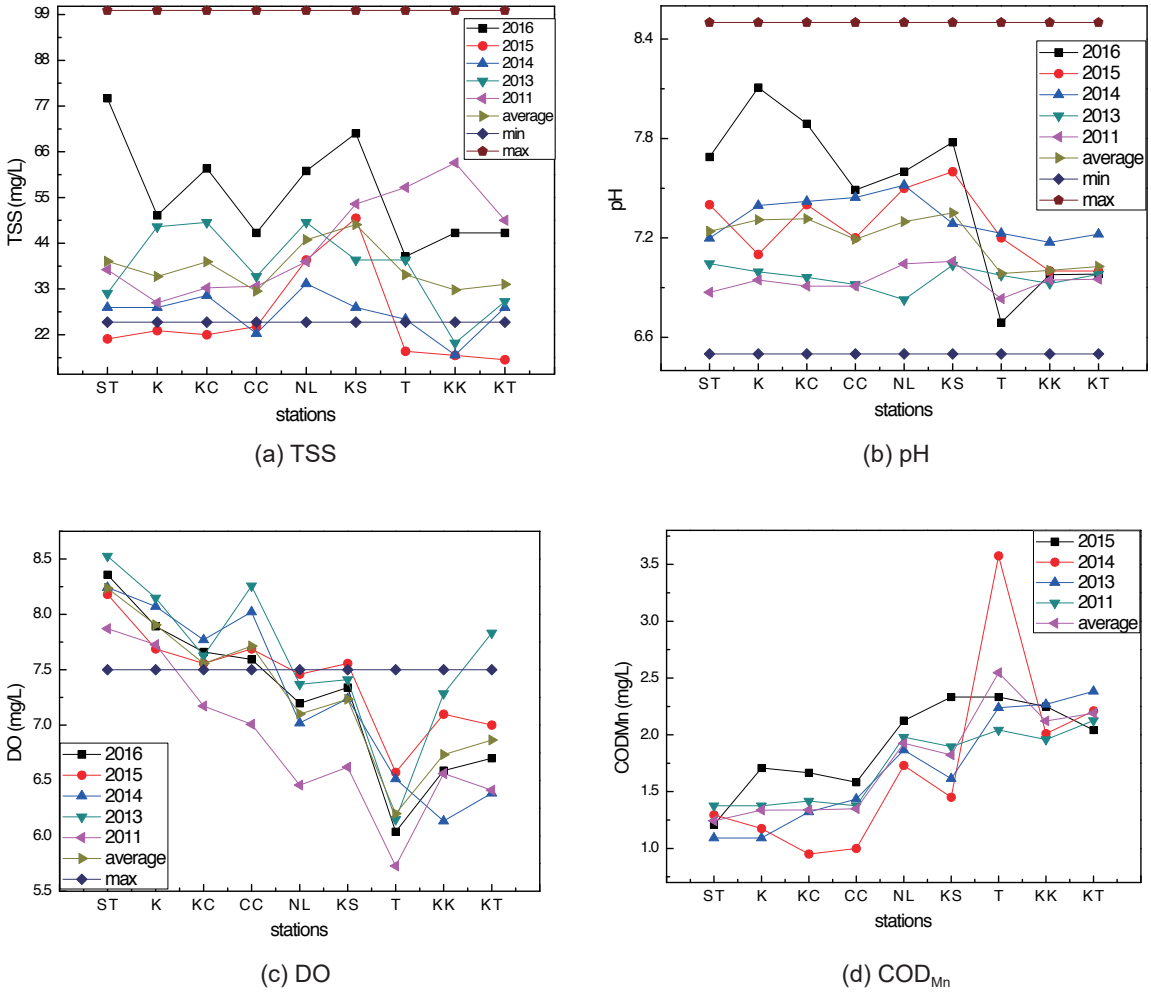


Figure 2-2 Changes of major environmental pollutants in Mekong River in Cambodia

Figure 2-3 Geographical location of Laos and the trend of Mekong River in its territory

2.2 Water Environment Status in Laos

The water yield of Mekong River significantly varies in different seasons. The water level is very low in the dry season in Laos, severely affecting the life of local people. Meanwhile, the water quality of Mekong River is excellent as a whole, and can basically meet people's needs along the river, but is poor in some sections as the waters are seriously polluted.

The trunk stream of Mekong River in Laos is 777.4 km long, and runs through 90% of its land. Besides, 35% of its water yield comes from 26% of the corridor zone of Laos.

The seasonal distribution of river flow and rainfall are closely related in Laos: around 80% in the rainy season (May-Oct.), and around 20% in the dry season (Nov.-Apr.). For some rivers (particularly Sebang Hiang, Se Bang Hieng and Se Done) in the central and southern parts of this country, the flow in the dry season is relatively small, accounting for about 10%-15% of the annual flow. The average annual rainfall is 1,900 mm in Laos, of which the rainfall in the north is 1,300 mm, and that in the south is 3,700 mm, showing a great difference between the north and the south.

Among the hydrological monitoring station established along the Mekong River, four are located in Laos, as shown in Figure 2-4 with the red boxes. These stations provide basic data for us.

