

Environmental Science and Engineering

Han-Yong Jeon *Editor*

# Sustainable Development of Water and Environment

Proceedings of the ICSDWE2022

 Springer

# **Environmental Science and Engineering**

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Han-Yong Jeon  
Editor

# Sustainable Development of Water and Environment

Proceedings of the ICSDWE2022

 Springer

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# Preface of ICSDWE2022

The 5th International Conference on Sustainable Development of Water and Environment (ICSDWE2022) was successfully held online via ZOOM on March 17, 2022.

The aim of ICSDWE2022 is to present the latest research and results of scientists (professors, students, Ph.D. students, engineers, and postdoc scientists) related to sustainable development of water and environment. The key goal of the conference provides opportunities for academic scientists, engineers, and industry researchers to exchange and share their expertise, experience, new ideas, or research result and discuss the challenges and future in their expertise.

ICSDWE2022 had a technical program consisting of 2 international keynote speeches, 18 oral presentations, and 5 poster presentations. Details are as below:

Two international keynote speeches were delivered separately by the Conference Chair Prof. Han-Yong Jeon from Inha University (South Korea) and Prof. Rosemary M. Gutierrez from the University of the Philippines Baguio (Philippines); each keynote speech lasted for 35 min including questions and answers.

Eighteen oral presentations and 5 poster presentations were delivered by experts and scholars, such as Prof. Eusébio Z. E. Conceição from Science and Technology Faculty of the University of Algarve (Portugal), Dr. Ekaterina Bogomilova, University of National and World Economy (Bulgaria), Prof. Yang Yunan, College of Space and Environment, Beihang University (China), Prof. Aihong Gai, College of Resources and Environmental Sciences, Gansu Agricultural University (China), Dr. Hidekazu Yoshioka, Shimane University (Japan), etc.

ICSDWE2022 has received 156 abstracts and full papers. After a preliminary review of the scope, originality, and language, ICSDWE2022 has sent those 134 full papers to reviewers to conduct a single-blind peer review. ICSDWE2022 has been able to accept papers only after reviewers double-checked the revised manuscripts and give their consent to accepting them; as a result, only 32 papers were accepted to be published in Springer Conference Series Environmental Science and Engineering [ISSN: 1863-5520].

On behalf of the conference chair, I would like to thank all the authors who contributed to ICSDWE2022 and the Technical Program Committee Members and

reviewers who gave their valuable comments and suggestions for improving the manuscripts. I also want to thank the publisher for publishing the proceedings. May the readers could enjoy the gain some valuable knowledge from it.

We are expecting more and more experts and scholars from all over the world to join the 6th ICSDWE2023.

Incheon, Korea (Republic of)

Prof. Han-Yong Jeon

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# Chapter 1

## Salinity Intrusion in the Vietnamese Mekong Delta, a Threat: Possible Causes, Effects on People's Life and Production, and Temporary Solutions and Adaptable Strategies



Nguyen Van Tho

**Abstract** The Vietnamese Mekong Delta is the most important agricultural production area in Vietnam. Most of this deltaic plain has an extremely low mean elevation of about 0.8 m above sea level and dissected by an inter-linked system of natural rivers and man-made canals connected to the sea. It is recognized as one of the areas worldwide most vulnerable to the impacts of climate change. In recent years, saline intrusion into the Vietnamese Mekong Delta has become increasingly serious due to a combination of factors, including the low topography, a dense system of rivers and canals connected to the sea, drought, low flow rates in the Mekong River during the dry season, growing competition for rapidly depleting water resources, sea level rise, and land subsidence. In 2020 saltwater intruded further inland than ever before and affected 10 out of 13 provinces of the Vietnamese Mekong Delta, causing severe damage to millions of hectares of farming land and the livelihoods of thousands of households. Solutions and adaptation strategies include storage of fresh water in ponds, shifting to farming systems and varieties that are more resilient to high salinity, changing cropping schedules, and building sluices to regulate salt-water intrusion. This paper discusses the main causes of salt intrusion, its effects on people's life and production, and adaptation strategies to mitigate its impacts.

**Keywords** Salinity intrusion · Vietnamese Mekong Delta · Climate change

### 1.1 Introduction

The Vietnamese Mekong Delta (VMD) is in the lower section of the Mekong River, adjacent to the sea. It covers an area of around 40,816 km<sup>2</sup> with a total population of over 17 million, accounting for more than 18% of the population in the country (GSO

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2020). The VMD consists of 13 provinces/cities: Long An, Tien Giang, Dong Thap, Vinh Long, Tra Vinh, Hau Giang, Soc Trang, Ben Tre, An Giang, Kien Giang, Bac Lieu, Ca Mau and Can Tho city, the central city of the region (Fig. 1.1). The VMD is characterized by a tropical monsoon climate with two distinct seasons: dry season and rainy season. The dry season usually starts from November of the previous year until April of the following year. The rainy season is from May to October.

The VMD is quite flat (Fujihara et al. 2016); most of this deltaic plain has an extremely low mean elevation of about 0.8 m above sea level (Minderhoud et al. 2019) and dissected by an inter-linked system of natural rivers and man-made canals connected to the sea. Vietnam is among the five countries most likely to be most affected by climate change, in large part due to its location, the economy’s dependence on sectors such as agriculture in flood-prone areas (WB 2018), and especially to the extreme vulnerability of the VMD to natural disasters and climate change (Clark et al. 2016). The VMD is the key agricultural production and aquaculture area of Vietnam, contributing half of Viet Nam’s rice output, 65% of aquatic products and

