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# Review of the high bed–low ditch system as an alternative to lowland paddy in tropical and subtropical Asia

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Many forms of traditional raised bed systems could be found around the world. Several of them have been identified as Globally Important Agricultural Heritage Systems (GIAHS) sites by Food and Agriculture Organization of the United Nations. Unlike traditional raised bed systems with similar structures in the Americas, the high bed–low ditch (HBLD) system in tropical and subtropical Asia, which is originated and developed from rice production, has been playing an important role in enhancing food security and maintaining farmer livelihood for centuries. Moreover, products provided by HBLD system are not only important for the livelihood of the local farmers, but also important for people living in the nearby towns and cities especially for vegetable and fruit supply. In this system, the ditches or sunken beds can be used to lower the groundwater table, retain nutrients and soil particles washed from the bed, grow rice or aquatic vegetables, and raise fish or shrimp. The HBLD system can also help to reduce salinity in coastal lowlands due to the presence of ditches. The raised beds can be used to grow various upland crops. Compared with rice monocropping, the adoption of HBLD system significantly improves the cropping intensity, productivity, employment, and income of farmers. Famers' long-term practices fully demonstrate that this system is a type of sustainable agriculture with strong adaptability to the changes of natural environment. However, it should also be noted that the large-scale development of HBLD systems is not simply dependent on natural conditions, but is also determined by specific socioeconomic factors, such as good transportation facilities, a well market system, and a sufficient supply of labor. As a model of equilibrium between food production and high levels of biodiversity maintenance, the HBLD system is an important agricultural heritage system with global significance, and it should be well preserved and utilized in new ways to realize its important multiple functions under conditions of rapid urbanization in lowland and coastal regions.

KEYWORDS

**agricultural heritage systems, high bed–low ditch system, *sorjan* system, raised-sunken bed system, raised bed system, lowland area, Asia**

# 1 Introduction

Adapting to local natural environment is an important feature of the ecological rationality of traditional agriculture. Our ancestors have developed a wide range of traditional techniques to live and farm in some challenging environments (Oo et al., 2022). Before industrialization, it was difficult for farmers to change landscapes on a large scale for the needs of foods. Therefore, farmers focused on planting suitable crops according to the landscape characteristics of the farmland and water table, and they also created various raised-bed and flat-bed planting systems (Luo et al., 1987). In lowland areas such as river deltas, lakesides, seasides, and swamps, the major constraints of agricultural production are the high water table, and the threat of flooding. Ecological conditions at such sites are rarely suitable for any food crop other than rice, so farmers, especially those in tropical and subtropical Asia, generally apply rice-based crop rotation systems (Molle et al., 1999; Van Cooten and Borrell, 1999; Phupaibul et al., 2002). For a long time, Asians have produced and consumed approximately 90% of the world's rice (Ito et al., 1989; Boonkong et al., 2023). Moreover, ancient local farmers also created various raised bed farming systems mainly for planting upland crops. The terms "raised fields," "ridged fields," "drained fields," and "cambered beds" are also used in the literature to describe raised beds. According to Denevan and Turner (1974), "raised fields" include any prepared land involving the transfer and elevation of soil above the natural surface of the earth in order to improve cultivating conditions, and three broad categories of functions can be delimited for raised fields: non-hydraulic, drainage, and moisture-retention. Most systems of land reclamation by traditional farmers in the tropics and subtropics involve significant modifications of land surface: terracing, irrigation, drainage ditching, and raised bed. Of these, raised bed cultivation (mounding and ridging) has received the least amount of attention. Until the1960s, discoveries of large numbers of Pre-Columbian raised beds throughout the Americas stimulated interest in this topic (Denevan, 1970; Denevan and Turner, 1974; Redclift, 1987). The best-known examples of raised bed systems are found at Xochimilco near Mexico City in Mexico and surrounding Lake Titicaca in the Andean countries of Peru and Bolivia, and many attempts have been made to recreate ancient agroecosystems for modern agricultural use since the 1970s (Boucher et al., 1983; Erickson, 1988, 1992; Crews and Gliessman, 1991).

Over the last 3 decades, especially since the designation of Globally Important Agricultural Heritage Systems (GIAHS) in 2002 by the Food and Agriculture Organization (FAO) of the United Nations, contemporary values of traditional agriculture have been increasingly recognized internationally (Mitchell and Barrett, 2015; Jiao et al., 2021). Since 2005, FAO has designated 86 agricultural systems in 26 countries as GIAHS sites. The GIAHS program identifies and safeguards these precious systems and their associated landscapes, agricultural biodiversity, knowledge systems, and culture, while increasing the resilience of people's livelihoods and implementing dynamic conservation strategies (FAO, 2022). Currently, many kinds of traditional raised bed systems can be found in lowland areas worldwide, including several GIAHS sites, such as the *Chinampas* Agricultural System in Mexico (Robles et al., 2018), the Andean Agriculture (*waru warus* or *caballones*) in Peru (Koohafkan and Altieri, 2017), the Ramli Agricultural System in Tunisia (FAO, 2020), the Floating Garden Agricultural Practices in Bangladesh (Chowdhury and Moore, 2017), the Mulberry-dike and Fish Pond System (Liu et al., 2018), and the Duotian Agrosystem (Bai et al., 2014) in China. An agroecosystem similar to the *chinampas* and *waru warus* in the lowland areas of tropical and subtropical Asia, is called high bed–low ditch (HBLD) system (Luo and Lin, 1991) or dike-ditch interactive system (Li, 2001) in Southern China, and is also called *sorjan* or *surjan* system (Domingo and Hagerman, 1982; Nazemi et al., 2012), dike-ditch system (Habiba et al., 2015), or raised-bed-dike (*rong chin* in Thai) system (Phupaibul et al., 2002) in Southeast Asia, raised bed and furrow system (Naresh et al., 2012; Velmurugan et al., 2016), or raised-sunken bed (RSB) system (Kannan et al., 2003) in India. This series of raised bed systems with similar water-land utilization approaches strongly suggest that this type of agroecosystem, despite having different local names, is widely adapted to the humid tropical and subtropical lowlands (Luo and Lin, 1991; Sayre, 2006). Unlike similar systems in the Americas, the HBLD, *sorjan*, raised-bed-dike, and RSB systems in Asia are always distributed on fringe of the rice-based systems and have been practiced widely by local farmers for centuries (Barghouti et al., 1992; Lin and Luo, 1993; Phupaibul et al., 2002). The Haizhu High Bed–Low Ditch Agroecosystem (HHBLDA), Guangdong Province, was included in the China-Nationally Important Agricultural Heritage Systems (NIAHS) in 2021, marking the beginning of actions for conserving this type of traditional raised bed system (Zhao et al., 2023). Given that these systems in tropical and subtropical Asia have not yet received sufficient attention in the field of agricultural heritage systems, the authors believe that a comprehensive review of the relevant literature is necessary for fully understanding their distinctive conservation values.