Figure 2-4 Location of hydrological stations along the Mekong River

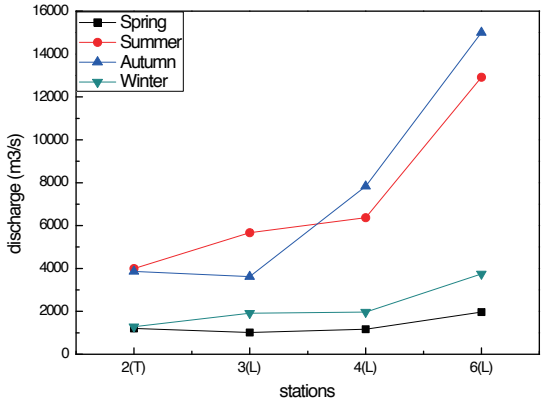
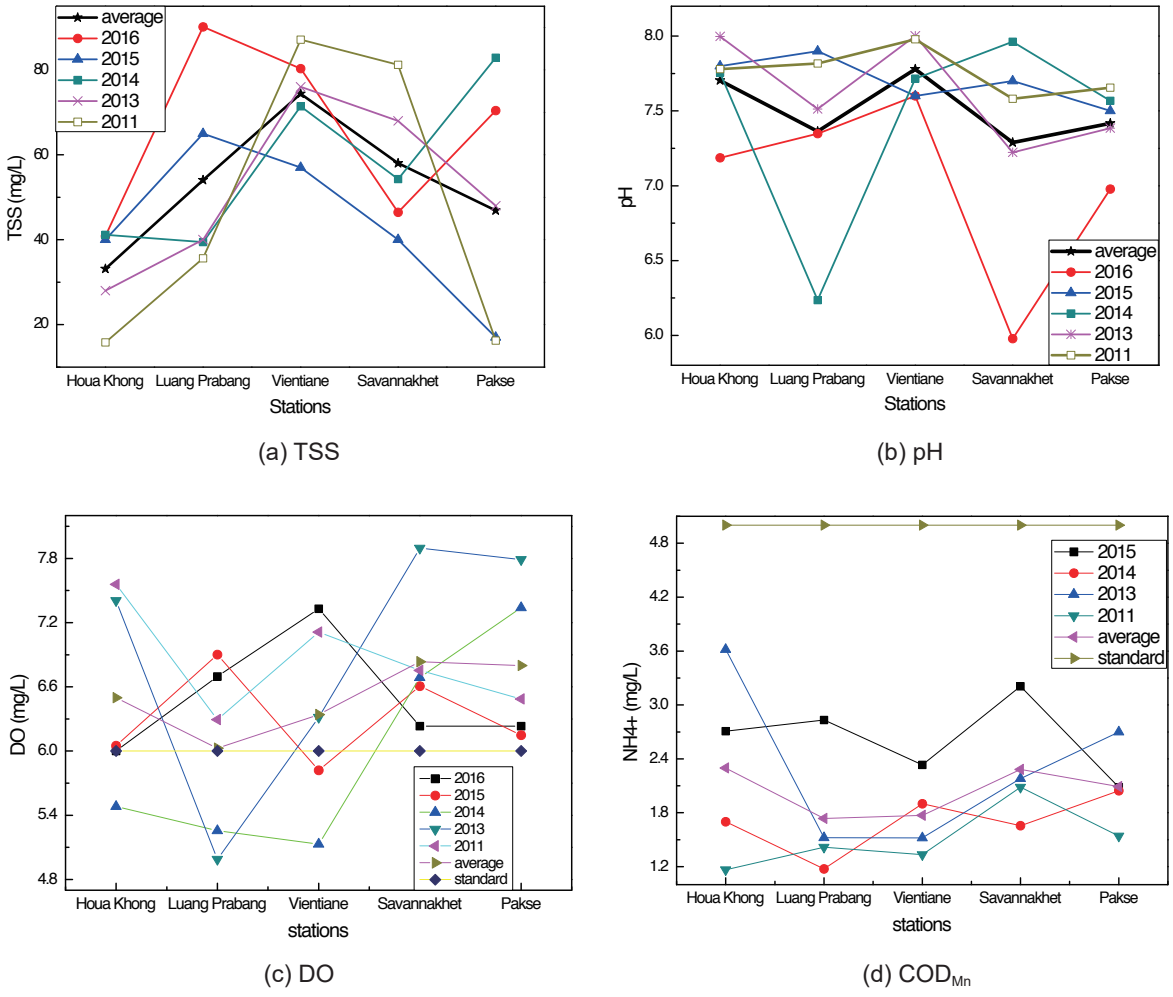


Figure 2-5 Average runoff of Mekong River in Laos in different seasons from 1960 to 2018

According to the average runoff of Mekong River in Laos, as shown in Figure 2-5, the water yield flowing into Laos gradually increased, and the runoff in summer and autumn was much larger than that in spring and winter. The water yield varied a lot in different seasons.

As shown in Figure 2-6 (a), the TSS in the reaches between the Savannakhet and Pakse sections of Mekong River in Laos was on the rise in 2014 and 2016, which was probably related with the weather in those years; the pH value, as shown in Figure 2-6 (b), was alkaline as a whole, and the changes were relatively gentle; the DO content, as shown in Figure 2-6 (c), basically exceeded the drinking water standard (6mg/L) in Laos, showing a good condition, but there was an exception in 2014 when the water quality was poor. The COD_{Mn} content, as shown in Figure 2-6 (d), presented a variation trend of first descending and then ascending, with the turning point approaching the Vientiane section.



(a) TSS (b) pH

(c) DO (d) COD_{Mn}

Figure 2-6 Changes of major environmental pollutants in Mekong River in Laos

2.3 Water Environment Status in Myanmar

According to research, the potential resources of surface water in Myanmar has reached 1.082 trillion m3, and the content is very abundant. Table 2-2 is a statistical table of potential water resources of surface and underground water in Myanmar. The total area of surface water is 739,000 km^2, and the annual runoff is 1.0819 trillion m^3.

Table 2-2 Statistical table of potential water resources of surface and underground water in Myanmar

River Basin	Basin Area (ten thousand km^2)	Flow (hundred million m^3)
Chiundwin	11.5	141.29
Ayeyarwady (Upstream)	19.3	227.92
Ayeyarwady (Downstream)	9.5	85.80
Sittoung	3.4	41.95
River in Rakhaing State	5.8	139.25
River in Thanintharyi Division	44	130.93
Thanlwin	15.8	257.92
Mekong (Myanmar Section)	2.8	17.63
Bilin River and other rivulets	0.8	31.17
Bago River	0.5	8.02
Total	113.4	1081.88

2.4 Water Environment Status in Thailand

The average annual rainfall is about 1,573 mm in Thailand, while the average annual surface runoff is about 21.3 billion m^3. The average annual flow of Mekong River in the Thai basin is 8.07 billion m^3, and the basin area in Thailand is 184,000 km^2. The average runoff of Mekong River along the border between Laos and Thailand, as shown in Figure 2-7, was gradually on the rise, and the runoff in summer and autumn was much larger than that in spring and winter, as the water yield varied a lot in different seasons.

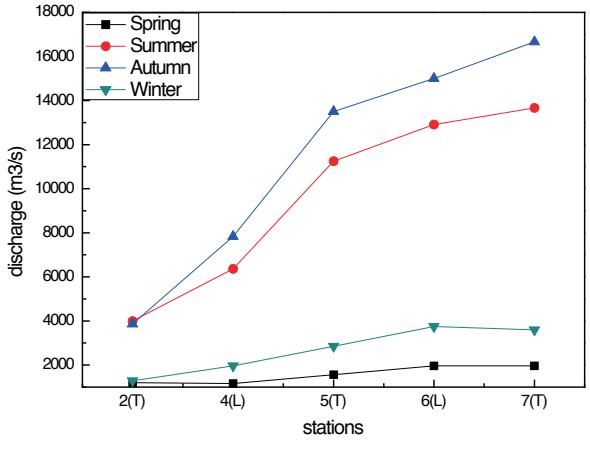


Figure 2-7 Average runoff changes of Mekong River along Laos-Thailand border in different seasons from 1960 to 2018

The TSS of Mekong River in the reach of the boundary river between Thailand and Laos, as shown in Figure 2-8 (a), was on the decline, as the Mekong River enters the plain region in this reach, leading to the slowdown of water flow, sinking of suspended solids, and gradual reduction of TSS content; the pH value, as shown in Figure 2-8 (b), was basically alkaline, and the changes were relatively gentle; the DO content, as shown in Figure 2-8 (c), exceeded the water standard of three types of surface water (6mg/L) in Thailand, showing a good condition; the COD_{Mn}, as shown in Figure 2-8 (d), presented a variation trend of first ascending and then descending, with the turning point approaching Nakhon Phnom.