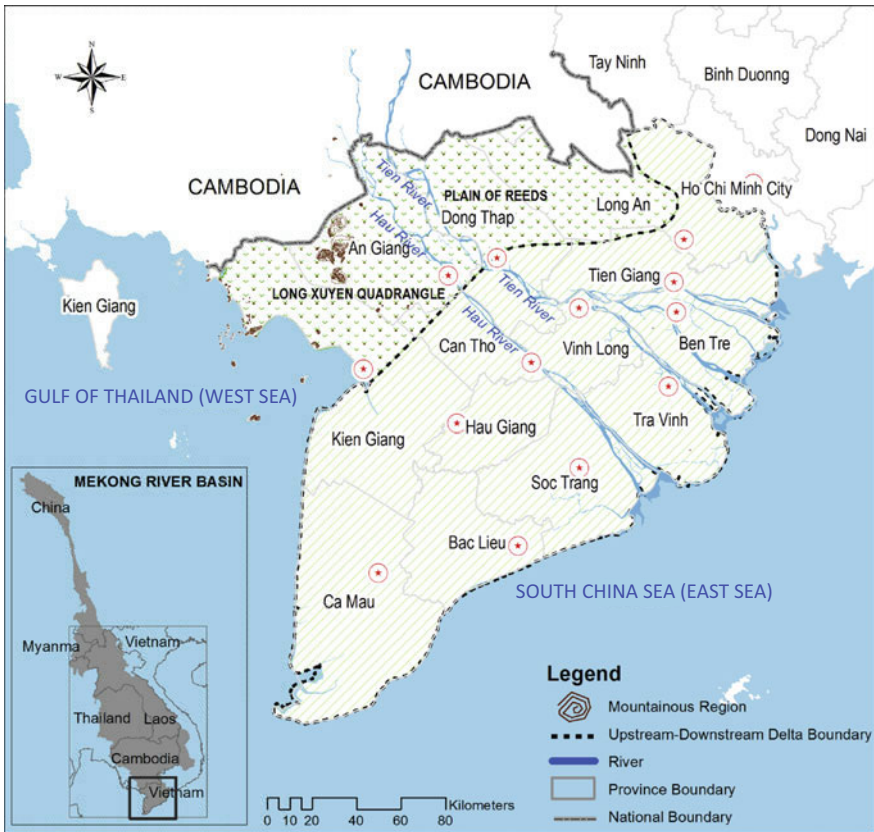


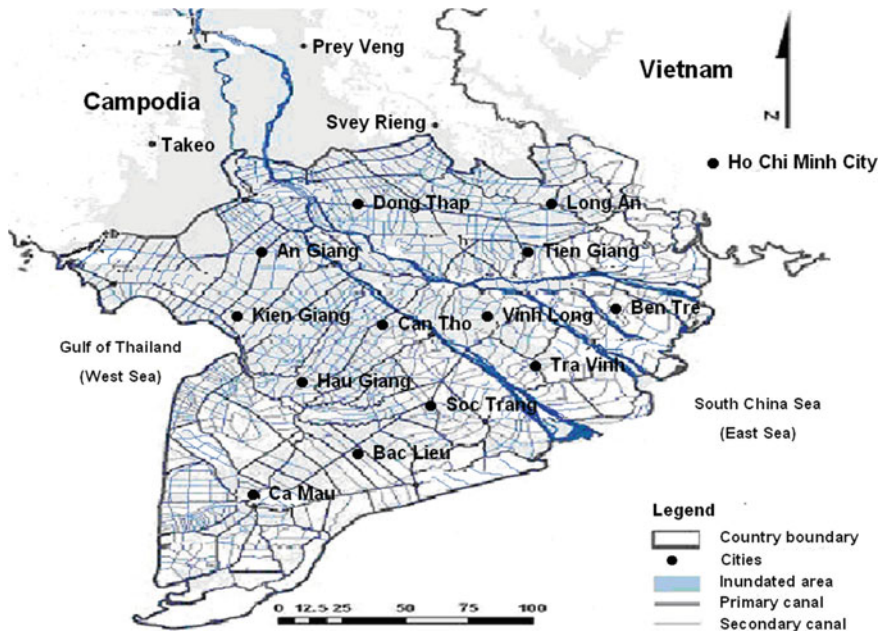
Fig. 1.1 Vietnamese Mekong Delta map and its provinces (Tran et al. 2019a)

70% of fruit. It also accounts for 95% of the country’s rice exports and 60% of total overseas shipment of fish (Besset et al. 2019). In recent years, salt intrusion into the VMD has become increasingly serious. This paper discusses the causes of salt intrusion, its effects on production and livelihoods, and adaption strategies to mitigate its impacts.

## 1.2 Causes of Saline Intrusion in the Vietnamese Mekong Delta

There are many causes for salt intrusion. First, low topography combined with a dense system of rivers and canals allow saline water to penetrate into the delta, especially those parts near to the coast, which are usually affected by saltwater intrusion during the dry season. The VMD has an inter-linked system of natural rivers and man-made canals connected to the sea which facilitate the movement of saltwater inland (Fig. 1.2).

A second major contributor to saltwater intrusion is low flow rates in the Mekong River during the dry season. Flow rates during the dry season are barely 2% of those in the wet season, and are insufficient to prevent extensive and sustained saline



**Fig. 1.2** Map showing the dense inter-linked system of natural rivers and man-made canals in the Vietnamese Mekong Delta (Adapted from MRC 2005)

intrusion (WB 2018). The overall hydrological regime in the VMD is directly affected by the upstream river flow, rainfall and the (differing) tidal regimes of the East Sea (South China Sea) and the West Sea (Gulf of Thailand). The low upstream flow period (December to May) occurs during the dry season and the earliest stages of the wet season. One reason for this is that the demand for hydropower has led upstream countries to construct series of dams on the main stream and tributaries of the Mekong River (Fig. 1.3). According to Bussi et al. (2021), a total of 284 dams have been built or are planned for construction on the Mekong River and its tributaries. Of these, 30 dams (seven already completed) are located on the main stem of the Mekong River, and the rest of them are on tributaries. There is evidence to show that existing dams already reduce the flow of water into the lower delta in the dry season (Cosslett and Cosslett 2014; Hecht et al. 2019; Binh et al. 2020). The seasonal discharge regime in the lower Mekong River is also expected to be affected directly by climate change; dry season discharges are predicted to decrease by 2% and the wet season discharges to increase by 5% over the next 30 years (Trieu and Phong 2015). Lower river flows, the lack of rain, and high evaporation during the annual dry season limit freshwater discharge rates which are unable to offset tidally driven salt intrusion. Consequently, salt intrusion often occurs in the Mekong River mouths and extends upstream inland from around December to May, with a peak at the end of April and early May every year.

Third, the VMD is facing growing competition for rapidly depleting water resources (WB 2018), mainly for agriculture and aquaculture. With an area of about 1.5 million ha of rice, including the late Winter-Spring (around January–February) and Summer-Early Autumn crops (sown around April–May), together with about 800,000 ha of aquaculture (670,000 ha of saline/brackish water and 130,000 ha of freshwater), the demand for fresh water for irrigation and aquaculture is very large (Anh 2019). Changes in rice cropping from 1–2 crops per year to 2–3 crops per year has increased the demand for water from about 400 m<sup>3</sup>/second in April to 600–700 m<sup>3</sup>/second (Anh 2019). Moreover, the construction of flood prevention dykes in the upstream areas of the VMD for agricultural cultivation, especially in two large low-lying areas, namely Dong Thap Muoi (Plain of Reeds) and the Long Xuyen Quadrangle has reduced the capacity of fresh water storage in upstream areas (Hoang et al. 2016). This has also contributed to a decrease in freshwater flows during the dry season. So, fresh water in the deltaic inland is not enough to prevent salt intrusion in this period, exacerbating saltwater intrusion into inland freshwater areas.

It has also been reported that the over-exploitation of ground water resources and land uses leading to land subsidence (Erban et al. 2014; Minderhoud et al. 2018), together with sea level rise induced by global climate change (Clark et al. 2016) have added to the threat of salinity intrusion in the VMD, and will continue to exacerbate the problem in the future.