# 2 Connotation and structure of the HBLD system

## 2.1 Concept and connotation

The HBLD system is widely applied for agriculture in Asian tropical and subtropical lowland areas (Figure 1), such as Southern China, Indonesia, the Philippines, Bangladesh, the Chao Phraya River Delta in Thailand, Malaysia, Vietnam, Sri Lanka, and Northeastern India (Milsum and Grist, 1941; Denevan and Turner, 1974; Suryadi, 1996; Dharmasena, 2004; Nursyamsi et al., 2014; Oo et al., 2022). As Herklots (1972) wrote in his book titled *Vegetables in South–East Asia*, with an image of an HBLD system in its cover page, this was a common technique adopted at sites where the water was abundant or too abundant throughout the monsoon countries of Southeast Asia. Although many studies have been conducted on these systems in tropical and subtropical Asia, there are few specialized definitions for them, to the extent that a synonym phenomenon of their names exists.

In the 1980s, Shiming Luo, a pioneer of Chinese agroecology, named an agroecosystem developed by farmers in the Pearl River Delta for upland crops under the condition of a high-water table as an HBLD (高畦深沟 in Chinese) system. The characteristics of this system include: (1) digging deep ditches in a certain distance in field according to the crops on bed, using ditch mud to raise beds, and a water layer staying in the ditch for a period; (2) upland farming, mainly for the growing of vegetables and fruit trees on beds; (3) planting rice/aquatic vegetables, or raising fish or shrimp in ditches, and returning the mud in ditches to the bed as organic fertilizer each winter; and (4) most of the structures remaining stable for years (Luo, 1985; Lin and Luo, 1989). According to Zhao et al. (2023), the

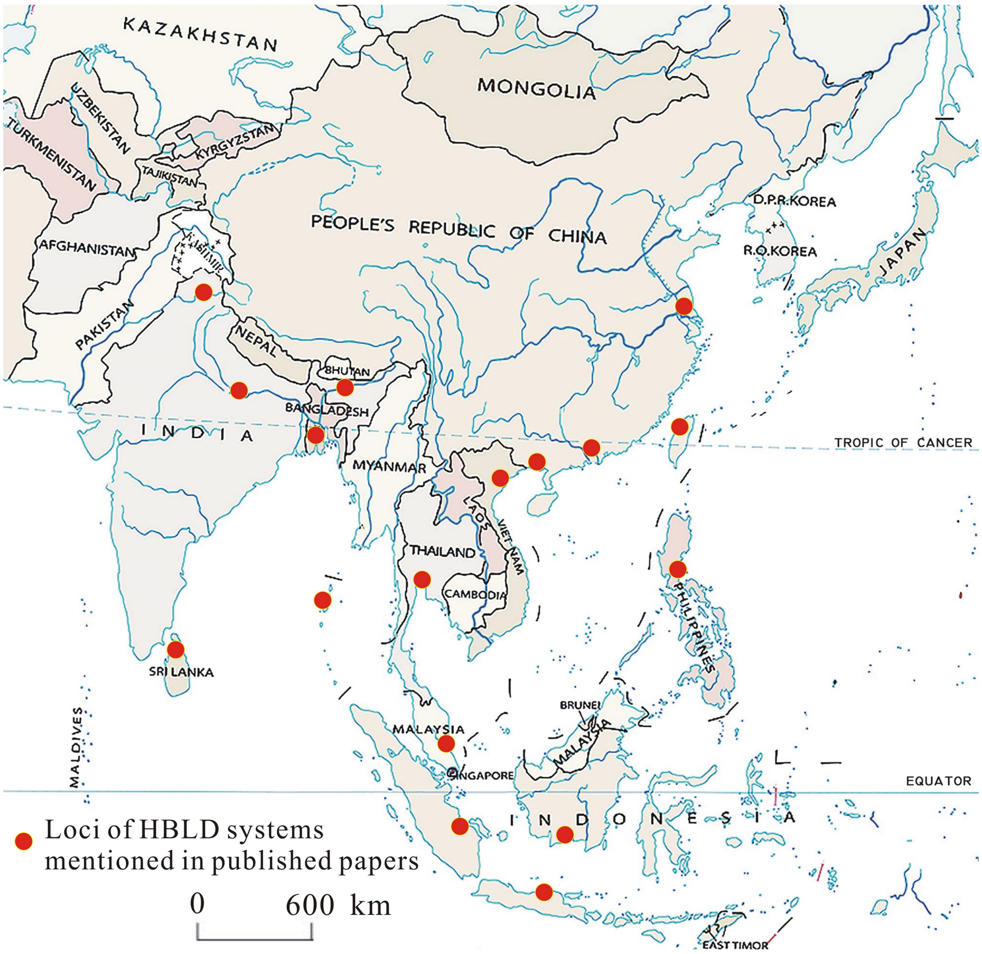


FIGURE 1
Loci of HBLD systems mentioned in published papers.

traditional agricultural landscapes of the HBLD system include dikes, artificial canals, water gates, raised beds, ditches, crop production, livestock and poultry production, and aquaculture within raised beds and the surroundings. HBLD is commonly referred to as the *sorjan* system in most Southeast Asian countries. The term *sorjan* system is adapted from the morphology of paddy fields, which, when viewed from above, look striped like *sorjan*, a traditional Javanese cloth with colored stripes (Domingo and Hagerman, 1982; Awal, 2014). Domingo and Hagerman (1982) defined a *sorjan* system as a series of constructed raised beds and lowered ditches where upland crops can be grown on the beds and wetland crops can be grown simultaneously in the ditches. This arrangement prevents the raised beds from being submerged by water during the high tide period, although water flows into the land between the raised beds (Domingo and Hagerman, 1982; Hundal and Tomar, 1985; Marwasta and Priyono, 2007; Awal, 2014; Trisnawati et al., 2022). In Thailand, a similar technique is called *rong chin* system. The system was introduced by paddy farmers who wanted to grow upland crops other than rice. Ditches were dug and soil was piled up next to the ditch resulting in the formation of an upland field in a strip shape surrounded by water (Phupaibul et al., 2002). In India, current RSB systems are mainly permanent, which is an innovative modification of traditional temporary *bun* (raised bed) system practiced by the farmers previously (Tomar et al., 1996; Gogoi et al., 2022). According to Muflikhah et al. (2018), the RSB system is a package of technologies that are adaptive and mitigate against climate change. In this system, there are an elevated parts (raised beds) and excavated parts (sunken-beds) that help farmers overcome the risks of drought and floods, including tidal waves. The HBLD, *sorjan*, *rong chin*, and RSB systems all have similar structures composed of straight raised beds and lowered ditches (sunken beds), and they clearly belong to the same type of agroecosystem despite having different names. Hence, the term "HBLD system" is used to represent this type of system in the remaining parts of this paper.