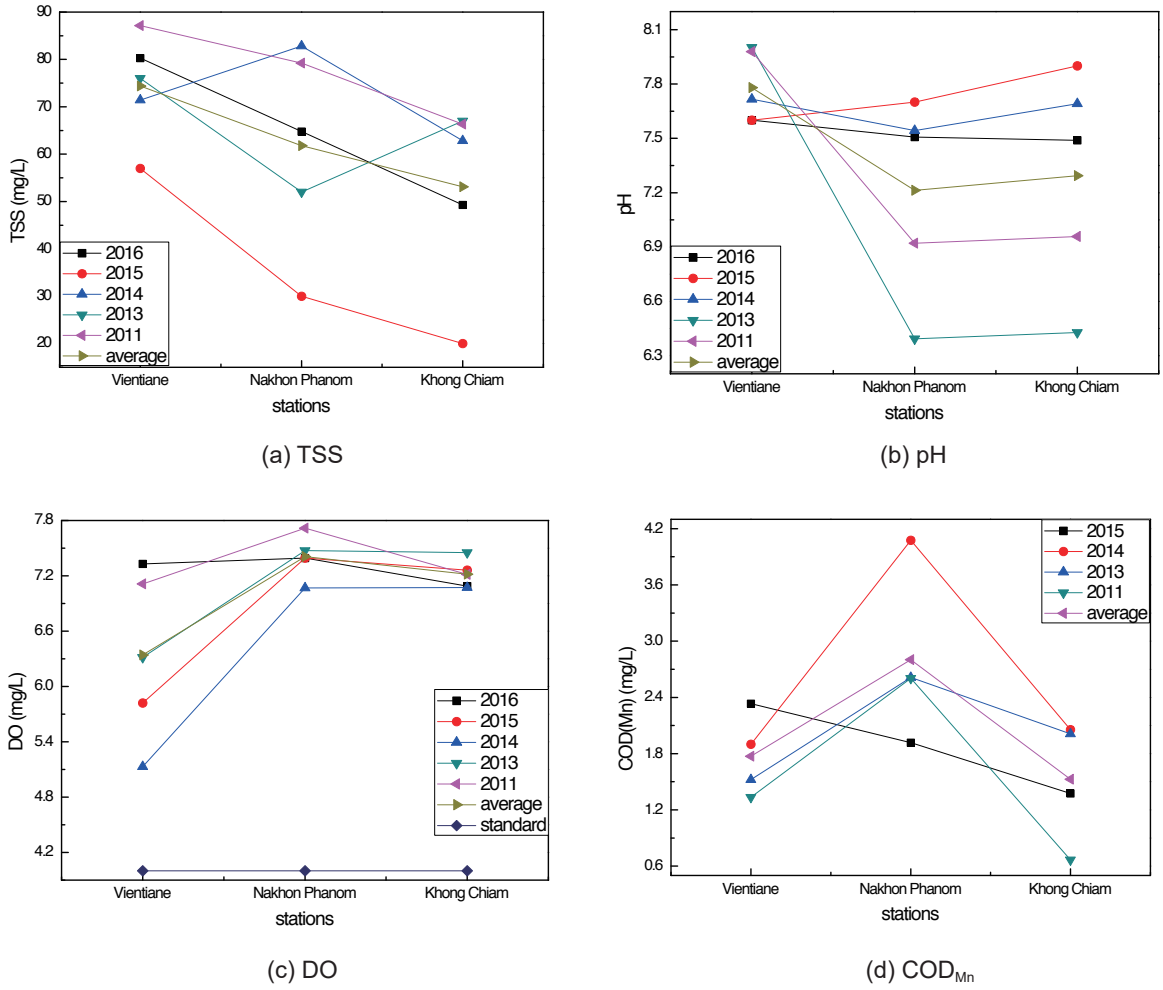


Figure 2-8 Changes of major environmental pollutants in the boundary river of Mekong River between Thailand and Laos

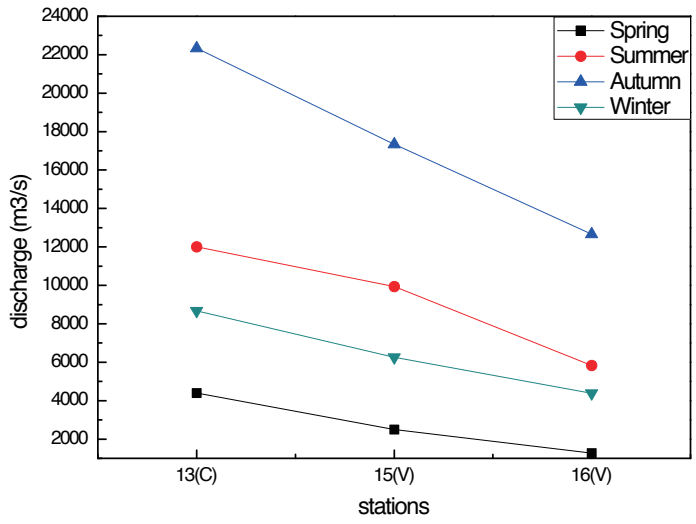


Figure 2-9 Average runoff changes of Mekong River in Vietnam in different seasons from 1960 to 2018

2.5 Water Environment Status in Vietnam

The surface water resources are abundant in Vietnam, and the average annual runoff is 89.1 billion m^3/year. According to the average runoff of Mekong River in Vietnam, as shown in Figure 2-9, the water yield of Mekong River along the My Tho was gradually on the decrease, and the runoff in summer and autumn was much larger than that in spring and winter. The water yield varied a lot in different seasons.

Vietnam established the environmental monitoring network at the end of 1994, used to monitor environmental factors including water quality. The monitoring sites are distributed in the basins of major big rivers, as shown in Figure 2-10, and conduct the sampling analysis on a regular basis.

Figure 2-10 Water quality monitoring stations in downstream of Mekong River

The TSS of Mekong River in Vietnam, as shown in Figure 2-11 (a), first declined and then ascended along Tan Chau, My Thuan and My Tho, rose after the river enters My Thuan as human activities started to increase, and basically remained unchanged alongChau Doc and Can Tho; the pH value, as shown in Figure 2-11 (b), was basically alkaline, but sharply fell along Chau Doc and Can Tho, leading to acidity in the end; the DO content of Mekong River in Vietnam, as shown in Figure 2-11 (c), gradually decreased, but exceeded the A2-grade standard of surface water in Vietnam; the COD_{Mn} concentration, as shown in Figure 2-11 (d), was much lower than the A2-grade standard of surface water in Vietnam, showing the water quality is excellent.