In addition to the causes mentioned above, strong onshore winds from the east during the Northeast Monsoon or “Chuong Wind” (a local name) also contribute to salt intrusion by pushing saline water deeper into the rivers.

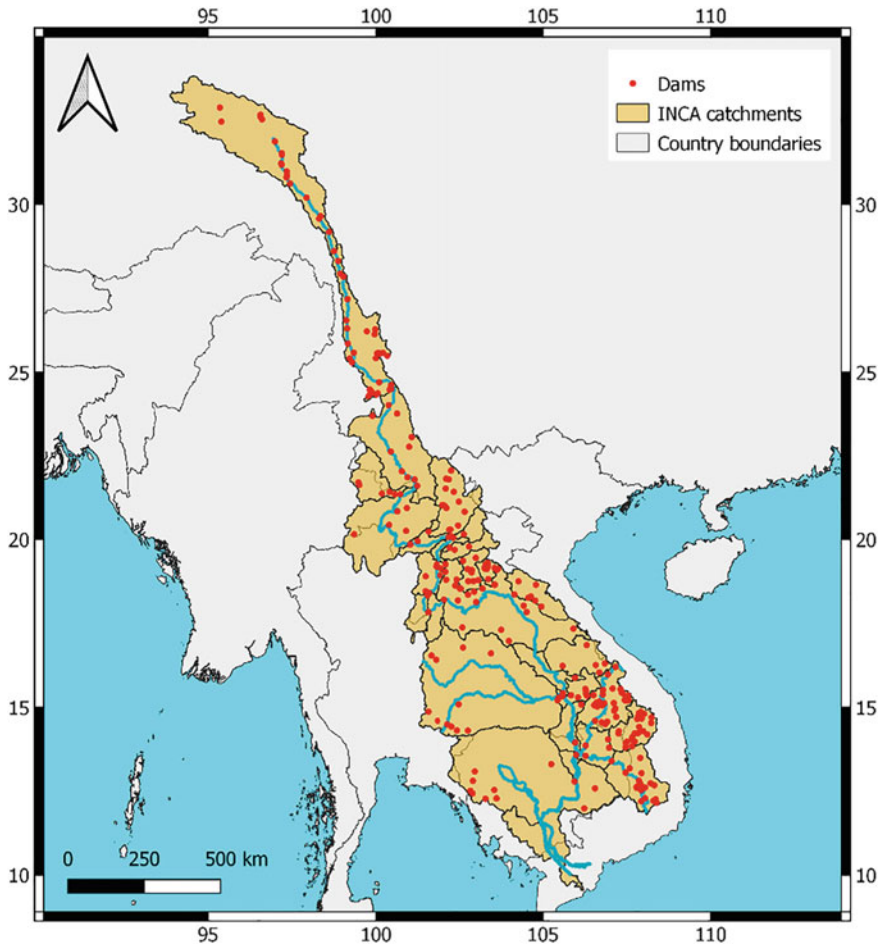


Fig. 1.3 Spatial distribution of dams within the Mekong River catchment (Bussi et al. 2021)

### 1.3 Effects of Saline Intrusion on People’s Life and Production

One of the most severe cases of saline intrusion in the VMD occurred in 2016, when the rainy season in 2015 started late and ended early, resulting in a much lower than average rainfall. This, together with the reduction in water flow in the Mekong River in the early months of 2016, led to elevated salinities extending as far as 93 km upstream in the Mekong Delta (on the Vam Co River, and up to 50–70 km in other estuaries (MARD 2016). This had severe adverse impacts on many economic sectors and people’s lives in 10 of the 13 provinces in the region (Long An, Tien Giang, Ben

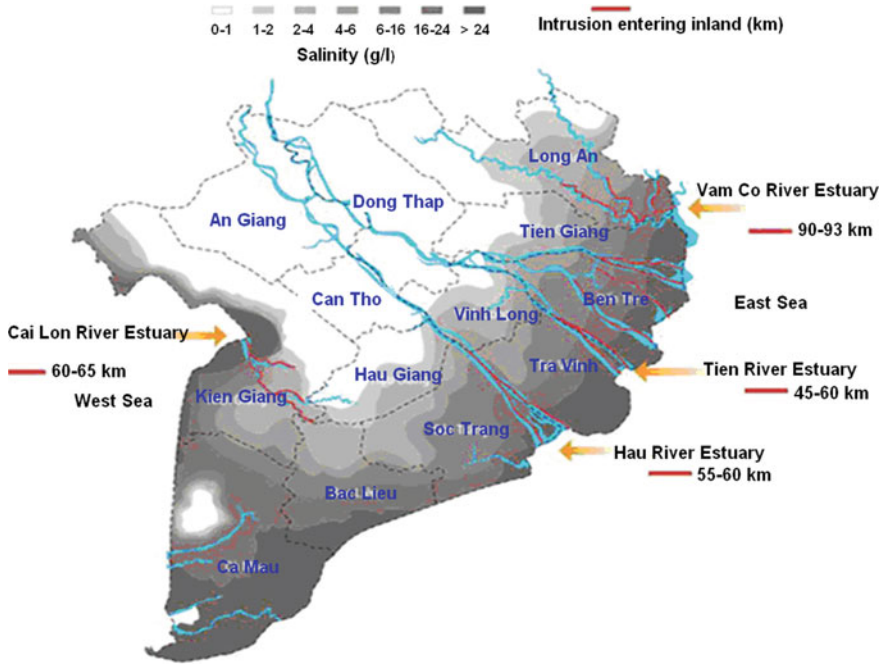


Fig. 1.4 Saltwater intrusion affected many provinces in the Mekong Delta until March 2016 (MARD 2016)

Tre, Tra Vinh, Soc Trang, Bac Lieu, Kien Giang, Ca Mau, Hau Giang and Vinh Long) (Fig. 1.4).

Saline intrusion also affected the availability of freshwater for domestic consumption and agricultural use, especially in many parts of Ca Mau, Kien Giang, Ben Tre, Tra Vinh, and Soc Trang which rely on groundwater for these purposes. Around 208,400 households (about 800,000 people), and many schools, clinics, hotels and factories experienced water shortages and salt intrusion (MARD 2016). According to Rentschler et al. (Rentschler et al. 2020), 22% of rice paddies in the VMD were exposed to salinity intrusion in 2016, leading to loss of 12% in national rice production and 8% in national agricultural GDP, directly affecting the livelihoods of some 3 million rice farmers.