## 2.2 Structure and landscape

The HBLD system has distinct regional characteristics, and there are often large or small differences in the structures in different regions. The determining factors for these differences include but are not limited to water table, soil structure, crop types, and irrigation facilities. In the HBLD system of the Pearl River Delta, soil raised from the ditches forms beds, and the width of bed ranges from 1.2 to 10 m depending on the type of crop grown. The width of the ditches ranges from 0.4 to 1.8 m, and the depth ranges from 0.4 to 1.5 m according to the depth of the water table on the side and the root system of the crop to be planted on the bed. The ditches contain water all year round. Systems for short-term crops such as vegetables and sugarcane usually have narrower beds and ditches, while systems for long-term fruits, such as banana, citrus, and litchi have wider beds and ditches (Luo and Lin, 1991; Lin and Luo, 1993). In the case of tidal swamp land, the ratio of bed-ditch in HBLD system needs to be relatively small, so as to effectively reduce the water table. Citrus cultivation in swamp land has been increasing along with the opening of tidal swamp land for agricultural purposes over recent years in Indonesia. The best land management method for citrus-rice farming on tidal swamp land is the HBLD system. The width of the ditches can be approximately 10–15 m, while the effective width of the raised bed is recommended to be approximately 2 m. The height of the raised bed varies depending on the depth of the pyrite layer and the tide (Ratule et al., 2020). In the Philippines, raised beds approximately 3 m wide alternate with furrows that vary in depth and width depending on the flooding depth during the rainy season. The raised beds provide adequate drainage for high-value upland crops. Rice is grown in ditches, which act as water reservoirs during drought (Hundal and Tomar, 1985). An expert suggested that the dimensions of the raised bed may be approximately 4 m wide and 30 cm above the water level, and that the bund or embankment around the area may be approximately 70–100 cm wide and 30 cm high. The ditches for growing rice, *gabi* (*Colocasia esculenta*) or *kangkong* (*Ipomoea aquatica*) should be 4 m wide and 30 cm deep, while a deeper ditch of approximately 1 m wide and 1–1.5 m deep could be constructed around the area for fish production (Garces, 2023). Aside from floating garden, the HBLD system is another principal system for saline and non-saline areas of coastal Bangladesh vulnerable to water logging (Rahaman et al., 2019). It is a system of raised beds that are 10 m long, 2 m wide, and 1 m high, with interspersed ditches that are 10 m long, 1.5 m wide, and 1.5 m deep. These ditches are constructed in the dry season, and the topsoil is put on the top of the beds. Vegetables and fruits can be cultivated on top of the bed, while trellises made with bamboo or other materials can support creeper vegetables over the ditches, and in the monsoon season, fish may even be cultured in ditches (Sattar and Abedin, 2012; Habiba et al., 2015). Previous studies have demonstrated the potential of the HBLD (RSB) system for increasing productivity of rice-based cropping systems in high rainfall areas of India. In the northeastern hill region, HBLD systems were constructed by researchers in sequence for efficient drainage and interplot water harvesting with a fixed width of 1 m for raised beds and 1.25 m for sunken beds. The length of all the plots was 8 m. The surface soil layer from each sunken bed was removed and deposited on the adjacent area marked for the raised bed, resulting a bed height of approximately 30 cm. All the crop residues and weed biomass were placed below the raised beds and covered with soil from the sunken beds (Das et al., 2014a,b). An HBLD system with a 1.5:1 width-ratio and a 30 cm elevation difference is the most effective land treatment for interplot water harvesting, and rice and *mash* (*Vigna mungo*) productivity in silty clay loam soil in high-rainfall areas of Himachal Pradesh, India (Sharma, 2003). In addition, the bed direction is recommended to be from east to west so that crops receive sufficient sun exposure (Muflikhah et al., 2018).

According to the types of production on beds, four types of HBLD system structures can be categorized: vegetable, fruit, field crop, and flower productions (Figure 2; Lin and Luo, 1993). Among them, vegetable cultivation is the most common type on beds (Haq et al., 2012). Taking the Tha Chin River Delta, Thailand as an example, the HBLD (*rong chin*) system was first introduced to produce vegetables, while fruit trees or flowers were seldom cultivated due to the river flooding during the rainy season (Phupaibul et al., 2002). In the suburb of Guangzhou, a central city of the Pearl River Delta, approximately 85% of the vegetable gardens were of the HBLD system type (Lin and Luo, 1993). Moreover, fruit production using the HBLD method was also common in the Pearl River Delta. Fruits

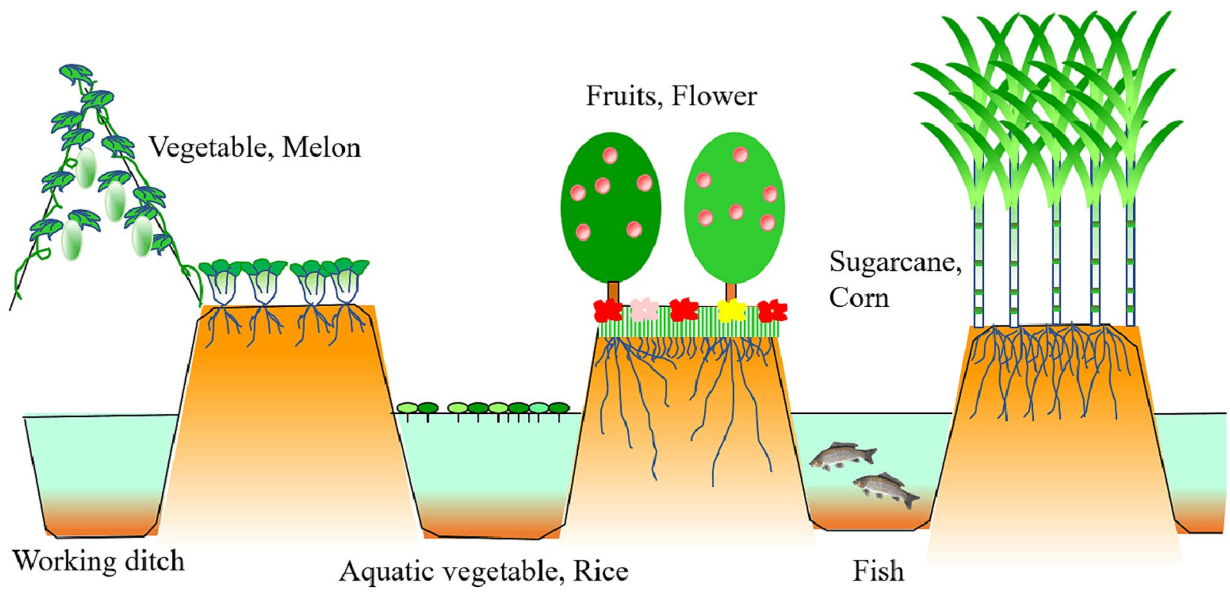


FIGURE 2
Landscape management of the HBLD system (Credit: Shiming Luo).