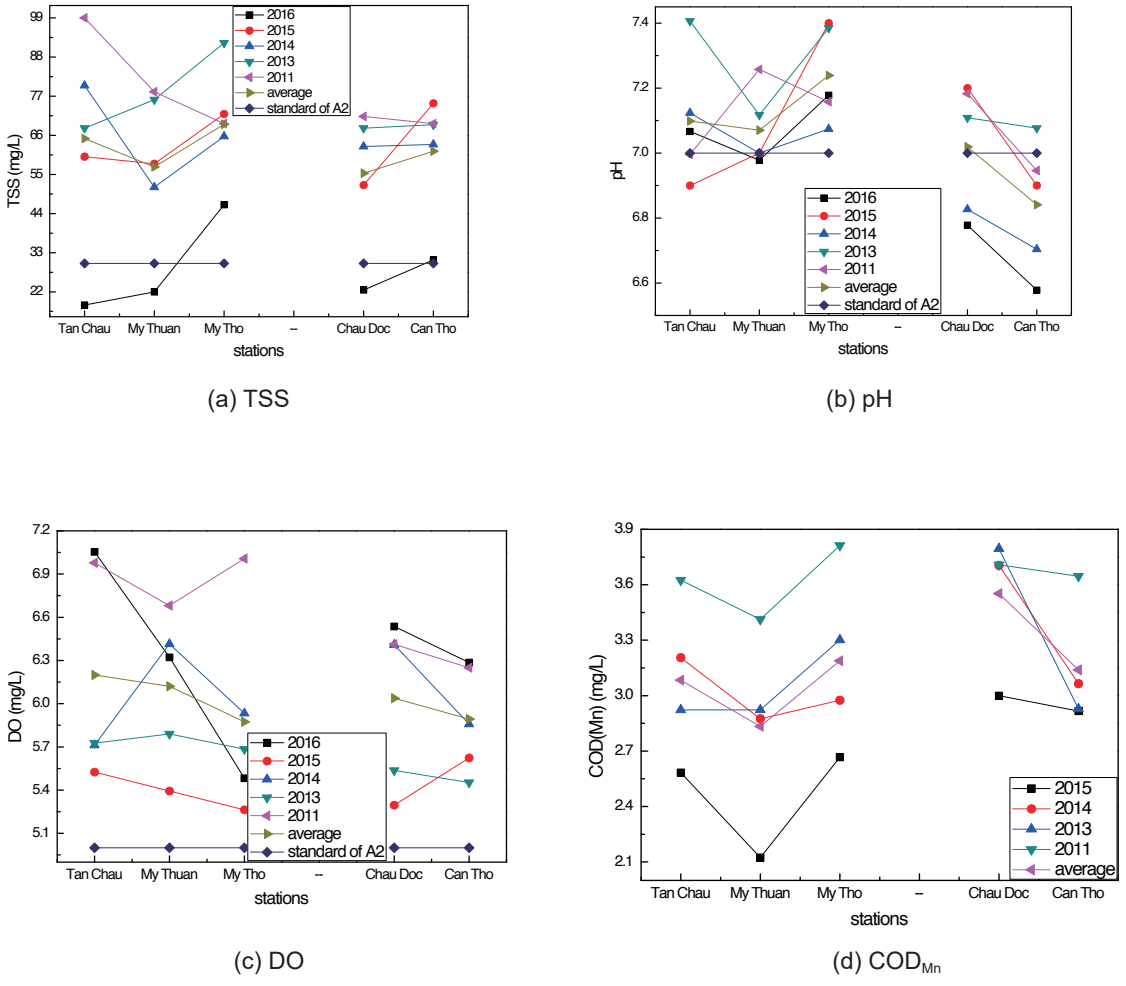


Figure 2-11 Changes of major environmental pollutants in Mekong River in Vietnam

2.6 Comparative Analysis of Water Environment Status in Lancang-Mekong Countries

A comparison of hydrological conditions in the Lancang-Mekong River Basin is as follows: along the Mekong River Basin, the water quantity increases first and then starts to decrease near Phnom Penh, which might be a result of an increase in water consumption due to a dense population after the river enters plans.

In general, water pollution in the Lancang-Mekong River Basin may be divided into pollution caused by natural factors and that caused by artificial factors. The upper basin is characterized by complicated geological structures and violent crustal movements, which often induce geological disasters such as landslides and debris flows that bring lots of sediments and suspended solids into rivers; in its more gentle middle and lower stretches, floods and rainstorms will often cause an increase in suspended solids and sediments and also in the turbidity of waters. However, artificial factors give rise to more serious pollution. As Lancang-Mekong countries are in the early days of development, where water quality management is not yet mature, the sewage treatment rate is too low and a large amount of domestic sewage and industrial wastewater is even directly discharged into rivers, causing pollution to the Mekong.

Chapter 3 Water Environment Monitoring and Management Framework in Lancang-Mekong River Basin

The water quality management framework in Lancang-Mekong River Basin is buttressed by competent administrations and agencies in Laos, Myanmar, Thailand, Cambodia, Vietnam and China, as well as government-formulated water environment pollution control plans.

3.1 Cambodia's Water Environment Monitoring and Management Framework

In Cambodia, central government agencies in charge of water environment management mainly consist of the Ministry of Environment (MOE), the Ministry of Water Resources and Meteorology (MWRM), the Ministry of Public Works and Transport (MPWT), the Ministry of Agriculture, Forestry and Fisheries (MAFF), the Ministry of Mines and Energy (MME) and Cambodia National Mekong Committee (CNMC). Among them, MOE, MWRM and CNMC are mainly in charge of water quality management. Taking Tonle Sap Lake for example, the list of Cambodian ministries engaged in lake protection is shown in Table 3-1.