The saltwater intrusion event of 2020 was even more serious than that of 2016, and it is the worst case of saltwater intrusion in the VMD until now. Saltwater intruded deeper inland than ever before and affected agricultural cultivation, aquaculture and livelihoods in 10 out of 13 provinces in the VMD. As an example of this, four villages, Dong Phu, Hoa Ninh, Binh Hoa Phuoc and An Binh, on a small island in the Tien River near Vinh Long city of Vinh Long province which had been in a fresh water area all year round for the past century, experienced a salinity of 4 g/l in the saltwater intrusion disaster of 2020. According to Phong (2020), water with a salinity of 4 g/liter affected 42.5% of the natural area of the whole VMD region,

equivalent to 1,688,600 ha, 50,376 ha more than in 2016. Ca Mau was the most affected province with damage to 16,500 ha of the crop area (including about 85% completely damaged, equivalent to 14,000 ha). For the 2019–2020 winter-spring rice crop, drought and saltwater intrusion affected about 41,900 ha, almost half of which (26,000 ha) experienced complete crop failure, in six provinces (Tra Vinh, Tien Giang, Soc Trang, Kien Giang, Long An and Ca Mau). Tra Vinh was the most severely affected province, with damage to 14,300 ha of rice. Drought and saltwater intrusion also damaged about 6,650 ha of fruit trees in six provinces (Long An, Tien Giang, Ben Tre, Vinh Long, Tra Vinh and Soc Trang), mainly due to a lack irrigation water, resulting in the complete loss of fruit production in 355 ha, and lower productivity elsewhere. More than 8,715 ha of aquaculture area in Ben Tre, Tien Giang, Kien Giang, Bac Lieu and Ca Mau also suffered damage. Altogether, a total of about 96,000 households, equivalent to about 430,000 people were affected by drought and saline intrusion in seven coastal provinces (Ben Tre, Soc Trang, Kien Giang, Ca Mau, Bac Lieu, Long An and Tra Vinh).

#### 1.4 Mitigation and Adaptation Strategies

Because of the agricultural and aquacultural significance of the VMD, local and central government authorities, and farm households have employed a range of engineering and land use strategies to adapt to or mitigate the impacts of saline intrusion. With respect to land use strategies, many farmers who live in areas affected by salt intrusion, have switched from a rice only or rice plus fish farming system to an integrated rice-shrimp farming system where they raise shrimp such as *Penaeus monodon* and *Litopenaeus vannamei* during the dry season and grow rice in the rainy season. This relatively new and very innovative solution carried out by farmers to adapt to saline intrusion helps both to increase farm productivity and to address the shortage of freshwater in the dry season. Another strategy to minimize the impacts of salinity dig an internal ditch system across the rice field to drain out saltwater and store freshwater, which has proven effective to maintain soil moisture and prevent salt deposition (Tran et al. 2019b). Farmers also pump freshwater into canals or small ponds lined with plastic or canvas, or in the case of orchards and vegetable gardens, in long tubular plastic bags which can be rolled up and reused in the future. This provides a better means to store and use freshwater for crop irrigation in conditions of prolonged heat or freshwater scarcity. Many farmers have converted their inefficient coastal rice farming areas, often threatened by saltwater intrusion, to aquaculture. They have also used more salinity-tolerant rice varieties, changed irrigation schedules, and altered rice-planting times to deal with salt intrusion.

Local and central governments have implemented many interventions to deal with saline water intrusion. At a community level, before salinity intrusion occurs, local authorities usually carry out community extension programmes to inform people on measures and tools to store fresh water, in order to ensure sufficient fresh water to sustain daily life and agricultural production during the period of drought or saline

water intrusion. A network of salinity monitoring stations has already been established throughout the VMD. The government has also built sluice gates at many strategic locations in the VMD to control the intrusion of saline water. Under current policy these are closed when salt levels reach 1.5 parts per thousand. Saline monitoring stations in the VMD have now been added by the government in accordance with the Prime Minister's Decision No. 16/QĐ-TTg issued on January 29, 2007, on the overall planning of monitoring network of National Natural Resources and Environment by 2020. The Prime Minister issued Directive No. 09/CT-TTg dated 12 March 2016 on the implementation of urgent measures to respond to saline intrusion in the VMD. The central government has provided financial support to communities and provincial authorities to mitigate the consequences of salt intrusion and reduce damage to agriculture and other economic sectors (Prime Ministerial Directive No. 09/CT-TTg dated 12 March 2016), committing a total of 523,700 million VND for the first phase (MARD 2016). According to a UNDP Disaster Management Unit Project (VIE/97/002) managed by the General Department of Land Administration, a sea dike of about 1,469 km in length is required to protect the VMD from saltwater intrusion and water level rise (Khong et al. 2018). The cost for a concrete sea dike 2 m high is about 1.16 million USD per km, rising to 2.8 million USD per km for height of 4 m (Khong et al. 2018). Thus the cost of building a 1,469 km long sea dike to protect the whole VMD is prohibitively expensive. Consequently, the central government has focused on supporting the construction of over 450 km of sea dikes, 1,290 km of river dikes and about 7,000 km of intra-field canals to reduce salinity intrusion and flooding in the most vulnerable parts of the VMD. In addition, the Government has recently built large sluice gates at the mouths of the Cai Lon (455 m in width) and Cai Be (85 m in width) Rivers in An Bien and Chau Thanh districts in Kieng Giang province on the west coast of the VMD, at an investment cost of over 3,300 billion VND. These replace a number of smaller, temporary sluice gates and control sea water and fresh water for agriculture and aquaculture in four provinces, Kien Giang, Hau Giang, and some parts of Ca Mau and Bac Lieu.

The Government of Vietnam has strengthened international cooperation with countries in the Mekong Committee and with China to reach agreement on common interests in the development and prosperity of the region in accordance with the 1995 Mekong Agreement, and has signed bilateral or multilateral agreements with each country, especially related to the use of Mekong River water. An example of this is that on March 7, 2016, the Ministry of Foreign Affairs of Vietnam issued a diplomatic note (No. 128/NG-ĐBA) to the Embassy of the People's Republic of China in Vietnam requesting China to increase water discharge from China's hydropower dams to the Lower Mekong River to help prevent salt intrusion. In response, Chinese authorities authorized emergency water discharge during the period from March 15, 2016 to April 10, 2016 (MOST 2016). This fresh water reached Vietnam in early April 2016 and helped to partly push the salt water wedge seawards. However, as more dams along the Mekong River come online, the lack of freshwater flow in the lower arms of the Mekong River will present an ever increasing challenge for dealing with salt intrusion into the VMD.

