Artificial Floating Islands: a Technology for Clean Water and Agricultural Production in Rural China

Zhaohua Li [*1], Yanqiang Li [1], Wei Huang [2], Lianhai Sang [2]

[1]School of Resources and Environmental Science, Hubei University, Wuhan 430062, P. R. China

[2]Water Resources Management Department, Yangtze River Scientific Research Institute, Wuhan 430010, P. R. China

zli@hubu.edu.cn

***Abstract*- The Artificial Floating Islands (AFIs) are an innovative variant of wetlands with substrates-rooted plants and free-floating aquatic plant systems, which consist of aquatic or terrestrial plants growing in a hydroponic manner with buoyant frames floating on the surface of water bodies. On the AFIs, plants are enforced to attain nutrition directly from the water column as they are not rooted in any substrate, which improves the uptake rates of nutrient into biomass. The plant products produced by AFIs can be easily harvested and subsequently used as animal even human food or be processed into biogas, biofertilizer and biomaterial, impelling the practical application of the technology due to the potential economic returns. More importantly, AFIs has the unique advantage of occupying no land area. The paper descripted the type, structure, function, and developing history of AFIs. By analyzing the social-economic benefits, suggestions were given to China for applying AFIs technology to improve the water environment and to cultivate crops thereby creating a "win-win" model for both environmental protection and agricultural development in rural places.**

Keywords*- *Artificial Floating Islands (Afis); Eutrophication; Waste Water Reruse; Rural China

I. INTRODUCTION

Comprising over 70% of the Earth's surface, water is undoubtedly the most precious natural resource that exists on our planet. Although we as humans recognize this fact, we disregard it by polluting our rivers, lakes, and oceans. Subsequently, we are slowly but surely harming our planet to the point where organisms are dying at a very alarming rate [1]. Regarding to our human beings, one fifth of the world's population is without access to safe drinking water and half of the population is without access to adequate sanitation. These service deficiencies primarily affect the poorest segments of the population in developing countries. In developing countries, water supply and sanitation for rural areas represents one of the most serious challenges in the years ahead [2].

However, wastewater management at all stages of handling is inadequate in rural areas. Poorly maintained or non-existent sewage systems, runoff from animal wastes, unregulated landfills with leachate that pollute aquifers, poorly maintained greenhouses, and increasingly, industrial effluents factor in to the wastewater and contamination problems. Untreated sewage in rural villages often flows freely into streets, agricultural fields, and wades, directly contaminating food and water, and directly contributing to a critical community and environmental health crisis [3, 4]. Attempted transfers of urban intensive technology to rural areas in most of developing countries have failed. Rural communities also typically lack the technical and management capacity to solve the problem alone. In most developing countries, very few applicable techniques have been successfully achieved to establish comprehensive and integrated programs for extensive wastewater treatment and reuse in rural areas [5].

The Artificial Floating Islands (AFIs) technology is borrowed from an analogous component in nature known as the floating island. These islands are formed as dense mats of vegetation - typically made up of cattails, bulrush, sedge and reeds - extend outward from shoreline wetlands. As the water gets deeper the roots no longer reach the bottom, so they use the oxygen in their root mass for buoyancy, and the surrounding vegetation for support to retain their top-side-up orientation. The area beneath these floating mats is exceptionally rich in aquatic biota [6].

AFIs is an innovative variant of wetlands with substrates-rooted plants and free-floating aquatic plant systems, which consists of aquatic or terrestrial plants growing in a hydroponic manner with buoyant frames floating on the surface of water bodies. The entire underwater surface of the plants serves as a base for the attaching of microorganisms, which favors the break-down of organic matters and the entrapment of suspended solids. Moreover, the plants are enforced to attain nutrition directly from the water column as they are not rooted in any substrate, which may improve the uptake rates of nutrient into biomass. The plant products produced by AFI can be easily harvested and subsequently used as animal even human food or be processed into biogas, biofertilizer and biomaterial, impelling the practical application of the technology due to the potential economic returns. More importantly, AFI has the unique advantage of occupying no land area. While AFIs have become a common environmental technique in some countries, their special features matching agriculture and waster-water treatment has not been fully understood in developing world. Thereby it is critically needed to give a brief introduction of perspective and progress of AFIs technology to enhancing the understanding of benefits that can be derived from AFIs.