Table 3-1 List of ministries engaged in the efforts to protect Tonle Sap Lake

Ministry	Affiliation	Responsibilities	Remarks
Ministry of Foreign Affairs and International Cooperation	ASEAN-Mekong unit	To deal with the framework for ASEAN-Mekong River Basin affairs and promote ASEAN integration	The Ministry is a member of Cambodia National Mekong Committee (CNMC)
Ministry of Agriculture, Forestry and Fisheries	Fishery sectors	To manage/issue fishing permits and govern other fishery areas	The Ministry is responsible for drafting fishery-related laws and regulations that guide the development of community-based fishery
	Ministry of Forestry	To manage the implementation of policies on forestry and wildlife	There are few policies relating to Tonle Sap Lake
Ministry of Environment	Many	To manage the core zones and protection zones of Tonle Sap Lake	The Ministry is responsible for drafting environmental laws and policies, Tonle Sap Lake is listed as biosphere; the development of Tonle Sap Lake Port (Chhong Kneas)
Ministry of Water Resources and Meteorology	Many	To formulate laws and policies on water resources; and develop/restore an irrigation network, etc.	Cambodia builds the Ministry into a core institution in charge of water management and a regulator of water permit/license; the Prime Minister serves as the Chairman of CNMC
Ministry of Public Works and Transport	Many	To be responsible for navigation, infrastructure development and river dredging, etc.	The Ministry once led the development of the Mekong region during 1957-2003
Ministry of Mines and Energy		To be responsible for hydropower and issuing licenses for mining riverbed placers and gravels, etc.	Petroleum and natural gas exploration are separately managed by competent agencies

3.2 Laos' Water Environment Monitoring and Management Framework

Set up on November 28, 2011, the Ministry of Nature Resources and Environment of the Lao PDR is an authority with functions and powers. Laos has integrated all solutions and plans with respect to environmental problems into the ministry and on this basis developed its environmental protection measures and plans. Laos has formed a water environment legal and policy system, as shown in Figure 3-1.

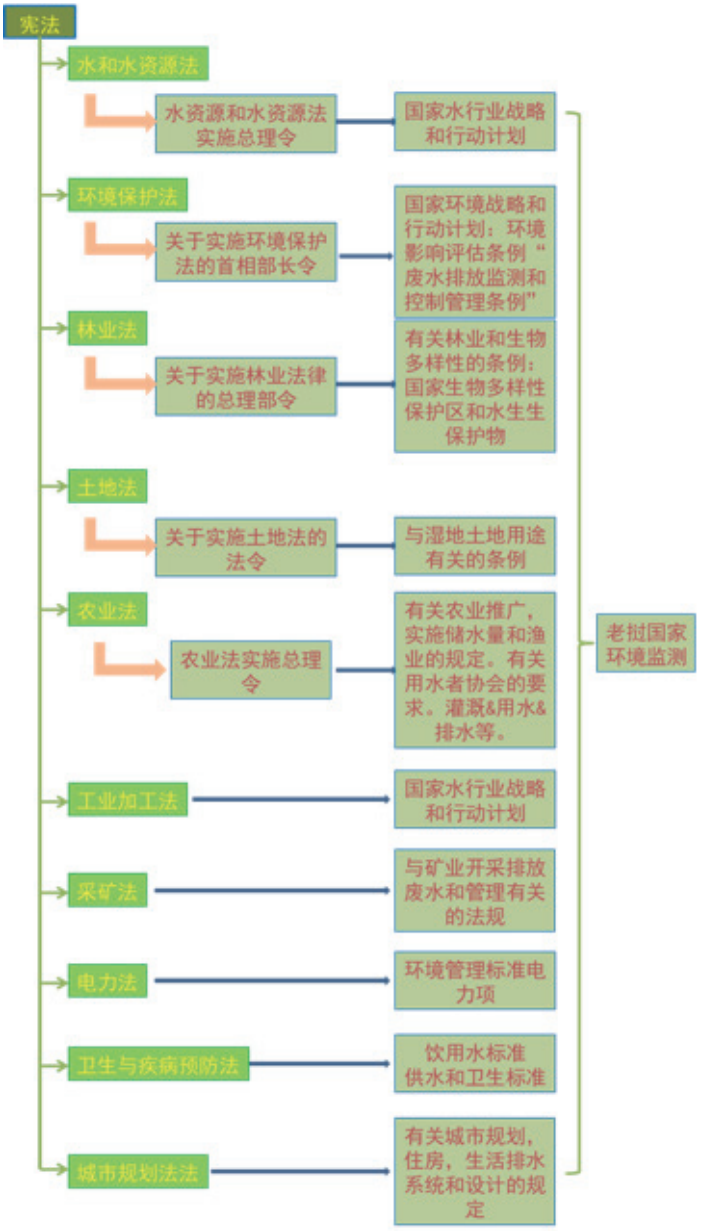


Fig. 3-1 Lao PDR's system of water environmental laws and policies

3.3 Myanmar's Water Environment Monitoring and Management Framework

Myanmar's water environment management department is mainly the Ministry of Natural Resources and Environmental Conservation. According to the division of functions, other government agencies involved in water environmental protection also include the Ministry of Agriculture, the Ministry of Livestock and Irrigation, the Wildlife Conservation Commission, and the Agricultural Service Bureau. Agricultural irrigation is the main way of using water resources in Myanmar. Therefore, the pollution of water bodies in Myanmar is mainly chemical fertilizer pollution and pesticide pollution. To this end, Myanmar has formulated and promulgated the "Pesticide Law" and "Water Resources and River Protection Law" to protect water bodies. In addition, Myanmar has also promulgated the "Myanmar Environmental Protection Law", the "Water Law of the Republic of the Union of Myanmar", and the "Groundwater Resources Protection Law of the Republic of the Union of Myanmar", which set out detailed regulations on water resources management and sewage prevention. At the same time, Myanmar has also regulated water resources management in the detailed rules for foreign investors to establish hydropower stations and reservoirs to maintain water security in Myanmar.

3.4 Thailand's Water Environment Monitoring and Management Framework

Thailand's water quality management system is comprised of Royal Irrigation Department under the Ministry of Agriculture and Cooperatives (MOAC), Metropolitan Waterworks Authority under the Ministry of Interior (MOI), Pollution Control Department (PCD), Department of Environment Quality Promotion (DEQP), Department of Marine and Coastal Resources; the Department of Water Resources; and Department of Groundwater Resources (DGR) under Ministry of Nature Resources and Environment (MoNRE).

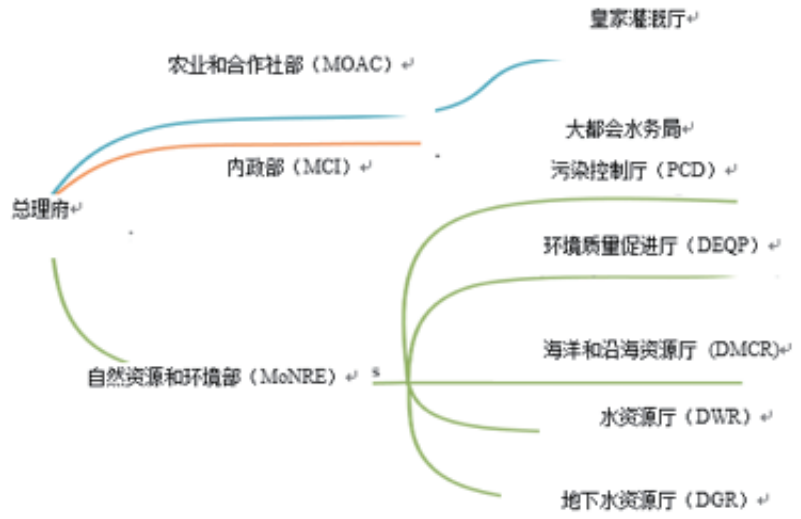


Fig. 3-3 Composition of the water quality management system

3.5 Vietnam's Water Environment Monitoring and Management Framework

In Vietnam, the Department of Construction and the Department of Agricultural and Rural Development have been established to take specific responsibilities for water supply and water sanitation control respectively in urban and rural areas. In recent years, the Department of Nature Resources and Environment has formulated a series of management plans to intensify water resources management and ameliorate problems about drinking water safety.