## 1.5 Conclusions

The VMD plays an important role in providing food and seafood not only for the region but also for the country, and for export. The delta is located at the end of the Mekong River, with relatively low terrain, along with the dense system of rivers and canals connecting to the sea. The pressure to use water in the region, the competition to exploit water from upstream countries especially in the dry season and rise level sea due to the effects of global climate change are the main causes leading to saline intrusion for the region. Saline intrusion has seriously affected the lives and production of thousands of households, and impacted on millions of hectares of farming soil in the region in recent years, especially in 2016 and 2020. Although a number of strategies have been employed to mitigate and adapt to the consequences of salt intrusion, current strategies may be ineffective in the longer term, because the problem is likely to become more serious in the future, mainly as a result of further reduction in fresh water flow due to dam construction, and because of rising sea levels. Therefore, the long-term delta wide strategy to adapt with saltwater intrusion should focus on “living with and adapting to saline intrusion”. This requires careful land use planning to develop and maintain salt-free upstream zones to grow food crops such as rice and fruit trees, and to cultivate freshwater aquaculture. Areas vulnerable to salinization can be converted to saltwater aquaculture (e.g. shifting ineffective rice-planting areas affected by saline intrusion to tiger shrimp cultivation) and areas at less risk of saline intrusion can switch to a combination of brackish water aquaculture and agricultural cultivation. These strategies could help people in the VMD to adapt to saline intrusion in the future while ensuring food security, stabilizing livelihoods, and maintaining economic development. Some farmers have already applied these alternative land use strategies, apparently with some success, but so far there have been no formal studies of their benefits and drawbacks, and over what time frames they might continue to be effective as adaptations to deal with the adverse impacts of salinity intrusion. Further studies of these and other potential options are needed to ensure that they are effective and they can bring cost-effective long-term benefits to the region.

## References

- Anh NN (2019) Causes of increased saline intrusion in the Mekong Delta and management solutions. <http://www.tongcucthuyloi.gov.vn/Tin-tuc-Su-kien/Tin-tuc-su-kien-tong-hop/catid/12/item/2671/nguyen-nhan-xam-nhap-man-tang-cao-o-dong-bang-song-cuu-long-va-giai-phap-quan-ly> (in Vietnamese language). Last accessed 25 July 2021
- Besset M, Gratiot N, Anthony EJ, Bouchette F, Goichot M, Marchesiello P (2019) Mangroves and shoreline erosion in the Mekong River delta, Viet Nam. *Estuar Coast Shelf Sci* 226:1–9
- Binh DV, Kantoush SA, Saber M, Mai NP, Maskey S, Phong DT, Sumi T (2020) Long-term alterations of flow regimes of the Mekong River and adaptation strategies for the Vietnamese Mekong Delta. *J Hydrol Reg Stud* 32:1–21

- Bussi G, Darby SE, Whitehead PG, Jin L, Dadson SJ, Voepel HE, Vasilopoulos G, Hackney CR, Hutton C, Berchoux T, Parsons DR, Nicholas A (2021) Impact of dams and climate change on suspended sediment flux to the Mekong delta. *Sci Total Environ* 75:1–12
- Clark PU, Shakun JD, Marcott SA, Mix AC, Eby M et al (2016) Consequences of twenty-first-century policy for multi-millennial climate and sea-level change. *Nat Clim Chang* 6:360–369
- Cosslett TL, Cosslett PD (2014) Major threats to Mekong Delta: climate change and mainstream dams. In: *Water resources and food security in the Vietnam Mekong Delta. Natural resource management and policy*, vol 44. Springer, Cham, pp 75–96
- Erban LE, Gorelick SM, Zebker HA (2014) Groundwater extraction, land subsidence, and sea-level rise in the Mekong Delta, Vietnam. *Environ Res Lett* 9:1–6
- Fujihara Y, Hoshikawa K, Fujii H, Kotera A, Nagano T, Yokoyama S (2016) Analysis and attribution of trends in water levels in the Vietnamese Mekong Delta. *Hydrol Process* 30:835–845
- GSO (General Statistics Office of Viet Nam) (2020) *Statistical Yearbook of Vietnam 2019*. Statistical Publishing House, Ha Noi
- Hecht JS, Lacombe G, Arias ME, Dang TD, Piman T (2019) Hydropower dams of the Mekong River basin: a review of their hydrological impacts. *J Hydrol* 568:285–300
- Hoang LP, Lauri H, Kumm M, Koponen J, van Vliet MTH, Supit I, Leemans R, Kabat P, Ludwig F (2016) Mekong River flow and hydrological extremes under climate change. *Hydrol Earth Syst Sci* 20:3027–3041
- Khong TD, Young MD, Loch A, Thennakoon J (2018) Mekong River Delta farm-household willingness to pay for salinity intrusion risk reduction. *Agric Water Manag* 200:80–89
- MARD (Ministry of Agriculture and Rural Development) (2016) Drought, saline intrusion in the Mekong Delta. <http://mtnn.mard.gov.vn/5/chi-tiet-tin-tuc-229/han,-man-tien-cong-dong-bang-song-cuu-long> (the paper in Vietnamese). Last accessed 25 July 2021
- Minderhoud PSJ, Coumou L, Erban LE, Middelkoop H, Stouthamer E, Addink EA (2018) The relation between land use and subsidence in the Vietnamese Mekong delta. *Sci Total Environ* 634:715–726
- Minderhoud PSJ, Coumou L, Erkens G, Middelkoop H, Stouthamer E (2019) Mekong delta much lower than previously assumed in sea-level rise impact assessments. *Nat Commun* 10(3847):1–13
- MOST (Ministry of Science and Technology of Vietnam) (2016) Saline intrusion in the Mekong Delta—effective solutions dealing with climate change conditions (in Vietnamese). <https://www.most.gov.vn/vn/tin-tuc/7039/xam-nhap-man-tai-dong-bang-song-cuu-long---nhung-giai-phap-ung-pho-hieu-qua-trong-dieu-kien-bien-doi-khi-hau.aspx>. Last accessed 25 July 2021
- MRC (Mekong River Commission) (2005) *Overview of the hydrology of the Mekong Basin*. Mekong River Commission, Vientiane
- Phong T (2020) The most severe drought and salinity in the history of the Mekong Delta (in Vietnamese language). <https://nhandan.vn/chuyen-lam-an/dot-han-man-nghiem-trong-nhat-trong-lich-su-dbscl-475180/>. Last accessed 30 July 2021
- Rentschler J, de Vries Robbé S, Braese J, Huy Nguyen D, van Ledden M, Pozueta Mayo B (2020) Resilient shores: Vietnam’s coastal development between opportunity and disaster risk. The World Bank, Washington, DC
- Tran DD, Halsema GV, Hellegers PJGJ, Hoang LH, Ludwig F (2019a) Long-term sustainability of the Vietnamese Mekong Delta in question: an economic assessment of water management alternatives. *Agric Water Manag* 223:1–12
- Tran TA, Nguyen TH, Vo TT (2019b) Adaptation to flood and salinity environments in the Vietnamese Mekong Delta: empirical analysis of farmer-led innovations. *Agric Water Manag* 216:89–97
- Trieu TTN, Phong NT (2015) The impact of climate change on salinity intrusion and Pangasius (*Pangasianodon Hypophthalmus*) farming in the Mekong Delta, Vietnam. *Aquac Int* 23:523–534
- WB (World Bank) (2018) *Vietnam-Mekong Delta water management for rural development project*. The World Bank, Washington, DC