II. TECHNOLOGY REVIEW

A floating island is a mass of floating aquatic plants, mud, and peat ranging in thickness. It is a common natural phenomenon that is found in many parts of the world, generally found on marshlands, lakes, and similar wetland locations. Sasser et al. define a natural floating marsh island as: "a marsh of vascular vegetation having a significant mat of live and dead roots, peat and detritus that floats over a layer of free water" [7]. Floating islands may comprise of small, mobile floating mats, or extensive, stationary vegetated mats covering hundreds of hectares of water surface and can even support mature stands of trees [8, 9].

A. Historical Perspectives

The natural phenomena of floating island had been thrived in a similar way to cultivate crops, which acquiring their nutrition directly from the water column rather than the soil or benthic silt, forming artificial floating islands (AFIs). Documentary records suggested that about 1700 years ago (China's Three Kingdoms Era), Chinese farmer started to adapt AFIs for planting rice and vegetables (Fig. 1). This floating aquatic cultivation is still applied in some Asian countries such as Myanmar (Fig. 2), India (Fig. 3), Bangladesh and China.

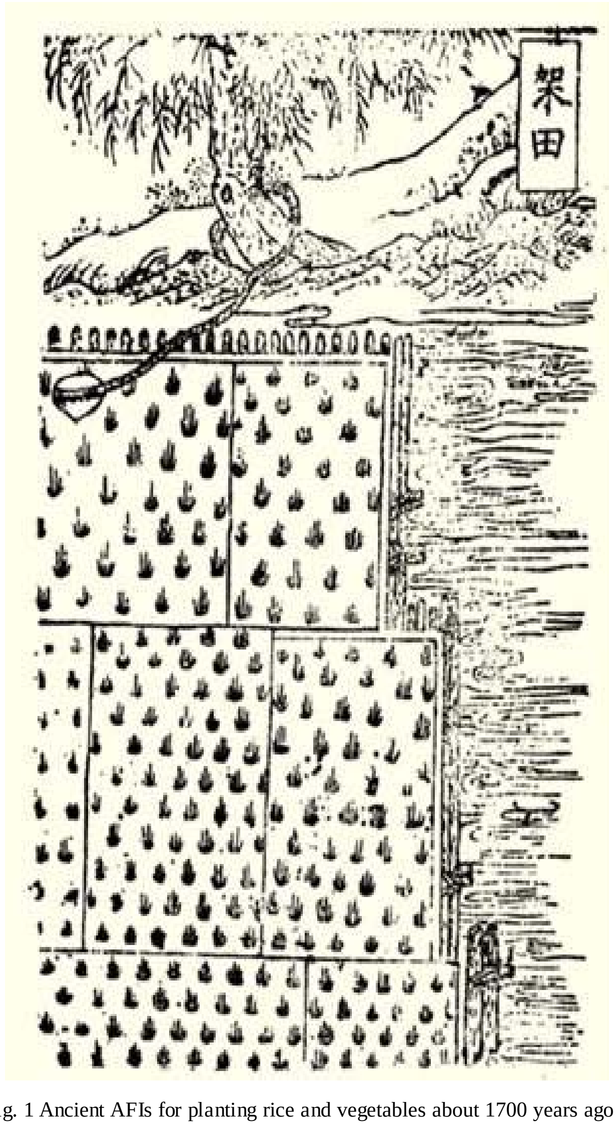

Fig. 1 Ancient AFIs for planting rice and vegetables about 1700 years ago in China (picture adapted from《Nong Shu》(Agricutural encyclopaedia), Vol.11, edited by Wang Zhen in Yuan Dynasity, published in AD1300)

Fig. 2 Current Idian floating farming islands

Fig. 3 Current Myanmar floating farming islands in Inle Lake

AFIs are also applied as human and animal habitats. The best known examples are those of the Uros people of Lake Titicaca, Peru, who build their villages upon what are in effect huge rafts of bundled totora reeds (Fig. 4). The Uros originally created their islands to prevent attacks by their aggressive neighbors, the Incas and Collas. Spiral Island was a more modern one-person effort of constructing AFIs in Mexico [10]. In 1900, AFIs were installed in New Hampshire (USA) lakes to provide nesting habit at for birds (AFI study group, 2000). In 1960s, Crawford (famous Father of Goose) used AFIs by a resident flock of Canada geese (*Branta canadensis*) in north-central Colorado [11].