Chapter 4 Water Quality Standards of Countries along the Lancang-Mekong River

4.1 Cambodia's Water Quality Standard

Cambodia's standard for surface water quality consists of two parts, which are based on the purpose of protecting bio-diversity and public health respectively, as shown below:

Table 4 -1 Water quality standards for biodiversity conservation for public waters in Cambodia

Parameters	River	Lake and Reservoir	Offshore Seawater
PH Value	6.5-8.5	6.5-8.5	7.0-8.3
BOD (mg/L)	1-10	1-8	2-8
Suspended Solids (mg/L)	25-100	1-15	-
Dissolved Oxygen (mg/L)	2-7.5	2-7.5	2-7.5
Bacillus Coli (MPN·100/mL)	<5000	<1000	<1000
Total Nitrogen (mg/L)	-	0.1-0.6	0.2-1.0
Total Phosphorus (mg/L)	-	0.005-0.05	0.02-0.09
Oil Contents (mg/L)	-	-	0

Table 4 -2 Water quality standards for public health for public waters in Cambodia

Parameter	Standard Value (ug/L)	Parameter	Standard Value (ug/L)	Parameter	Standard Value (ug/L)
Tetrachloride	<12	Chloroform	<<12	Organic Mercury	0
Benzene hexachloride	<0.03	1，2Trichloroethanol	<10	Lead	<10
DDT	<10	Trichloroethanol	<10	Hexavalent chromium	<50
Endidrin	<0.01	Trichlorobenzene	<0.4	Arsenic	<10
Dieldrin	<0.01	Hexachlorocyclohexane	<0.05	Selenium	<10
Aldrin	<0.005	Benzene	<10	Polychlorides	0
Isodrin	<0.005	Tetrachloroethanol	<10	Chlorides	<0.005
Perchloroethanol	<10	Calcium	<1		
Hexachlorobutylene	<0.1	Total mercury	<0.5		

4.2 Laos' Water Quality Standard

Laos' water quality standard contains 30 parameters. Among them, 2 are physical parameters; 2 biologic parameters; 2 radioactive parameters; and 24 chemical parameters. The chemical parameters involve those targeting heavy metal elements and toxic compounds (as shown in Table 4-4). Laos' standard for surface water quality does not involve parameters for oil and fat. For more details about the standard for surface water quality, please refer to Table 4-3 and 4-4.

Table 4-3 Parameters of Laos' standard for surface water quality monitoring

Physical / chemical parameters	**Temperature, pH Value, Electrical conductivity, TSS, Ca, Mg, Na, K, Alk, Cl, SO_4, NO_3-N, NH_4-N, PO_4-P, Tot-P, DO&COD**
Pesticide residues	DDT, Aldrin, Dieldrin, Chlorinated hydrocarbon
Biological parameters	Faeces, coliform groups, Streptococcus faecalis, bottom fauna density
Sediment transport	Suspended sediment concentration

Table 4-4 Laos' standard for surface water quality			
Parameter	**Symbol**	**Unit**	**Parameter**
Chromaticity, smell and Taste			Within the acceptable range
Temperature	T	℃	Within the acceptable range
pH Value	pH		5 ~ 9
Dissolved Oxygen	DO	mg/L	6
Chemical Oxygen Demand	COD	mg/L	5
Five-day BOD	BOD_5	mg/L	1.5
Total Coliform	Coliform Bacteria	MPN/100ml	5000
Faecal Coliform	Faecal Coliform	MP/100ml	1000
Nitrate Nitrogen	NO_3-N	mg/L	<0.5
Ammoniacal Nitrogen	NH_3-N	mg/L	0.2
Phenol	C_6H_3-OH	mg/L	0.005
Copper	Cu	mg/L	0.1
Nickle	Ni	mg/L	0.1
Manganese	Mn	mg/L	1.0
Zinc	Zn	mg/L	1.0
Cadmium	Cd	mg/L	0.005
Hexavalent Chrome	Cr_6^+	mg/L	0.05
Lead	Pb	mg/L	0.05
Mercury	Hg	mg/L	0.002
Arsenic	As	mg/L	0.01
Cyanide	CN^-	mg/L	0.005
Radioelement α	A	Becquerel /L	0.1
Radioelement β	B	Becquerel /L	1.0
Total Organic Chlorine	——	mg/L	0.05
DDT	$C_{14}H_9Cl_5$	mg/L	1.0
α-BHC	αBHC	mg/L	0.02
Dieldrin	$C_{12}H_8Cl_6O$	mg/L	0.1
Aldrin	——	mg/L	0.1
Heptachlor and Heptachloroepoxide	——	mg/L	0.2
Endrin	——	mg/L	None

4.3 Myanmar's Water Quality Standard

Myanmar has not developed its own surface water quality standard and thus adopts relevant international standard. Listed below is Myanmar's standard for waste water, rain water runoff, sewage and sanitary discharge and Yangon's water quality standard.

Table 4-5 Myanmar's standard for waste water, rain water runoff, sewage and sanitary discharge

Parameter	Unit	Standard Value
BOD_5	mg/L	50
Ammonia	mg/L	10
Arsenic	mg/L	0.1
Cadmium	mg/L	0.1
COD	mg/L	250
Chloride	mg/L	0.2
Chromium Hexavalent	mg/L	0.1
Total chromium	mg/L	0.5
Copper	mg/L	0.5
Cyanide (free)	mg/L	0.1
Cyanide (total)	mg/L	1
Fluoride	mg/L	20
Heavy metals (total)	mg/L	10
Iron	mg/L	3.5
Lead	mg/L	0.1
Mercury	mg/L	0.01
Nickle	mg/L	0.5
Oil and grease	mg/L	10
PH	S.U.a	6-9
Phenols	mg/L	0.5
Selenium	mg/L	0.1
Silver	mg/L	0.5
Sulfides	mg/L	1
Temperature rise	℃	<3b
Total coliform group	100mL	400
Total phosphorus	mg/L	2
Total suspended solids	mg/L	50
Zinc	mg/L	2

4.4 Thailand's Water Quality Standard

Based on the intended use, Thailand's surface water quality standards are divided into 5 categories. In Thailand, there are 26 rivers, which are put under 4 geographic regions, involving the central part, the northeast part, the south part and the east part. The rivers are subject to the quality standards based on 5 water bodies which specify the category of water quality and its parameters at different segments of the main rivers.