# Chapter 2

## Improved Stochastic Fractal Search Algorithm for Joint Optimal Operation of Cascade Hydropower Stations



Zhanxing Xu, Jianzhong Zhou, Yuqi Yang, and Zhou Qin

**Abstract** The joint optimal operation of cascade reservoirs can not only improve the overall capacity of flood control and disaster reduction, but also increase the power generation benefit of hydropower stations, which is conducive to the efficient utilization of water resources in the basin. Long-term joint operation of hydropower stations is a typical multi-stage constrained optimization problem, which has the characteristics of high dimension, nonlinear and strong coupling. To solve this problem effectively, this paper proposes an improved stochastic classification algorithm (ISFS) based on the stochastic fractal search (SFS) algorithm and the disruption operator. The simulation results of 13 benchmark functions show that the algorithm can effectively improve the optimization performance of SFS. The calculation results of the joint operation of four cascade hydropower stations in the upper reaches of the Yangtze River show that the proposed algorithm is superior to the comparison method in terms of convergence speed and solution quality, and the overall power generation of cascade hydropower stations is significantly increased, which proves the advantages of the proposed algorithm in solving the joint operation problem of reservoir groups.

**Keywords** Improved stochastic fractal search algorithm · Cascade hydropower stations · Joint optimal operation

### 2.1 Introduction

In the context of “emission peak, carbon neutrality” policy, clean energy such as hydro energy, wind energy and solar energy are gradually highlighting their advantages

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of renewable and low emission, and vigorously developing clean energy will be the main direction of world energy strategy development in the future. Due to the inherent intermittence and fluctuation of wind power and photovoltaic, its extensive grid connection will directly affect the safe and stable operation of the power grid, and hydropower energy will play a more important role in the future power system with the characteristics of rapid start and stop, strong regulation performance and low operation cost (Sun et al. 2021).

Hydropower dispatching is a necessary means for space–time regulation of hydropower energy. Scientific optimal dispatching is beneficial to improve the utilization rate of hydropower energy and is of great significance for the full play of water resources in the basin (Yang et al. 2016). Mathematically, hydropower dispatching involves multiple decision variables and physical constraints, which is a complex constrained optimization problem. In order to solve this problem effectively, researchers all over the world have successfully developed various optimization methods. It mainly includes linear programming, nonlinear programming, dynamic programming, and other deterministic algorithms, but with the increase of computational dimension, this kind of algorithm has a disadvantage in computational efficiency (Feng et al. 2020). With the development of artificial intelligence and system theory, intelligent optimization algorithm has been deeply studied and widely used in hydropower optimal operation.

Genetic algorithm (GA), individual swarm optimization (PSO), differential evolution algorithm (DE), gravitational search algorithm (GSA), and other swarm intelligence methods have stronger adaptability and higher efficiency than traditional optimization algorithms (He et al. 2019). In recent years, they have been widely studied in solving reservoir optimal operation problems. However, swarm intelligence methods are usually limited by premature convergence and unstable solutions. Therefore, researchers try to develop more effective optimization tools to solve hydropower dispatching problems. Stochastic fractal search (SFS) is a new swarm intelligence method, which is inspired by fractal theory in geometry and has better global search ability and solving efficiency (Salimi 2015). In order to explore the feasibility of a stochastic fractal search algorithm in the optimal operation of cascade reservoirs, we developed the long-term optimal operation model of XLD, XJB, TGR, and GZB cascade hydropower stations, and proposed an improved stochastic fractal search algorithm to improve the optimization performance of standard SFS. Numerical experiments and real-world simulation results show the effectiveness and robustness of the method.

The main contributions of this study are as follows: (1) the generation scheduling optimization model is developed for cascade hydropower stations; (2) An ISFS algorithm combined with disruption operator is proposed to improve the performance of SFS; (3) Compared with the existing methods, this method achieves better results in numerical experiments and practical simulation, and provides a practical method for complex engineering optimization problems. The rest of this paper is organized as follows. Section 2.2 gives the operation optimization model of cascade hydropower stations. Section 2.3 presents the ISFS method. Section 2.4 tests the feasibility of

ISFS in 13 benchmark functions. Section 2.5 gives the application of ISFS to cascade hydropower station scheduling problem. The conclusions are summarized in the end.

## 2.2 Optimization Model for Cascade Hydropower Stations

### 2.2.1 Objective Function

In this research, taking the maximum total output of cascade hydropower stations as the optimization criterion, the objective function is described as follows:

$$E = \max \sum_{i=1}^M \sum_{t=1}^T K_i \cdot H_{i,t} \cdot Q_{i,t} \cdot \Delta t \quad (2.1)$$

where  $E$  is the total power generation of cascade hydropower stations;  $M$  is the total number of power stations;  $T$  is the total number of dispatching periods;  $K_i$  is the comprehensive output coefficient of the  $i$ th power station;  $H_{i,t}$  and  $Q_{i,t}$  is the average generating head and generating flow of the  $i$ th power station in  $t$ th period, respectively;  $\Delta t$  is the length of each period.

### 2.2.2 Constraints

(1) Water level constraint:

$$\underline{Z}_{i,t} \leq Z_{i,t} \leq \overline{Z}_{i,t} \quad (2.2)$$

where  $\overline{Z}_{i,t}$  and  $\underline{Z}_{i,t}$  represent the maximum water level limit and minimum water level limit of the  $i$ th power station in  $t$ th period respectively.

(2) Initial and final water level constraints

$$Z_{i,0} = Z_{i,\text{Begin}}, Z_{i,T} = Z_{i,\text{End}} \quad (2.3)$$

where  $Z_{i,\text{Begin}}$  and  $Z_{i,\text{End}}$  are the water level limits at the beginning and end of the dispatching period of the  $i$ th power station.

(3) Output constraint:

$$\underline{N}_{i,t} \leq N_{i,t} \leq \overline{N}_{i,t} \quad (2.4)$$

where  $\overline{N}_{i,t}$  and  $\underline{N}_{i,t}$  are the maximum output system and minimum output limit of the  $i$ th power station in  $t$ th period.

(4) Discharge constraint:

$$\underline{Q}_{i,t} \leq Q_{i,t} \leq \overline{Q}_{i,t} \quad (2.5)$$

where  $\overline{Q}_{i,t}$  and  $\underline{Q}_{i,t}$  are the maximum and minimum discharge limits of the  $i$ th power station in  $t$ th period.

(5) Equation of water balance:

$$V_{i,t+1} = V_{i,t} + (I_{i,t} - Q_{i,t}) \cdot \Delta t \quad (2.6)$$

where  $V_{i,t}$  and  $V_{i,t+1}$  are the initial and final storage capacity of the  $i$ th power station period respectively;  $I_{i,t}$  and  $Q_{i,t}$  are the inflow flow and discharge flow of the  $i$ th power station period respectively, and  $\Delta t$  is the period length.