Fig. 4 Village on artificial floating islands of Uros in Lake Titicaca, Peru

Since late 1980s, AFIs have been applied on environmental protection for water purification. In 1979, German started using a modern AFI design, called Sc-hwimmkampen; meaning “floating campus” [12]. In the early 1980’s, Japanese scientists design and testing of large AFI s in Lake Biwa. A great deal of information was learned to improve their structural design and biological benefits. The International Conference of Lakes -Kasumigaura 95 was hosted by Japan in 1995 and resulted in increased interest in this technology [13]. Since then, AFIs technology has also spread to Korea, Australia, Canada, China, India, Germany, UK and the USA [14].

B. Environmental Benefits

AFIs technologies can accomplish a variety of tasks in both natural and constructed bodies of water. Its environmental benefits include: (1) To create habitat for fish and birds: AFIs can support growth of aquatic plant and thus create a habitat and offer shelter for birds, insects, and other bio-organisms. It also provides “spawning bed” for fish. As a result, the ecological diversity is intended to restore and improve after construction of AFI; (2) To purify water: The growth of aquatic plants densely on the AFI and the micro-organisms attached in the AFI help purify water a lot. Besides, the AFI can inhibit growth of phytoplankton due to that it occupies water surface and form a “shadowing effects”; (3) To break wave and protect littoral zone: The AFI is designed to dissipate wave and can help stabilize and protect littoral zone through reducing wave impacts and erosion, and thus advantageous to the recovery and growth of vegetation in the littoral zone; (4) To improve landscape: The growth of different plants on floating island form a favorable landscape; (5) To control algae: AFI will not eliminate algae directly. The synergy of plants and micro-organisms does the job: micro- organisms /biofilm is able to sequester the nutrients out of the water column faster than algae; and algae starve in the wake. This procedure is more advantageous than chemical fight against algae for it leaves no dead algae behind – what would later become more nutriments; (6) To produce agricultural products: In some cases flowers, vegetables, and grains can be cultivated on AFIs. Agricultural products could be exported from the AFIs as byproducts of environmental protection.

In rural places, AFIs have the ability to purify wastewater, maintain pond health or restore stressed natural bodies of water. In natural ponds, they rejuvenate water badly impacted from landfill and septic tank lagoon wastes and reduce the impact of eutrophication, or nutrient enrichment. Applications in the developing world, particularly in rural areas, are endless. They have the capability, when integrated with other natural systems technologies, to treat sewage to advanced wastewater and water reuse standards.

The process of AFIs treating the waster-water like this: (1) Micro-organisms colonize the matrix of the island, as well as the root and rhizome system, - creating the biofilm -, and take nutriments out of the water; (2) Phosphates and nitrates pass through the metabolism or the micro-organisms and are thus transformed into an ‘easier digestible form’; (3) The transformed nutriments are deposited directly on the roots of the plants; (4) The plants take them in and build with them the biomass above the water level: leafs and stems; (5) The biomass is harvested; taking the excess nutriments effectively and permanently out of the water.

During the treating process, AFIs restorate the water environment by: (1) Intriducing oxygen and circulation to the stressed environment that often lacks sufficient oxygen-rich surface areas necessary to maintain a balanced ecology; (2) Utilizing native higher plants and artificial media as bio-film substrate to support rich microbial and animal communities; (3) Acting as a chemostat and incubator by producing great volumes of beneficial microorganisms that flow into the surrounding water and feed on excess nutrients and organic pollutants; and (4) Providing opportunities for benthic communities to establish themselves in the bottom areas that were once oxygen poor (Fig. 5).