Table 4-6 Category of Thailand's surface water source

Category	Use
Class I	Those that haven't been influenced by any waste water from any human activities, and can be used for: (1) daily use after sterilized; (2) biological growth; (3) preservation of ecosystem
Class II	Those that have been influenced by waste water of a certain human activities, and can be used for: (1) daily use after sterilized and overall water conditioning; (2) protection of water creatures; (3) fishery industry; (4) swimming and water sports
Class III	Those that have been influenced by waste water of a certain human activities, and can be used for: (1) daily use after sterilized and overall water conditioning; (2) agricultural purpose
Class IV	Those that have been influenced by waste water of a certain human activities, and can be used for: (1) daily use after sterilized and overall water conditioning; (2) industrial purpose
Class V	Those that have been influenced by waste water of a certain human activities, and can be used for transportation

Thailand's surface water quality standards contain 28 parameters. Among them, 2 are physical parameters; 2 biologic parameters; 1 radioactive parameters (involving radio-element α and β) and 23 chemical parameters. Accordingly, monitoring methods are made for them.

Table 4-7 Thailand's surface water quality standard

Water quality parameter	Unit	Percentile	Highest requirements (dependent on types of water quality that are being used)					Monitoring methods
			A	B	C	D	E	
1.Color, smell and taste	-	-	T	T'	T'	T'	-	-
2.Temperature	℃	-	T	T'	T'	T'	-	Measuring with temperature meter during sampling
3.pH	-	-	T	5-9	5-9	5-9	-	Measuring with pH meter, Electromagnetic loss
4.Dissolved Oxygen	mg/L	P20	T	6.0	4.0	2.0	-	Azide modification
5.BOD	mg/L	P80	T	1.5	2.0	4.0	-	Azide modification at 20 ℃ for 5 consecutive days
6.Total coliforms	MPN/100mL	P80	T	5,000	20,000	-	-	Multi-tube fermentation
6.Fecal coliform count	MPN/100mL	P80	T	1,000	4,000	-	-	Multi-tube fermentation
7.Nitrate nitrogen (NO3)	mg/L	-	T	5.0			-	Cadmium reduction
8.Ammonia nitrogen (NH3)	mg/L	-	T	0.5			-	Distillation denitrification
9.Phenol (phenols)	mg/L	-	T	0.005			-	Distillation of 4-aminopyrene
11.Copper (Cu)	mg/L	-	T	0.1			-	Atomic absorption-direct suction
12.Nickle (Ni)	mg/L	-	T	0.1			-	Atomic absorption-direct suction
13.Manganese (Mn)	mg/L	-	T	1.0			-	Atomic absorption-direct suction
14.Zinc (Zn)	mg/L	-	T	1.0			-	Atomic absorption-direct suction
15.Cadmium (Cd)	mg/L	-	T	0.005* 0.05**			-	Atomic absorption-direct suction
16.Chromium sulfite (Hexavalent chromium)	mg/L	-	T	0.05			-	Atomic absorption-direct suction
17.Lead (Pb)	mg/L	-	T	0.05			-	Atomic absorption-direct suction
18.Total mercury	mg/L	-	T	0.002			-	Atomic absorption-cold vapor technology
19.Arsenic (As)	mg/L	-	T	0.01			-	Atomic absorption-direct suction
19.Cyanide (CN)	mg/L	-	T	0.005			-	Pyridine.
21.Radioactive α-β radiation	Bq/L	-	T	0.1			-	Barbituric acid
22.Total organochlorine	mg/L	-	T	0.05			-	Low background ratio counter
23.DDT	μg/L	-	T	1.0			-	Gas chromatography
24.α-BHC	μg/L	-	T	0.02			-	Gas chromatography
25.Dieldrin	μg/L	-	T	0.1			-	Gas chromatography
26.Aldrin	μg/L	-	T	0.1			-	Gas chromatography
27.Heptachlor and heptachloroepoxide	μg/L	-	T	0.2			-	Gas chromatography Gas chromatography
28.Endidrin	μg/L	-	T	annot be detected with designated detection methods			-	Gas chromatography

Note: Special regulations are made on Type II, III and IV water source standards. Type I is based on natural conditions, and there is no specific regulation on Type IV; 2. DO, or dissolved oxygen, means the minimum value; 3. T means natural conditions; T indicates that the water temperature should not be higher than when it is under natural conditions, which is 3 °C; 4.* means that the content of solid $CaCO_3$ in the water is no higher than 100mg/L; ** means that the content of solid $CaCO_3$ in the water is higher than 100mg/L; 5. °C means Celsius degree. 6. P20 means that the percentage of waste water samples that were successively collected is 20%; P80 means that the percentage of waste water samples that were successively collected is 80%; 7. MPN represent Most Probable Number.

4.5 Vietnam's Water Quality Standards

Vietnam has its own surface water quality standards with its distinctive characteristics. For example, the standards still contain plenty of parameters for pesticide and herbicide, which can be explained by some historic issues. Besides, it also imposes stricter standards on nitrate nitrogen and nitrous nitrogen than other countries.

Table 4-8 Classification of Vietnam surface water source

Category		Use
Class A	Class A1	Class A1 can be a reliable source for domestic use, and for the purposes specified within the category of A2, B1 and B2.
	Class A2	Class A2 can be a reliable source for domestic use, only after industrial treatment; it can also be used for plants in the aquatic ecosystem, or the purposes specified within the category of B1 and B2.
Class B	Class B1	Class B1 can be used for irrigation or other purposes that have similar requirements for water quality, and for the purposes specified within the category of B2.
	Class B2	Class B2 can be used for water transportation or other purposes that have lower requirements for water quality.

Table 4-9 Limit value of parameters for surface water quality in Vietnam [65]