(6) Water level amplitude constraint:

$$\Delta \underline{Z}it \leq \Delta Zit \leq \Delta \overline{Z}it \quad (2.7)$$

where  $\Delta \overline{Z}it$  and  $\Delta \underline{Z}it$  respectively represent the upper and lower limits of the fluctuation amplitude of the water level of the  $i$ th power station in  $t$ th period.

(7) Hydraulic connection between cascade hydropower stations:

$$I_{i,t} = Q_{i-1,t} + q_{i,t} \quad (2.8)$$

where  $I_{i,t}$  is the inflow of the  $i$ th power station in  $t$ th period,  $Q_{i-1,t}$  is the outflow of the upstream power station, and  $q_{i,t}$  is the interval inflow of the upstream and downstream power stations.

## 2.3 Improved Stochastic Fractal Search Algorithm

### 2.3.1 Overview of Stochastic Fractal Search Algorithm (SFS)

Stochastic fractal search algorithm (SFS) searches the optimal solution by the diffusion property of fractal. The algorithm mainly includes two processes, diffusion process and update process. In diffusion process, the Gaussian distribution is selected as the random walk mode, in which each individual is diffused around its current position to generate a new generation. This step can be regarded as the exploitation phase of SFS algorithm. For each individual that diffuses, the position of each new individual is created through Gaussian walking and find the best individual among

all individuals (Fig. 2.1). The Gaussian walking function can be expressed as one of the following two equations:

$$GW_1 = Gaussian(\mu_{BP}, \sigma) + (\varepsilon \cdot BP - \varepsilon' \cdot P_i) \tag{2.9}$$

$$GW_2 = Gaussian(\mu_P, \sigma) \tag{2.10}$$

where  $\varepsilon$  and  $\varepsilon'$  are random numbers between  $[0, 1]$ , BP is the optimal individual,  $P_i$  is the position of the  $i$ th individual,  $\mu_{BP}$  and  $\sigma$  are Gaussian distribution parameters.

After that is the update process of the SFS, which can be considered as the exploration stage of the algorithm. The process consists of two updates. The first update is for individual components, and the chance of individual component change is determined by sorting individual fitness values and calculating performance indicators. The better the individual fitness, the greater the chance of individual component change, the change formula of performance index and individual component is as follows

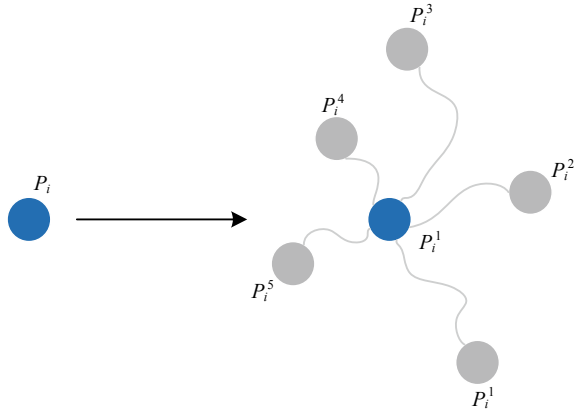
$$P_{ai} = \frac{rank(P_i)}{N} \tag{2.11}$$

$$P'_i(j) = P_r(j) - \varepsilon(P_i(j) - P_i(j)) \tag{2.12}$$

where  $P'_i$  is the new modified position of  $P_i$ ,  $P_r$  and are random selected individuals in the population.

The second update process aims to change the position of an individual by considering the position of other individuals in the population. This procedure improves the quality of exploration and thus meets the attributes of diversity. Before the second update process begins, all individuals obtained from the first update process need to be sorted again based on Formula 2.10, and then modify the position of  $P'_i$  as

**Fig. 2.1** Diffusing a individual in SFS



follows:

$$\begin{cases} P_i'' = P_i' - \varepsilon' \cdot (P_i' - BP) \varepsilon' \leq 0.5 \\ P_i'' = P_i' + \varepsilon' \cdot (P_i' - P_r') \varepsilon' > 0.5 \end{cases} \quad (2.13)$$

where  $P_i''$  is the position of the individual after the second update,  $P_r$  and  $P_i$  are two different random points selected from the group,  $BP$  is the best point and  $\varepsilon$  is a random number within the range  $[0, 1]$ .

### 2.3.2 Improved Stochastic Fractal Search Algorithm (ISFS)

**Improved strategy.** In practice, it is found that although the SFS algorithm has better global convergence ability than GA, PSO, DE, GSA, and other algorithms, there are still problems of precocity and falling into local optimum when standard SFS algorithm solves some complex optimization problems. In order to improve the performance of the SFS algorithm, a disruption operator is introduced in this section, which is incorporated into the diffusion and update evolution process of the algorithm, an improved stochastic fractal algorithm is proposed.

It is assumed that there is gravitational interaction among individuals in the current system, and other individuals in the system may be disturbed and scattered by the gravitational interaction of the current iterative optimal individual (Fig. 2.2). In order to prevent the divergence of solution and the complexity of the algorithm, the ratio of the distance between each individual and the nearest individual and the distance between the individual and the optimal individual of the system is calculated. If the ratio is less than a certain threshold  $C$ , the individual will be destroyed:

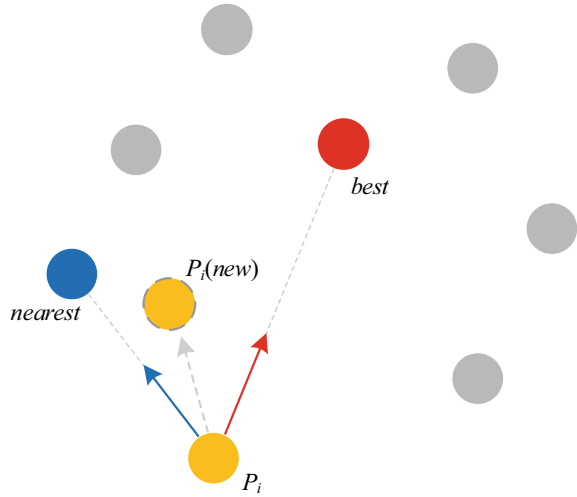
$$\frac{R_{i,j}}{R_{i,best}} < C \quad (2.14)$$

where  $R_{i,j}$  and  $R_{i,best}$  represent the Euclidean distance between the  $i$ th individual and the nearest individual in the decision space and the Euclidean distance between the individual and the optimal solution individual in the system, respectively. When the individuals disperse, the threshold  $C$  must be large enough to provide more exploration ability. When the individuals gather, the threshold  $C$  needs to be small to increase the development ability of the algorithm.