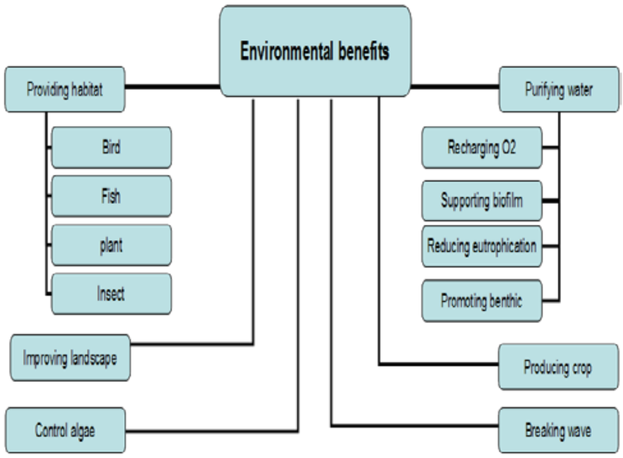

Fig. 5 Environmental benefits of artificial floating islands (AFIs)

III. AFIS STRUCTURE

A. Bouyant Structure

AFIs come in many shapes and sizes, depending on their desired function. Typically, in floating islands, buoyancy is provided artificially through the use of a floating structure or raft which supports the growth of the plants. For example, Floating Islands International injects expanded polystyrene foam into their polyester matrix in order to provide the desired level of buoyancy. In other applications, sealed PVC or PP pipes, polystyrene sheets, bamboo or inflatable vinyl pillows have been used to provide flotation. In general however, there are three main approaches that have been adopted: (1) The construction of a buoyant frame that supports some sort of mesh on which the plants grow (Fig. 6); (2) The use of a buoyant material which itself serves to support the growth of the plants (Fig. 7); (3) The development of an auto-buoyant plant mat which may involve the provision of small buoyant structures that support the initial development of appropriate plants species that have an affinity for creating auto-buoyant mats such as appropriate plants species that have an affinity for creating auto-buoyant mats such as *Typha* spp.

Fig. 6 Buoyant frame AFIs designed by Hubei University (Frame is of welded high-density polyethylene (HDPE) pipes filled with polyfroms)

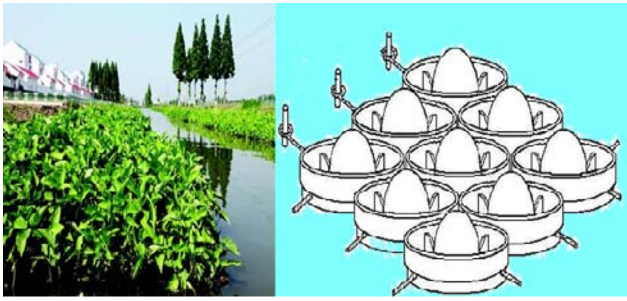

Fig. 7 Bouyant material AFIs designed by Hubei University (Material is comprised of polyester fibre matrix injected with polystyrene foam to form a floating platform).

Generally, the most common approach involves the creation of a floating raft or pontoon that consists of a buoyant frame enclosing a permeable material into which wetland vegetation can be planted and establish. In many cases, a floating frame is constructed using sealed lengths of PVC or other plastic pipes. These may be joined together to form a buoyant square or rectangular frame, or used as individual linear sections that are connected in some other way to form a floating frame (Fig. 8).

Floating bed,Germany

Floating bed,Germany

Floating bed, the U. K.

Floating bed, USA

Floating bed, Korea

Floating bed, New Zealand

Floating bed, Taiwan,China

Floating bed, mainland China

Fig. 8 Diversity of bouyant structure in different countries

B. AFIs Types

According to its platform structure, the AFIs are classified into two types, the dry type and the wet type (Tab. 1). The Wet type with frame is the most frequently used type until now, sharing about 70% or more, dry type shares 20%, and wet type without frame shares about 10%.

TABLE I TYPE OF AFIS

Type		**Characteristics**
Wet Type	Mat-with-frame	Vegetation base: usually inundated by water. Dominant plant: emergent plant, such as reed, cattail, etc. Advantages: habitat for bird resting and fish spawning, water purification, etc.
	Mat-without frame	Vegetation base: up-part emergent out of water. Dominant plant: hydrophyte plant. Advantages: habitat for birds resting, natural landscape
	Floating log type	Vegetation base: contacts with water. Dominant plant: water-resisting plant such as willow. Advantages: habitat for birds, ducks
	Waste tire type	To use wasted tire and pet bottle for plant growing. Easily making with low cost.
Dry Type	Box type	Vegetation base: doesn't contact with water. Dominant plant: terrestrial tree and grass. Advantages: Habitat for bird resting and fish spawning, good landscape, wave-broken
	Floater type	Vegetation base: doesn't contact with water. Dominant plants: emergent plant such as reed, cattail. Advantages: habitat for birds, duck, aquatic animals