grown on beds include long-term fruits such as litchi, longan, carambola, and Chinese wampee; mid-term fruits such as orange and tangerine; and short-term fruits such as banana and pineapple. Peanut, soybean, and vegetables were often grown in the orchards during the early period of fruit trees. Mushrooms were sometimes grown under the shade of fruit trees (Luo and Lin, 1991; Lin and Luo, 1993). According to Malek and Uddin (2009), most farmers in coastal Bangladesh had a moderately favorable attitude toward fruits cultivation using HBLD method. Due to the threat of temporary water logging during the rainy (monsoon) season, long-term crop production was rare in the HBLD (RSB) systems in Northwest India. In contrast, vegetable and field crop cultivation on raised beds and rice cultivation on sunken beds were practiced widely (Dagar et al., 2001). Production in ditches includes fish, edible snails, and water-tolerant crops such as rice, *Ipomoea aquatica*, and watercress (*Nasturtium officinale*) (Lin and Luo, 1993). Moreover, rice, fish, and duck can be grown simultaneously in ditches with greater depths (Domingo and Hagerman, 1982; Peal, 2015). Some ditches lie fallow, and are used only for field operations such as watering, harvesting, fertilization, transportation, or provision of space for the trailing of creeper vegetables such as bean and melon (Lin and Luo, 1993; Ahrnad et al., 1995; Phupaibul et al., 2002).

The emergence and development of the HBLD system cannot be separated from the specific natural environment and socioeconomic background. When external conditions change, the structures and landscapes of HBLD systems often also change, reflecting the typical adaptive characteristics of agricultural heritage systems (Min and Sun, 2009). Bangladesh is one of the most cyclone-prone areas in the world. In Patuakhali, 50, 20, and 15% of the respondents planted vegetables, fruit trees, and woody trees in their homestead areas, respectively, using the HBLD system. Woody trees planted in this system showed the greatest vulnerability to the super cyclone *Sidr*, which was the one of the most devastating disasters to have ever occurred in Bangladesh. Following *Sidr*, respondents were not interested in using the HBLD system for planting woody trees (Haq et al., 2012). Haizhu Island in Guangzhou, China has a history of HBLD system dating back more than 1,000 years, making it an important fruit-, vegetable-, flower-, and tea-producing area. In the 1980s, due to the impact of urbanization, the main source of residents' incomes was no longer farming, therefore, fruit cultivation, which requires less labor than production of other crops production, dominated this area (Zhao et al., 2023). In traditional agricultural areas such as the coastal area of Bangladesh, the high price of inputs and insufficient capital are the two major constraints on crops cultivation in HBLD (Uddin et al., 2009). The continuous loss of farmlands, increase in land rent, and increase in off-farm employment are often major threats to the preservation of these systems in suburban areas (Phupaibul et al., 2002; Zhao et al., 2023).

# 3 History and development of the HBLD

## 3.1 Historical tracing

Like the "convergent adaptation" in biological evolution, the evolution of agroecosystems in different regions with similar natural and socioeconomic conditions also displays a consequence of "structure convergence." In other words, facing the same constraints of agricultural production, such as a high water table and the threat of flooding, farmers in different regions are likely to adopt similar technologies during a long-term adaptation effort. The practices of farmers in tropical and subtropical Asia indicate that HBLD systems are viable and feasible for coastal lowlands and river valleys of hilly regions with high rainfall where the groundwater table is high, and the parent material of soil formation is usually alluvial soil, which is suitable and easy to be raised (Mishra and Saha, 2007; Das et al., 2021; Romaneckas, 2022). These systems are usually located on the fringe of rice-based systems and were developed by local farmers to enrich their diets and increase economic benefits. Their large-scale development generally requires the following supporting factors: (1) good transportation facilities, generally close to a city; (2) a well market system; and (3) a sufficient supply of labor (Herklots, 1972; Domingo and Hagerman, 1982; Hundal and Tomar, 1985; Luo and Lin, 1991; Sulaiman et al., 2019). Previous studies confirmed that Southern China and Java, Indonesia are the two origin centers of HBLD system. The management of wetlands for agriculture using raised beds has been practiced extensively by Chinese farmers for at least 2,000 years (Thurston, 1992). The *Annals of Lv Shi*, a book that was written more than 2,200 years ago in China, states that crops should be planted on sunken beds in highlands and on raised beds in lowlands (Jin, 1983). The HBLD system is an alternative application of raised bed system in the lowland areas of Southern China. Starting in the 11th century, with the rapid development of *polders* (diked paddy-fields) and the popularization of rice–wheat rotation systems, HBLD systems have been widely used in Southern China (Liang, 1989; Li, 1997). HBLD systems in the Pearl River Delta have received the earliest and most attention from scholars and researchers. Franklin H. King, an American agronomist, and George W. Groff, an American horticulturist, recorded the HBLD landscapes of the Pearl River Delta in pictures and text. In March 1909, King saw a temporary HBLD system constructed by farmers for winter vegetable cultivation after the planting of two crops of rice (King, 1911). Groff, the first agricultural missionary working in China, found that the HBLD system of orchard planting, so frequently used in Guangzhou, seemed especially adapted to some subtropical fruits, and a very large acreage of litchi was thus grown (Groff, 1921). In India, Bangladesh, and most Southeast Asian countries, the HBLD (*sorjan*) system is widely recognized to have originated from Java Island, Indonesia, where the population is high and space for crop planting is quite limited (Brady, 1982; Domingo and Hagerman, 1982; Sulaiman et al., 2019). However, its origin time in Java is still unclear, although this technology was already recorded in 1941 (Nursyamsi et al., 2014). According to Pasandaran and Zuliasri (2001), in the early stages of development, HBLD was practiced in the downstream portion of an irrigation system in the northern coastal area of Java. It was used either to solve the problem of floods or drought. In the case of risk reduction for flooding as practiced in the northeastern tip of West Java, rice was planted on the top of the furrow and the lower part of the bed was used for fish ponds. In contrast, rice was planted on the lower part of the bed, and secondary crops were planted in the upper part, as in the case of the irrigation systems to reduce the risk of water scarcity in the downstream area of the irrigation system in the coastal area of central Java.