For the individuals that meet the conditions, the position information of each individual is adjusted according to Eq. (2.15):

$$\begin{cases} X_i(new) = X_i(old) + R_{i,j} \cdot U(-0.5, 0.5) \text{ if } R_{i,best} \geq 1 \\ X_i(new) = X_i(old) \times U(-0.5, 0.5) \text{ otherwise} \end{cases} \quad (2.15)$$

**Fig. 2.2** Sketch map of the disruption operator



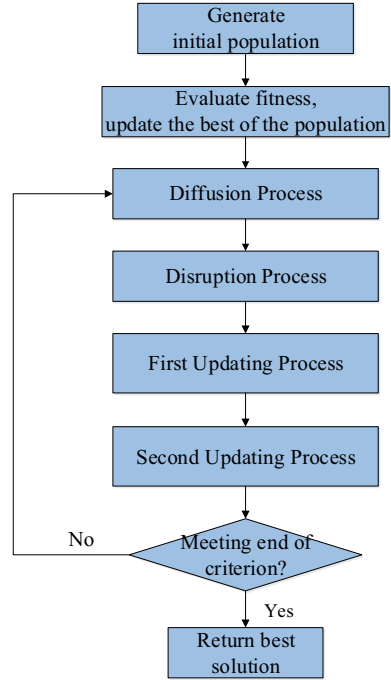
where  $R_{i,j}$  is the distance between the  $i$ th individual and the nearest  $j$ th individual, and  $U(-0.5, 0.5)$  is a random number in the range of  $[-0.5, 0.5]$ . The formula shows that when  $R_{i,best} \geq 1$ , the algorithm increases the ability of exploration and tries to explore the better solution in the search space. When  $C < 1$ , the development ability of the algorithm is gradually enhanced to improve the local optimization performance, which can improve the flexibility of solving more complex problems.

**Execution procedure of the proposed method.** Taking the standard SFS algorithm as the parent algorithm, by introducing the above disruption operator, we embed it into the diffusion update program of the SFS algorithm, and then propose an improved SFS algorithm, as shown in Fig. 2.3.

The overall procedure used by the proposed ISFS algorithm can be described as following steps.

- Step 1: Set the parameters of the algorithm and initialize the population.
- Step 2: Calculate the fitness value of each individual in the population and find the global optimal individual.
- Step 3: Each individual in the population is diffused by Gaussian walk, and the individual is replaced by the optimal individual generated in the process of each split diffusion, and the global optimal individual is found.
- Step 4: Execute the disruption operator to update the position of the individuals satisfying Eq. (2.14).
- Step 5: Execute the first update.
- Step 6: Execute the second update.
- Step 7: Determine whether the number of iterations reaches the maximum number of iterations. If the maximum number of iterations has been reached, the algorithm ends and outputs the result; Otherwise, execute step 3.

**Fig. 2.3** A block diagram of the proposed ISFS algorithm



## 2.4 Numerical Experiments to Verify the ISFS Performance in Benchmark Functions

To test the optimization performance of the improved algorithm proposed in this paper, 13 benchmark functions in Tables 2.1 and 2.2 are used to test the optimization performance of the ISFS and the SFS. In the simulation experiment, the dimension of the benchmark function is set as 30, the number of individual population is set as 50, and the total number of iterations is set as 1000. The test function is tested 30 times by ISFS and SFS. Then the results and convergence curves are compared and analyzed.

### 2.4.1 Benchmark Functions

Tables 2.1 and 2.2 are benchmark functions used to test the algorithm, where  $n$  is the dimension of benchmark function,  $S$  is the definition space of each benchmark function, and is a subset of real number set  $R^n$ . The minimum values of benchmark functions in Tables 2.1 and 2.2 in the definition space are all zero, except for  $F_8$  which has a minimum value of  $-418.9829 \times n$ . Except for  $F_5$ ,  $F_{12}$ ,  $F_{13}$  and  $F_8$ , the

**Table 2.1** Unimodal test functions

Test function	S	$f_{opt}$
$F_1(X) = \sum_{i=1}^n x_i^2$	$[-100, 100]^n$	0
$F_2(X) = \sum_{i=1}^n  x_i  + \prod_{i=1}^n  x_i $	$[-10, 10]^n$	0
$F_3(X) = \sum_{i=1}^n (\sum_{j=1}^i x_j)^2$	$[-100, 100]^n$	0
$F_4(X) = \max_i \{ x_i , 1 \leq i \leq n\}$	$[-100, 100]^n$	0
$F_5(X) = \sum_{i=1}^{n-1} [100(x_{i+1} - x_i^2)^2 + (x_i - 1)^2]$	$[-30, 30]^n$	0
$F_6(X) = \sum_{i=1}^n ([x_i + 0.5])^2$	$[-100, 100]^n$	0
$F_7(X) = \sum_{i=1}^n ix_i^4 + random[0, 1)$	$[-1.28, 1.28]^n$	0

**Table 2.2** Multimodal test functions

Test function	S	$f_{opt}$
$F_8(X) = \sum_{i=1}^n -x_i \sin(\sqrt{ x_i })$	$[-500, 500]^n$	$-418.9829 \times n$
$F_9(X) = \sum_{i=1}^n [x_i^2 - 10 \cos(2\pi x_i) + 10]$	$[-5.12, 5.12]^n$	0
$F_{10}(X) = -20 \exp(-0.2 \sqrt{\frac{1}{n} \sum_{i=1}^n x_i^2}) - \exp(\frac{1}{n} \sum_{i=1}^n \cos(2\pi x_i)) + 20 + e$	$[-32, 32]^n$	0
$F_{11}(X) = \frac{1}{4000} \sum_{i=1}^n x_i^2 - \prod_{i=1}^n \cos(\frac{x_i}{\sqrt{i}}) + 1$	$[-600, 600]^n$	0
$F_{12}(x) = \frac{\pi}{n} \{10 \sin^2(\pi y_1) + \sum_{i=1}^{n-1} (y_i - 1)^2 [1 + 10 \sin^2(\pi y_{i+1})] + (y_n - 1)^2\} + \sum_{i=1}^n u(x_i, 10, 100, 4)$ $y_i = 1 + \frac{x_i + 1}{4} u(x_i, a, k, m) = \begin{cases} k(x_i - a)^m & x_i > a \\ 0 & -a < x_i < a \\ k(-x_i - a)^m & x_i < -a \end{cases}$	$[-50, 50]^n$	0
$F_{13}(X) = 0.1 \{\sin^2(3\pi x_1) + \sum_{i=1}^n (x_i - 1)^2 [1 + \sin^2(3\pi x_1 + 1)] + (x_n - 1)^2 [1 + \sin^2(2\pi x_n)]\} + \sum_{i=1}^n u(x_i, 5, 100, 4)$	$[-50, 50]^n$	0

optimal positions of other test functions are all  $[0]^n$ , in which the optimal positions of 5, 12 and 13 are all  $[1]^n$ , and the optimal positions of  $F_8$  are  $[420.96]^n$ .