TABLE II FIXING TYPE OF AFIS

Items	Gravity Type	Anchor Type	Pole Type
Water depth	Possible in every depth	Water deeper, requirement higher	Water deeper, pole longer
Geology	No influence	influence	influence
Displacement with water level	Horizontal displacement	Horizontal displacement	Vertical movement
landscape	Exposure of anchor in the low level season	Anchor is fixed under water without exposure	Exposure of poles don't do good to landscape, but it may offer resting places for birds.
Economically	Heavier the weight, much cost of both material and construction	Material is expensive, but construction is less expensive than gravity type	Shallow places, cost is less than gravity and anchor type
Construction	large size machine, and complex construction	Less large machine and less complex than gravity	Large machine and difficult construction

The basic physical components to AFIs are: the floating structure to support media, air distribution systems and dense arrays of higher plants, including shrubs and trees; the high surface area media for attached-growth (biofilm) treatment and support of diverse biological communities; the air distribution system for aeration and circulation.

C. AFIs Fixing

There are 3 methods for fixing of AFI: gravity type, anchor type, and pole type. See Figs. 9-11.

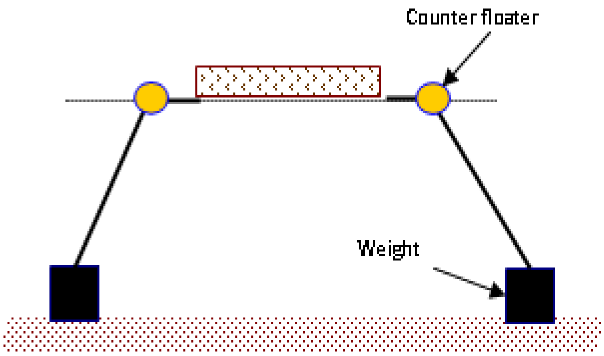

Fig. 9 Gravity type fixing

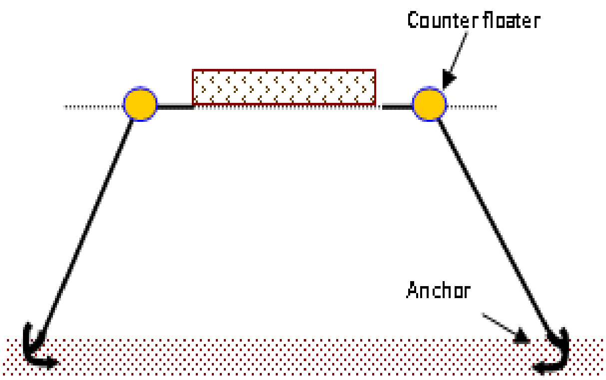

Fig.10 Anchor type fixing

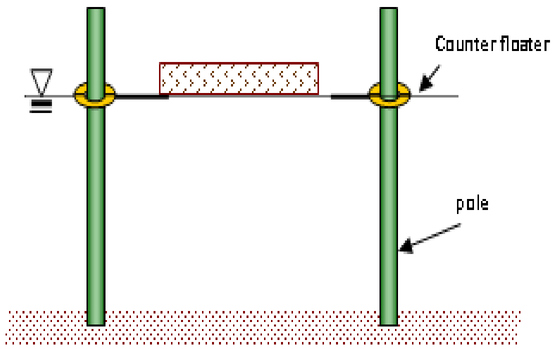

Fig.11 Pole type fixing

IV. AFIS FOR AGRICULTURAL PLANTATTION

A. Floating Field in China

China has a long history for hydroplantation. About 1700 years ago in Jin Dynasty, a Chinese book entitled "Southern grass" recorded that the local farmers using reed raft to making floating field, on which vegetables were growing. As the time being, ancient farmers in southern China started to build permanent floating field (Fengtian in Chinese): a framework was made by wood or bamboo, and then wild rice stems or reeds were filled into the frame. Thereafter, mud was covered the floating mat to form arable island. The floating island was tied with a rope to the bank. When stronge wind or heavy rain came, the farmer pushed them away for parking in sheltered places; when weather condition improved, then returned them go to the open water.