In addition to the factor of structure convergence, the development of HBLD systems in tropical and subtropical Asia is also attributed to a long-term process of technological dissemination, although more historical evidence needs to be uncovered. The Chinese people first settled in Southeast Asia more than 2,000 years ago. They constitute the most numerous alien group in this region (Rae and Witzel, 2008). Java Island is undoubtedly the second origin center; however, considering the 1,000 year history of southern Chinese migration to this area, the possibility of Chinese migrants spreading the HBLD technique to Java cannot be ruled out. In Thailand, the HBLD (*rong chin*) system is also known as the *Chinese ditch and dike system* (Hardeweg, 2008). The Chinese migrants have a long history in Thailand, and the Chinese immigration accelerated during the 19th century. Most areas of the Chao Phraya Delta, known as Thailand's *rice bowl*, are suitable for planting rice. On the fringe of the rice-based systems that dominated delta agriculture, since the 1870s, Chinese migrants and their Sino-Thai descendants with limited access to land and capital have developed HBLD systems in the lowlands of the Damnoen Saduak area. They adopted the HBLD technique to rise dikes for this old tidal marsh and built a large canal network ensuring drainage and irrigation year-round. In the garden between land and water, the farmers were able to grow a vast range of vegetables and fruits (Cheyroux, 2000). Vegetable cultivation under HBLD systems was practiced in the western half of the Chao Phraya Delta, mainly along the Mae Klong River, Tha Chin River, and many canals in the Ratchaburi, Nakhon Pathom, Nontha Buri, and Suphan Buri Provinces. This system in many regions was introduced by the descendants of Chinese farmers who migrated from Bangkok to continue their vegetable gardening in the last century (Phupaibul et al., 2002). Milsum and Grist (1941) described the formation of the HBLD system by Chinese gardeners in Malaysia. Raised beds in high water table situations were as much as 0.6 m in height, but in drier sites they were lower. Although there is currently insufficient evidence, it is highly likely that the HBLD (*sorjan*) technique in the Philippines, Bangladesh, and India was introduced from Indonesia. The HBLD (RSB) system does not seem to have emerged for a long time in India. In the river valley areas of the northeastern region, most of the farmers grow only one crop of rice during the rainy season (May–October) and subsequently, valley areas at mid and low altitudes remain fallow. Cultivating vegetables under the HBLD system significantly changed the socio-economic conditions of the farmers. Recently, farmers have taken to raising two crops a year (Sanwal and Yadav, 2007).

## 3.2 Popularization and conservation

The HBLD system has been used since immemorial times and continues to play an important role in modern agriculture in wetland systems. It is of particularly importance that this technology is readily accessible to small-scale farmers in developing countries (Sayre, 2006). In the 1980s, the area of HBLD system expanded rapidly, and the scale reached its historical peak by the early 1990s, with an area exceeding 5,000 ha and accounting for approximately 7.5% of the total cultivated land of the Pearl River Delta, China (Lin and Luo, 1993). In Thailand, The HBLD (*rong chin*) system covered an area of 8,120 ha in 2006 as reported by the Royal Irrigation Department (Hardeweg, 2008). In the past 4 decades, the HBLD (RSB) system has been vigorously promoted by the Indian Council for Agricultural Research in the river valley areas of Northeastern India where crop production is constrained by both drought and waterlogging (Dagar et al., 2001; Singh et al., 2011; Das et al., 2014a,b). In the Philippines, to maximize farm productivity and ensure sufficient and regular income for farming families, the Visayas State University-Agriculture and Fisheries Technology Business Incubation project started a commercialization program of its technologies in 2015 dubbed "Research to Market." One technology for adoption or technology transfer was the HBLD (*sorjan*) cropping system in response to climate change (Garces, 2023). The Philippine Rice Research Institute developed and assessed three modified HBLD models to help increase the food sources, and incomes of rice farmers in the context of crop diversification, intensification, and integration (Quilang et al., 2019). As one of the adaptation measures for agriculture to implement the *National Adaptation Programs of Action* formulated by the Government of Bangladesh in 2005, promoting adaptation to coastal crop agriculture to combat salinity intrusion through maize production under HBLD cropping systems in tidally flooded agroecosystems has been prioritized (Singh and Bantilan, 2009). Indonesia has approximately 10 million ha of tidal swamp land with agricultural potential, so the HBLD system has become an important management practice (Noorsyamsi et al., 1984). By 2001, HBLD had been practiced extensively in the reclaimed tidal-swamp area of Sumatra and Kalimantan (Pasandaran and Zuliasri, 2001). In addition, many villages in Kalimantan Selatan, Indonesia, have not only become famous agritourism destinations, but also attracted the attention of many international researchers, due to their HBLD landscapes (Nursyamsi et al., 2014). By 1990s, the HBLD system had been successfully introduced by scientists to many non-Asian countries such as Australia, Rwanda, and Guinea-Bissau (Van Gent and Ukkerman, 1993; Ashby and Sperling, 1995; Van Cooten and Borrell, 1999).

There is not any formal statistics so far available about the area of HBLD system in Asia and around the world. This system usually existed in lowland area with high water table, especially in the delta areas in the lower reaches of the major rivers. The maximum area of HBLD system may not exceed 5% of the total farmland in any Asian country. Uddin et al. (2009) indicated that among the six individual characteristics of farmers in coastal areas of Bangladesh, education level, supporting media used and knowledge of vegetable cultivation using the HBLD method had a significantly negative relationship with their problem confrontation. A large extent of paddy land in coastal lowland areas in the Wet Zone of Sri Lanka was abandoned or became marginal due to complex and unfavorable hydrologic conditions. The HBLD system is more agronomically and economically productive, environmentally friendly, and well suited to the social environment of this area. Dharmasena (2004) proposed that the appropriate species and varieties, time of planting, management, and protection of crop and fish components that suit the prevailing soil, water, climate, and biota present at the sites must be determined. Institutional support for the construction of alternate bed and ditch profiles as well as for the extension of necessary knowledge of management was vital in developing and popularizing the proposed model. Many HBLD systems in the Pearl River Delta involve single crop production on beds and are fallow in ditches, resulting in the low-efficient multilevel nutrient utilization and the insufficient light, soil, and biological resource utilization. Therefore, it is necessary to construct a reasonable ratio of bed-ditch, then, use intercropping on bed and planting aquatic crops or raising fish in ditch to form a three-dimensional structure, which can improve light energy and land-water use efficiency (Lin and Luo, 1989). With urban sprawl, traditional agricultural systems often inevitably face the risk of degradation and extinction (Pribadi and Pauleit, 2015; Su et al., 2020). The HHBLDA, as one China-NIAHS located in the Southern part of Guangzhou urban area, was saved through the government's implementation of a new policy named "land acquisition to keep agricultural use" in 2012. This case shows that an agricultural heritage system can co-exist with urban land uses during urbanization because of its important ecosystem service functions (Zhao et al., 2023).