No.	Parameter	Unit	Standard Value			
			A		B	
			A1	A2	B1	B2
1	pH Value	—	~ 8.5	~ 8.5	5 ~ 9	5 ~ 9
2	(DO)	mg/L	≥6	≥5	≥4	≥2
3	TSS		20	30	50	100
4	COD		10	15	30	50
5	BOD_5 (20℃)		4	6	15	25
6	NH_4+ (by N)		1	2	5	1
7	Cl-		250	400	600	—
8	F-		1	5	5	2
9	NO_2- (by N)		0.1	0.2	0.4	0.5
10	NO_3- (by N)		2	5	10	15
11	PO_4- (by P)		1	2	3	5
12	CN-		0.05	0.05	0.1	0.1
13	Arsenic		0.1	0.2	0.5	1
14	Cadmium		0.05	0.05	0.1	0.1
15	Lead		0.02	0.02	0.05	0.05
16	Cr^{3+}		0.05	0.1	0.5	1
17	Cr^{6+}		0.01	0.02	0.04	0.05
18	Copper.		0.1	0.2	0.5	1
19	Zinc.		0.5	1	1.5	2
20	Nickel.		0.1	0.1	0.1	0.1
21	Iron.		0.5	1	1.5	2
22	Mercury		0.001	0.001	0.001	0.002
23	(Anionic) Surface activator		0.1	0.2	0.4	0.5
24	Petroleum		0.01	0.02	0.1	0.3
25	Phenol (total)		0.005	0.005	0.01	0.02
26	Organic residueRemaining	µg/L	0.002	0.004	0.008	0.01
	Aldrin+		0.01	0.012	0.014	0.02
	Endidrin		0.05	0.1	0.13	0.015
	EndidrinHCB BHC		0.001	0.002	0.004	0.005
	DDT		0.005	0.01	0.01	0.02
	Endosulfan.		0.3	0.35	0.38	0.4
	Lindane		0.01	0.02	0.02	0.03
	Chlordane		0.01	0.02	0.02	0.03
27	Organophosphorus parathion.		0.1	0.2	0.4	0.5
	Malathion		0.1	0.32	0.32	0.4
28	Chemical herbicide					
	2.4D		100	200	450	500
	2.4.5T		80	100	160	200
	Paraquat		900	1200	1800	2000
29	Total alpha radioactivity	Becquerel /L	0.1	0.1	0.1	0.1
30	Total beta radioactivity	Becquerel /L	1.0	1.0	1.0	1.0
31	Escherichia coli	MPN/100mL	20	50	100	200
32	Total coliforms	MPN/100mL	2500	5000	7500	10000

Chapter 5 Prospect of Lancang-Mekong Cooperation in Water Quality Monitoring

2On December 17, 2018, the 4th Lancang-Mekong Cooperation (LMC) Foreign Ministers' Meeting was held in Luang Prabang, Laos. The six countries agreed to focus efforts on the construction of LMC economic development belt and carry out cooperation in areas such as production capacity, innovation, well-being, and environmental protection. They promised to continuously strengthen mechanism building, so that the LMC mechanism and other sub-regional mechanisms can complement and promote each other to make greater contributions to sub-regional economic and social development. With the aim of productive, innovative, inclusive, green and open Lancang-Mekong region, they will continue to foster the "3+5+X" cooperation framework and make the LMC mechanism deeper and more efficient by strengthening cooperation at local levels.

Deepening environmental cooperation and implementing the Green Lancang-Mekong Initiative is an important way to the target of green Lancang-Mekong region. The meeting highlighted the five closely linked drivers of building the LMC economic development belt, i.e. coordinated, industrial, innovative, green, and integrated development. Green development as one of the drivers requires significantly improving the ecological environment and protecting and rationally using water resources. The Green Lancang-Mekong Initiative is to explore the environmental governance model suitable for Lancang-Mekong countries, which will contribute to green development with priority given to ecology.

Environmental protection represents one of the future LMC directions. The meeting called for deeper environmental cooperation by jointly implementing the Green Lancang-Mekong Initiative and carrying out pragmatic cooperation in environmental governance and biodiversity conservation, with a view to green, low-carbon and circular development.

The Green Lancang-Mekong Initiative is designed and implemented by the Lancang-Mekong Environment Cooperation Center under the guidance of the Ministry of Ecology and Environment of China to implement the Lancang-Mekong Environment Cooperation Strategy. It is a flagship project under the LMC framework that focuses on environmental policy mainstreaming, capacity building, joint research, and demonstration project. Since its launch, positive progress has been made in cooperation network building, capacity building project innovation, regional joint research, and demonstration project, towards the objective of regional flagship project of sustainable development. In the future, the Lancang-Mekong Environmental Cooperation Center will carry on the Green Lancang-Mekong Initiative and step up Lancang-Mekong environmental cooperation, with put focus on policy dialogue, capacity building, demonstration cooperation, and technology industries, in an effort to promote regional sustainable development in economic, social, and environmental dimensions.

Based on the systematic analysis of water environment monitoring and management systems, the following suggestions are put forward for Lancang-Mekong cooperation in water quality monitoring:

First, attention should be paid to the Lancang-Mekong construction of water quality monitoring standards and management systems. The Lancang-Mekong countries face different challenges in the capacity building for water quality monitoring. For example, Laos has relatively weak water quality monitoring capacity, including expertise and skills, while Myanmar lacks water quality monitoring technology and equipment, especially facilities for monitoring industrial wastewater discharge. The Environmental Cooperation Center will be enhanced to effectively deepen Lancang-Mekong cooperation in the formulation of water quality monitoring standards. Focusing on water quality monitoring standards and management, regional surveys and capacity building activities can be organized, so that the Lancang-Mekong countries can build and improve respective water quality monitoring standard and management systems according to their needs.

Second, capacity building and cooperative project in water quality monitoring will be carried out. At present, most of the Lancang-Mekong countries are in the start stage of water quality monitoring capacity building, where water quality monitoring is not yet systematic due to lack of monitoring equipment, technology and talents. Guided by the Lancang-Mekong Environmental Cooperation Strategy, it is advisable to take the opportunity of Lancang-Mekong water quality monitoring capacity building activities to promote Lancang-Mekong cooperation on water quality monitoring and management and gradually implement demonstration projects on water quality monitoring and water environment management. This meets the needs of Lancang-Mekong countries in water environment management.

Third, technical solutions for water quality monitoring should be shared, and financing models such as green finance and private-public partnership (PPP) explored to promote Lancang-Mekong water environmental protection. The Lancang-Mekong countries should jointly explore investment and financing models for water quality monitoring and water environmental protection. They can widely attract investments through green bonds and PPP projects of water environment governance, and strengthen cooperation with international organizations in green investment and financing. Meanwhile, they should cement the hardware facilities for water quality monitoring to drive the systematic improvement of water environment management capacity of the entire region.

Fourth, demonstration projects and technology and knowledge sharing platforms should be designed for Lancang-Mekong water quality monitoring. According to the pragmatic needs of Laos, Cambodia and other Lancang-Mekong countries for the construction of water quality monitoring stations and labs, projects should be implemented as soon as possible, using a state-led model with social engagement, to introduce China's water quality monitoring stations, water quality analysis labs, and excellent water treatment technologies to the region. Moreover, Chinese outstanding technical companies will be invited to establish the Lancang-Mekong technology and knowledge sharing platform and capacity building base for water environment monitoring, which will provide specific services for the management and technical staff of Lancang-Mekong countries.

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About LMEC: Lancang-Mekong Environmental Cooperation(LMEC), established in 2017 in Beijing, China, aims to boost the capacity of environmental governance of each country and achieve regional sustainable development through the promotion of environmental cooperation among the Lancang-Mekong Countries.