Floating field is a major invention in the history of agriculture. It expanded the cultivated area and provided the farmer with a way to pass the drought. In Tang and Song dynasties, floating fields were widely applied in southern lowland of China. However, it seems the floating field disappeared in recent centuries.

Since 1990s, a number of Chinese scientists re-introduced modern AFIs technology from Japan and

Germany. Hubei University, as one of pioneer insititions for AFIs research, started to selected suitable plant species for AFIs plantation in 2003. More than 80 species have been selected, and among them 12 species are recommended for aquatic cultivation in southern China (Fig. 12) [15].

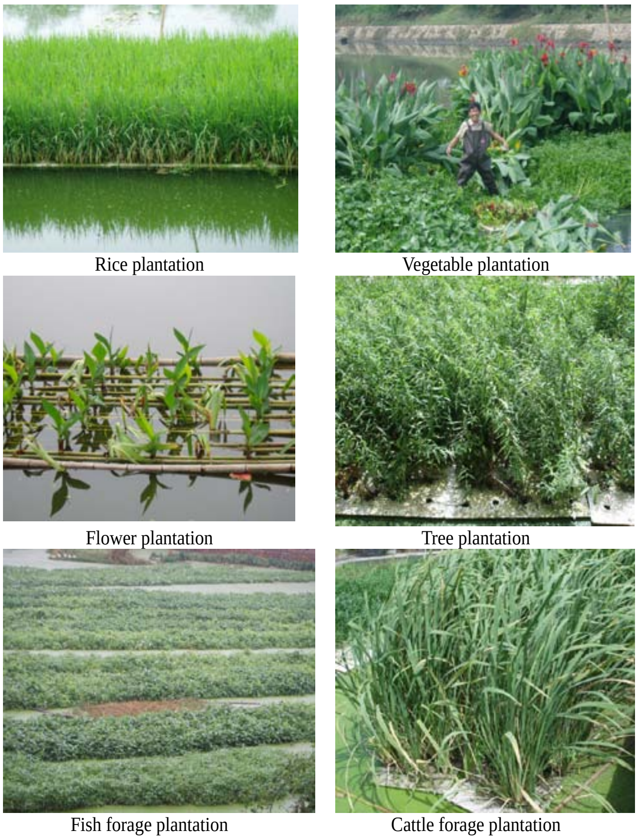

Fig. 12 Modern floating field developed by Hubei University in China

B. BAIRA in Bangladesh

Baira is an indigenous practice of the farmers of Gopalganj, Barisal, Patuakhali, etc. southwest districts of Bangladesh for cultivating seasonal vegetables and seedlings during the monsoon. Water hyacinths are congregated on the water to make flouting organic platform the platform usually anchored in the convenient places of beel or canal. The surface of floating platform once decomposed and seeds of selected vegetables are placed in to a growth media pre-pared with the roots of submerged floating vegetation. Growth media is then put on the platform for germination and subsequent rising. Since the growth medium is organic, the seedlings grow fast and usually the farmers sell the seedlings like cucumber, gourd, etc. in the local market. The seedlings are plans planted in the soil. Cultivation in the biara is a means of earning money for cultivars during monsoon when whole beel and its peripheries are inun-dated for about six moths of the year.

There are 23 species of vegetables such as gourd, cucumber, eggplant, chili, spinach, ladies finger, lettuce, pumpkin, cauliflower, cab-bage, etc., and 6 of spices such as zinger, garlic, etc., that have been successfully produced and harvested on baira (Fig. 13) [16].

Fig.13 Photographs of Baira Farming in Pirojpur and Gopalgonj districts in Bangladesh

Baira cultivation is a useful technique to practice widely in the floodplains of Bangladesh. People in the floodplains of Bangladesh are mostly poor. These vulnerable people are constrained by not having cropping space in terms of access to or ownership of lands. In some cases, even when they do have the access, the land is submerged under flood water for around four months, restricting its use for cultivation. As a result, most of the local people have to depend only on one crop per year. Under such condition, the use of baira provides the farming community with additional cropping space at the time most suitable for cultivation.