# 4 Functions and benefits of the HBLD system

## 4.1 Ecological functions

In lowland areas of tropical and subtropical Asia, the absence or excess of freshwater resources nearly defines the cropping seasons of rice-based farming systems. The accumulation of water in wetland rice fields and lower landscape positions limits the planting of upland crops. During the rainy period, upland crops cannot be grown without major land modifications, such as the HBLD system (Barghouti et al., 1992). The first effect of HBLD system is lowering water table levels, which makes upland crop farming possible. After the beds were raised from the original field level, whether during the rainy season or dry season, the water tables of the HBLD system used for sugarcane, banana, and tangerine production were 10–36 cm lower than the water table of the rice field. The deeper the ditch within this range, the better the growth of plant root systems. Hence, farmers were more flexible in their cropping system, according to family and market needs (Lin and Luo, 1993). Second, soil erosion and nutrient loss greatly reduced due to the buffering effect of existing water layers in ditches. Excess water is drained from the ditch during rainy season or water is preserved for irrigation during the dry season (Ahrnad et al., 1995). If there is no water layer in ditches, the eroded soil and nutrients will be directly removed from the system, which will cause serious soil and nutrition loss (Lin and Luo, 1993; Tomar et al., 1996). Third, this system can reduce the decomposition of organic matter. The rates of annual decomposition of organic matter in ditches were always lower than those on beds. The decomposition rate tested by the field incubation method indicated that 4–8% more organic matter could be preserved in ditch than on bed after 1 year of decomposition (Lin and Luo, 1993). The farmers' practice of returning ditch mud to the bed increases not only the height of the bed but also the soil fertility. The amount of mud formed by debris from crops and eroded soil each year in the ditch was 51–157 t $ha^{-1}$, depending on the crop on the bed. The mud was rich in soil organic matter (3.6–5.7%) and nutrients, was returned to the bed each year (Luo and Gliessman, 2016). Last, modification of field topography through the construction of alternate raised beds and ditches (sunken beds) improves the physical environment in the field, particularly the aeration status of the soil and creates proper conditions for the growth of crops other than rice (Tomar et al., 1996; Naresh et al., 2012; Gogoi et al., 2022). There is a significant improvement in soil chemical and biological parameters due to continuous organic productions under the HBLD land configuration (Das et al., 2014b). Moreover, the ditches play an important role in reducing nonpoint pollution. In HBLD systems growing banana, 89.8% of the nitrogen, 75.0% of the phosphorus, 94.8% of the potassium, 81.1% of the organic matter, and 95.8% of the soil particles in the run-off water from the bed were retained in the ditch. Similarly, 69.0, 60.6, 90.6, 42.7, and 91.0% of the nonpoint pollutants were reduced in the HBLD system in which sugarcane was grown on the bed (Table 1). Rather than directly leaving the system, the return rates of nitrogen in these systems were 22.2% for HBLD with sugarcane on the bed, 41.0% for HBLD with tangerine, and 63.6 and 68.4% for two HBLD systems both with banana on the bed (Lin and Luo, 1993).

In regions with different natural conditions, the ecological functions possessed by the HBLD system also vary. Appropriate and integrated land management technology for utilizing wetlands with optimal and sustainable productivity is needed because swamp ecosystems are naturally fragile (Ratule et al., 2020). The determining factor for the success of agricultural cultivation in tidal swamplands is water availability, which fluctuates throughout the plant's growing period. In the HBLD system, there are dry parts (raised beds) that anticipate farmers against the risks of floods including tidal wave (Muflikhah et al., 2018). In Indonesia, climate extremes such as drought (El-Niño) and wetness (La-Niña) have a high frequency of occurrence (Rusmayadi et al., 2022). The northeastern hill region of India receives very high rainfall, characterized by the "too much-too little" syndrome, and farmers there must face the threat of water logging and drought in different seasons (Das et al., 2014b). Currently, HBLD cultivation, viewed as one of the best options for farmers, adapting to climate change, is very popular at the community level in the coastal regions of Bangladesh. Approximately 30% of innovative farmers were habituated to cultivating vegetables on lowlands using HBLD method in coastal area of Bangladesh (Uddin et al., 2009). Another field study found that 61.67% of respondents adopted the mean of HBLD system for sustainable agricultural production in the context of climate change in Banskhali Upazila (Barua and Rahman, 2020). The long-term practices of these systems in the above areas clearly show their high resistance to climatic changes and extreme climatic events. In coastal and humid tropical island regions soil salinity is a serious threat to agricultural sustainability due to sea water inundation. Restoring the ecosystems and degraded soils of these regions is vital for provisioning ecosystem services for local people (Mondal et al., 2001; Velmurugan et al., 2015). The HBLD system is an example of land shaping for successful crop production in waterlogged sodic soil for small to medium land holders

TABLE 1 Nonpoint pollutants in the run-off water reduced by the ditches in HBLD system in Xinhui County within the Pearl River Delta (Lin and Luo, 1993).

| Crop on bed | Sample source (from-to) | *N* (ppm) | $P_2O_5$ (ppm) | $K_2O$ (ppm) | Organic matter (ppm) | Soil particle (mg·$L^{-1}$) |
|---|---|---|---|---|---|---|
| Banana | Bed to ditch | 14.7 | 3.6 | 144.2 | 112.6 | 4442.9 |
| | Ditch to river | 1.3 | 0.9 | 7.6 | 21.5 | 183.7 |
| Sugarcane | Bed to ditch | 15.3 | 3.3 | 100.3 | 76.9 | 2523.7 |
| | Ditch to river | 4.8 | 1.3 | 9.4 | 44.1 | 228.0 |

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(Verma et al., 2016). In this system, the beds remain above the water level and water remains in the ditches, hence, salts from the beds can leach down to the ditches via rainwater (Hasan et al., 2018). Previous studies indicated that the HBLD system in the coastal lowlands of India reduced the overall salinity by 85%, and over the years, the salinity and sodium toxicity in the furrow water decreased, making it suitable for irrigation and fish culture (Velmurugan et al., 2015, 2016). In addition, coastal farmers also cultivated multiple stress-tolerant crop varieties that can withstand salinity and submergence (Hasan et al., 2018; Gopalakrishnan et al., 2019). On the highly alkali soils (pH > 10) of Northwest India, the HBLD technique appears to be quite successful for raising plantations such as pomegranate (*Punica granatum*) and salvadora (*Salvadora persica*) which otherwise suffer setbacks due to water stagnation. In sunken beds, crop rotations such as rice-wheat (salt-tolerant varieties) and kallar grass (*Leptochloa fusca*)-berseem (*Trifolium alexandrium*) rotations can achieve great success. This not only provides satisfactory crop yield but also helps in ameliorating the soil at faster pace without applying any costly amendments (Dagar et al., 2001). A great risk of secondary salinization is associated with too wide of a raised bed. Land fragmentation when the raised bed is too small greatly hinders farming operation efficiency. Researchers have developed guidelines that are quite useful for large-scale adoption of this model among field workers (Verma et al., 2016).

The development of the HBLD system has led to the creation of diverse farmland use patterns in the lowland areas of tropical and subtropical Asia. Although the related studies are rare, there is no doubt that rich agricultural biodiversity is a typical characteristic of this system. The HBLD system has the advantage of being able to grow rice and other crops simultaneously. Some studies suggested that the diversity and abundance of insects in monoculture systems were lower than in mix cropping systems. Herdiawan et al. (2020) reported that there was no significant difference in the number of species in HBLD and conventional rice fields, however, HBLD rice fields showed a higher insect abundance (1,216 individual insects) than conventional rice fields that had only 746 individuals. The high levels of interspecific and intraspecific diversity found in many traditional farming systems have well-proven advantages for managing plant diseases and maintaining yield stability (Thurston, 1992). Compared with the rice monocropping, planting paddy using HBLD method increased the species richness of pests, at the same time reduced their single species abundance. In other words, the HBLD method was an effort to keep pest populations at a low and balancing level (Trisnawati et al., 2022). The HBLD system is one of the local cultural wisdoms for dealing with pest and plant disease problems in the Special Region of Yogyakarta, Indonesia. Alfarisy et al. (2024) confirmed that the HBLD system had more natural enemies of pests than the monoculture farming system in this region.

## 4.2 Social and economic benefits

HBLD as a diversified and integrated farming system ensures food security because families have various sources of food. Rice is produced for carbohydrates, fish for protein, and vegetables with high nutritional value are also produced. The system ensures more stable income for families because of the regular cash flow from diversified and high-value crops (Habiba et al., 2015; Pasion, 2016). In many lowland areas, floodwater remains on crop fields and char lands, such as riverine lands, islands, and newly emerged lands, for an extended period. In the absence of uplands, vegetables and fruits cannot be grown. Most of the char lands remain fallow even after the recession of floodwater. Normally vegetables and fruits must be purchased from outside to meet local demands. Moreover, the communities in these areas are typically unable to afford the high price of vegetables and fruits and thus cannot incorporate these items into their regular diets (Yu et al., 2010; Islam, 2018). Crop diversification through the HBLD system has been recognized as an effective strategy for judicious use of land and water resources as well as for poverty alleviation by achieving food and nutrition security in a sustainable manner (Das et al., 2014b; Gogoi et al., 2022). With the application of HBLD method, agricultural productions in coastal communities of Bangladesh have also been improved, which has enhanced the food security for vulnerable people (Sattar and Abedin, 2012; Habiba et al., 2015).

Compared with rice monocropping system, the economic benefits generated by many HBLD systems are relatively higher (Table 2). In

TABLE 2 Comparison of the economic benefits of the HBLD system and rice monocropping system ($ha^{-1}$ $year^{-1}$).

| Study area | Cropping system | | Cost of cultivation (USD) | Gross return (USD) | Net return (USD) | References |
|---|---|---|---|---|---|---|
| Northeastern India | Bed | Potato/Tomato/French bean/Carrot—Okra/Brinjal/French bean—Cabbage/Broccoli | 1,782* | 3,523 | 1,741 | Das et al. (2014a) |
| | Ditch | Rice—Pea/Lentil | | | | |
| | Rice monocropping | | 392 | 775 | 383 | |
| Pearl River Delta of Southern China | Bed | Tangerine/Sugarcane/Banana (*Musa paradisiaca*)/Banana (*M. paradisiaca* var. *sapientum*) | 2,266** | 5,893 | 3,748 | Lin and Luo (1989) |
| | Ditch | Fallow | | | | |
| | Rice monocropping | | 1,094 | 1,888 | 794 | |

*The three data points in this row are the average of 10 demonstration sites.
**The three data points in this row are the average of 4 cropping systems.

the 1970s, trials conducted at the International Rice Research Institute of the Philippines showed that growing some upland crops on the bed of HBLD system was profitable. By adopting the HBLD system, planting off-season, high-value crops, and raising aquatic vegetables and fish in ditches, higher market value was possible. This system was initially labor intensive. However, farmers can economize by using family or off-season labor (Domingo and Hagerman, 1982; Van den Eelaart, 1982; Francis, 1986). In Indonesia, a study on a tidal land farming system under the HBLD system revealed that mixed citrus and coconut with rice farming resulted in the highest farmer income compared with rice monocropping (Anwarhan and Sulaiman, 1985; Sulaiman et al., 2019). Lin and Luo (1993) confirmed that the total investments required for HBLD systems were 36.6–172% greater than those for rice production in paddy fields, but the total incomes of the HBLD systems were 86.8–492% higher than those of rice monoculture. The net profits were 102–932% higher. In Northeastern India, the crop and water productivity of monoculture rice in lowlands was low. Some farmers also followed *bun* cultivation for growing vegetables after *kharif* (monsoon/autumn) rice, but the sunken area was not utilized for cultivation. Under such circumstances, a permanent HBLD (RSB) system was a viable alternative for promoting crop diversification, increasing productivity and income (Kannan et al., 2003; Gogoi et al., 2022). Tomar et al. (1996) demonstrated the potential of the HBLD system for increasing agricultural production in Vertisols of high-rainfall areas. An economic viability analysis of the HBLD system indicated that the net return was Rs. 13,363 $ha^{-1}$ $annum^{-1}$ compared with the Rs.1,003 $ha^{-1}$ from soybean grown under traditional farming practices. Das et al. (2014a,b) reported the significant improvements in cropping intensity, productivity, employment, and farmer income due to the adoption of HBLD system compared with farmers' practices of rice monocropping. The average rice equivalent yield of the HBLD system was 16.20 t $ha^{-1}$ compared with 3.24 t $ha^{-1}$ under the farmers' practices. The increases in employment and water-use efficiency were 445 and 291% respectively, due to the addition of HBLD compared with monoculture rice practices. Compared with that under rice monocropping, the water productivity was four times higher. The multiple cropping index, cultivated land utilization index, and diversity index also increased substantially due to the HBLD land configuration. Another study in the same region reached similar conclusions, and further revealed that the various cropping sequences under HBLD system enhanced the benefit-cost ratio by 75.5–513.2% compared with that under non–HBLD practice (Gogoi et al., 2022). In addition, the tourism economic benefit of the HBLD system located in the urban and suburban areas is also reflected. Bang Kachao area, an HBLD system site in the southern part of Bangkok, Thailand has been well-known as one of the tourist destinations at a short distance to the city, which are mostly based on the tourism resources generated from agriculture (Khaokhrueamuang, 2014).