C. Floating Agriculture in Myanmar

In Myanmar, floating cultivation is successful traditional technologies and practice of the Intha peoples. Floating islands are formed from coarse grasses, reeds, sedges, and other aquatic vegetation, some of which grow submerged while others have floating runners with aerial parts well above the water surface. The dead parts of aquatic and marsh plants become entangled together and are bounded by bog mosses and algae into expanses of fen which float freely. There are swan into blocks 2 m wide and up to 180 m long. The remainder of the decaying aerial portion is burnt out. Black silt from the bottom of the lake is carried by flat boats and spread over it to the extent the bed is not sunk but still floating. Then floating islands are towed into position and anchored with bamboo poles.

Fig. 14 Floating agriculture in Inle Lake, Myanmar

The floating islands thus become a growing medium for planting fruits, flowers, vegetables, and other cash crops from which a lot of income is derived by the Intha. The floating islands can be used up to about 15 years or as long as the submerged mattress can hold its buoyancy. The sunken mass of decayed material has to be taken out of the lake bottom and put back on the land. However, the practice of farming on floating cultivation also encroaches into the diminishing area of the lake, since over time, the floating beds become solid ground and it is one of the adverse effects [17].

V. PERSPECTIVE IN RURAL CHINA

A. Eexpend Arable Land

China has a large population but limited resources per inhabitant as well as insufficient reserves, which poses several problems. The country must feed 22% of the world's population with only 10% of global arable land. Currently, there are only 118,755 million hm^2 of arable land, or only slightly more than 900 m^2 per inhabitant, which is less than 40% of the global average. Even more alarming is that these limited resources are constantly diminishing [18].

But on the other hand, China has quite lot of watery areas such as lake and rivewrs. In total, there are more than 50,000 rivers with a basin area of over 100 km^2, 1,500 of them with a basin exceeding 1,000 km^2. The total drainage area of the outflowing rivers covers 65.2% of the country's territory. There are 2693 lakes in China, mainly scattered over five drainage basins, with a total area of 81,414.6 km^2 [19]. If 5% of water area of Chinese lakes is cultivated with AFIs, the aquatic "farmland" may increase by 4070.7 km^2, which equivalences to feed 7.63 million people.

B. Improve Water Environment

Eutrophication was recognized as a pollution problem in European and North American lakes and reservoirs in the mid-20th century. Since then, it has become more widespread. Surveys showed that 54% of lakes in Asia are eutrophic; in Europe, 53%; in North America, 48%; in South America, 41%; and in Africa, 28%. China's lakes and reservoirs are experiencing accelerated eutrophication and degraded water quality. Zhao et al. (1995) found that most of the 34 lakes studied were of mesotrophic status in the 1970s; the percentage of eutrophic lakes increased from 5% to 55% between 1978 and 1987. Currently, 57.5% of the 40 main freshwater lakes in China have become eutrophic and hypertrophic [20].

Eutrophication can be human-caused or natural. Untreated sewage effluent and agricultural run-off carrying fertilizers are examples of human-caused eutrophication. Eutrophication generally promotes excessive plant growth and decay, favouring simple algae and plankton over other more complicated plants, and causes a severe reduction in water quality. Enhanced growth of aquatic vegetation or phytoplankton and algal blooms disrupts normal functioning of the ecosystem, causing a variety of problems such as a lack of oxygen needed for fish and shellfish to survive. Health problems can occur where eutrophic conditions interfere with drinking water treatment.

But when we change a view point, the water pollutants such nitrogen and phosphorus are necessary nutrients for agricultural plantation. Our practices suggested that AFIs can remove 30% of water nutrients when covered 15% of the water surfaces (Fig. 15).

Fig. 15 Vegetable plantated on AFIs in ponds

It can remove 37% of TN, 30 of TP when covered 15% of water surface.

C. Enhances Eco-friendly Agriculture Practice

As chemical fertilizers are not used in AFIs cultivation, this cultivation practice does not harm the environment by supplying chemical pollutants to the water. Further more, since residue from AFIs could be used as organic fertilizer for winter crops, this practice cuts down pollution from chemical fertilizer. Therefore, AFIs technology is not only improving the water environment, but also providing crops, thereby creating a "win-win" model for both environmental protection and agricultural development in rural China.

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