## 5 Representativeness of the HBLD system as a potential GIAHS

The selection of a GIAHS follows five basic criteria which represent the totality of tangible and intangible values/benefits, functionalities, goods, and services provided by the agricultural system. To be recognized as a GIAHS site, it must be of global importance based on its values and characteristics (Koohafkan and Altieri, 2017). The practices of the HBLD system fully demonstrate the importance of traditional wisdom for the future of our agriculture and food system. Taking the HHBLDA in Guangdong Province, China as an example, the following supplements to the values, characteristics, and conservation of the HBLD system can be made.

First, the HBLD system inherits invaluable traditional knowledge, ingenious adaptive technology, and management systems of water resources in the coastal or riverside lowland areas. In the HHBLDA site, ancient farmers knew that they must build surrounding dikes and install proper water gates for controlling the water table on site before reclaiming lowland area. The water gate is a wooden semi-automatic water control device, and currently only a small number of old farmers know its manufacturing techniques. The direction of ditches is always designed to be at a 90° angle to the river or canal direction, so that the kinetic energy of the tides can be fully utilized to push water in or out. In addition, some proverbs on the rhythms of tides and rainfall are also popular with the masses. Dike-pond system is another well-known agroecosystem in the same region. The most significant difference between the dike-pond system and the HBLD system is that the former is mainly for aquaculture and silk production, while the latter is mainly for upland crop planting. Although their main products differ, these systems possess similar mechanisms for adapting to humid subtropical lowland environments (Luo, 2001). By adopting the HBLD system, up to seven crops can be planted continuously each year, so commercial farming here was highly developed, formerly. Currently, many of farmers are still skilled in cultivating many fruits and vegetables. Moreover, some farmers also set up nets around raised beds to raise ducks and chickens under fruit trees. Agricultural activities are carried out without harming the local wildlife. The HHBLDA site (Haizhu Wetland Park) was successfully listed in the Wetlands of International Importance in 2023 due to its geographical rarity and representativeness. In other countries, farmers often adopt a mixed cropping system of rice and dryland crops, and the relevant traditional knowledge is also worth systematically summarizing.

Second, the HBLD system usually carries rich meanings in culture. The large-scale development of the historical HBLD system in Haizhu Island was determined by its specific natural and socio-economic conditions. In the past, Haizhu Island was in the suburb area adjacent to Guangzhou Port. The well-developed commercial farming and the situation of high population density determined that it was economically more benefit to change the rice cropping systems to HBLD systems for agricultural production. Furthermore, this agricultural model had effectively promoted material and cultural exchanges between urban and rural residents. The rural clans had played a critical role in the construction and maintenance of dikes and water gates, as well as the management of water resources and river muds. As Ang et al. (2021) reported, the collaboration between farmers to build elaborate irrigation infrastructure, distribute water, dredge, and drain had strengthened the emergence of collectivist values. Nowadays, although the livelihoods of community residents no longer mainly rely on farming, most of them have a passion for conserving traditional farming cultures, such as the popular Dragon Boat Festival and Water God faith, which still preserve the cultural genes passed down from the agrarian society.

Third, urbanization is one of the major threats to the dynamic conservation of the HBLD system. Coastal areas where are the main distribution regions of HBLD systems, are also locations for many important cities and ports with a rapidly developing economy and a high population density (Creel, 2003; Rahim et al., 2013). The HHBLDA in Guangzhou is the only China-IAHS site that is located within a mega city. After a 3-decade-long struggle between the ecological conservation and urban sprawl, a total of 790-hectares farmlands were purchased by city government from farmers in 2012. There were only a small number of farmers hired to manage the farmlands. Hence, inevitably some new challenges arose. Ecological functions are far more emphasized than agricultural production functions by the farmland managers at present. The separation of farmlands with farmers' community and the heavy task of ecological conservation have led to a high operating cost of wetland park and a low level of local farmers participation (Zhao et al., 2023). Preserving the important agricultural heritage systems within a city is a new challenge that deserves further exploration. If the management issues of this site can be effectively addressed, many useful experiences should be available for the dynamic conservation of other intra- and peri-urban agricultural heritage systems worldwide.

Last, scientific popularization and academic research of HBLD system need to be strengthened. In the HHBLDA site, although most community residents are familiar with agricultural production processes, they know very little about the value and significance of HBLD system. Therefore, diverse forms of science popularization actions aimed at community residents and the public are necessary to be conducted, which are also meaningful for other HBLD system sites. Meanwhile, further research is needed for this important agricultural heritage system in terms of its development mechanisms, agricultural biodiversity, possible degradation, structure diversity in different regions, and adaptive management methods. Through the further study of this case, a new balance point can be found between the production and ecological functions of the HBLD system. In addition, the structure differences between the HBLD system and other raised bed systems such as *duotian* in Southeast China, floating garden in Bangladesh and Myanmar, *waru warus* in Peru, and *chinampas* in Mexico are worth further study. The HBLD system allows for the cultivation of rice in the ditch due to the shallow water level, which may be the most notable feature of this system from other raised bed systems.

## 6 Conclusion

As a traditional system in lowland areas of tropical and subtropical Asia, the HBLD consists of a series of straight constructed raised beds and lowered ditches where upland crops can be grown on the beds and aquatic crops or fish can be grown simultaneously in the ditches, which make it adapting very well to the high-water table regions and well balancing between the food production and the high level of biodiversity. Our review highlights that the HBLD system is originated and developed from rice production, and its large-scale development cannot be separated from a specific socioeconomic environment. Southern China and Java, Indonesia are the two origin centers for this system. The structure convergence effect and the technical exchange through human migration have played key roles in the course of Asian HBLD system expansion. In recent years, the literature increasingly emphasizes environmental, social, and economic benefits of this system in India, Bangladesh, and some Southeast Asian countries. The scale of HBLD systems has achieved new growth in these countries. Meanwhile, Southern China has witnessed the decline of this system mainly due to the city sprawl and modern agriculture development. Government departments and researchers in Guangdong Province, China have taken a series of actions on the conservation of this important agricultural heritage system. The long history of traditional agricultural structures and agro-technical systems is undoubtedly the results of their rational and logical development in their existing contexts. The wisdom contained in HBLD systems is worth continuously exploring, understanding, improving, and reusing. Like *chinampas* in Mexico, *waru warus* in Peru, and floating garden in Bangladesh, the HBLD (*sorjan*) system in China and Indonesia is also an important agricultural heritage system with global significance by its significant ecological, economic, social, and cultural values. Asia has made rich contributions to GIAHS designations. The conservation of HBLD systems deserves more attention, especially under the conditions of rapid urbanization in many lowland and coastal regions.

## Author contributions

FZ: Conceptualization, Funding acquisition, Investigation, Methodology, Writing – original draft, Writing – review & editing. SL: Conceptualization, Investigation, Writing – review & editing. JZ: Conceptualization, Funding acquisition, Methodology, Writing – review & editing.

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## Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

## Publisher's note

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