Shortage of Water Resources in Jaffna Peninsula of Sri Lanka

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***Abstract*—With elaborate reviews and on-site investigations, this paper systematically depicts the water resource status of Jaffna Peninsula from perspectives of both lagoon water and groundwater. The main problems that local government faced in water resources development and utilization process are heterogeneity of rainfall time and lack of water resource management measures, which lead to difficulties in rainwater harvesting/utilization, seawater intrusion and rising problems of water pollution. A water crisis has derived from above issues and severely restrains the local development. Therefore, an integrated water resources management plan is extremely urgent for Jaffna Peninsula.**

Keywords- Sri Lanka; Jaffna Peninsula; Lagoon; Groundwater; Integrated Water Management

I INTRODUCTION

Jaffna Peninsula is located in the northernmost part of Sri Lanka, near the Bay of Bengal. It is about 88 kilometers long and 24 kilometers wide. Jaffna Peninsula and India face each other across the Pauk Strait, and its southern part is connected to the main island of Sri Lanka by Elephant Passage, with an area of about 1000 square kilometers. It is mainly composed of Miocene limestone. The water area on the peninsula is large, and there are three large-scale lagoons. According to statistics from Sri Lanka's Provincial Irrigation Department Northern Province (PIDNP), the average annual rainfall in Jaffna region is about 1250 mm; the total water resources are about 1.25 billion cubic meters, and the available water resources is about 250 million cubic meters. It is estimated that recent demand for water is about 51 million cubic meters. There is no water supply and drainage system on the peninsula. The random storage of fishery and domestic garbage is common. There is no unified drainage and treatment channel for sewage. The overall environmental management situation is poor.

The region has a tropical monsoon climate, and its main feature is high temperature throughout the year, which is divided into significant dry and rainy seasons. Flat terrain and long dry season make it difficult to effectively store and use rain in the rainy season. In addition, lack of rational planning and management of groundwater extraction has led to continued intensification of seawater intrusion in this area, further exacerbating local shortage of fresh water resources. Based on collection and analysis of the existing research results and information held by government departments, this paper systematically depicts the current status and problems of water resources in Jaffna Peninsula, analyzes its causes deeply in combination with local physical geography and socio-economic status, and emphasizes the importance of integrated water resources management system for the region.

II BACKGROUND OF THE STUDY AREA

A. Socioeconomic overview

The total population of Jaffna Peninsula is about 300,000, of which the Tamil population is the main. The largest city on the peninsula is Jaffna with a population of about 130,000. The population on the east side of the peninsula is relatively scattered. There are extensive coconut forests and oil palm plantations on the peninsula, and the peninsula is rich in rice, taro and tobacco. There are many local residents engaged in fisheries, and salt fields are distributed along the lagoon and coastal areas. Jaffna once had a developed manufacturing and food processing industry, but it gradually declined after 1995 [1]. At present, the output value of plantation and fishery accounts for more than 60% of the region's main economic output value, but nearly half of the farmers do not own their own land.

B. Overview of Physical Geography

(1) Topography

The overall topographic relief of Jaffna Peninsula is relatively small, and there is a large-scale lagoon (Elephant Pass Lagoon) at the junction between the peninsula and main island, which almost separates the peninsula from the main island, A large-scale water storage project (Iranamadu Tank) is constructed at about 20 km south of the junction. The peninsula is divided into four parts by lagoon and ocean cutting. The western islands are distributed with a relatively sparse population. The larger islands are mainly Kayts Island. The central and western regions are the main population distribution areas. Jaffna City is located near the sea in the south of the region. This area is relatively separated from the eastern side of the peninsula during the rainy season affected by the lagoon. The northeastern part is covered with sandy beaches with a length of nearly 50 km. There are sandy pore aquifers with the best mining

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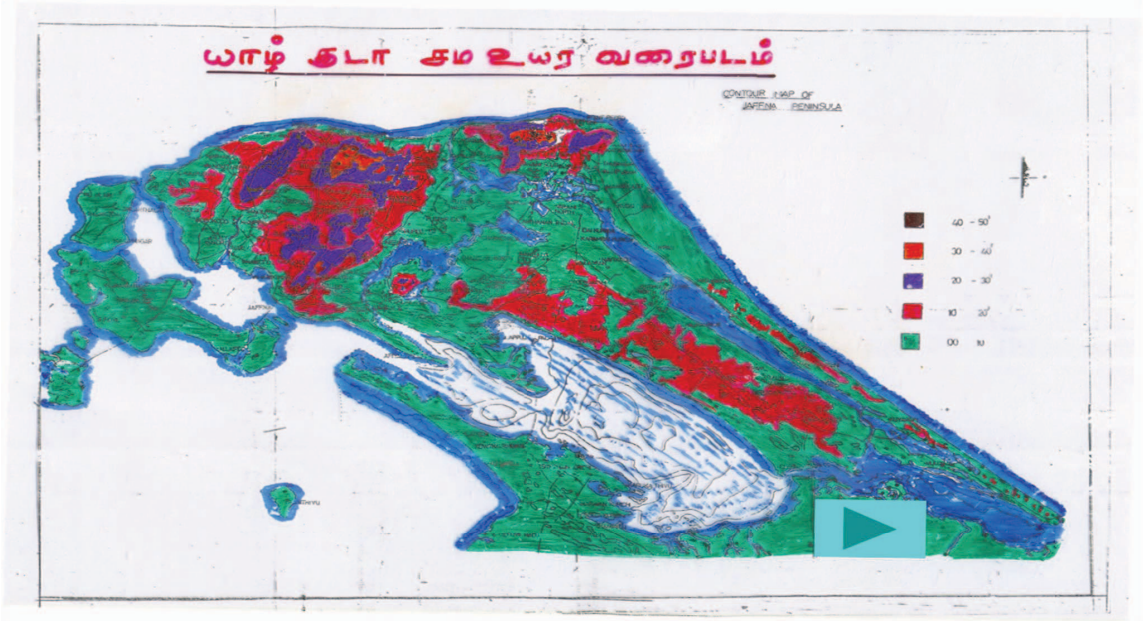
conditions on the peninsula, but the area is affected by tropical storms. The southeast region is located in the bay, and the north and south sides are adjacent to the lagoon. It is less affected by tropical storms and the terrain is flat, but most of the land in this area does not belong to the Jaffna administrative region.

The Jaffna Peninsula is relatively flat with a maximum elevation of approximately 12 meters. The islands, the central lagoon area, and the coastal beach area in the northeast have the most flat terrain, only slightly above sea level. The mid-west and northern regions are relatively high above sea level and are relatively high points on the peninsula. The terrain in the southeastern region is not undulating. In general, the water storage capacity of the Jaffna Peninsula is poor, and it is difficult to build large-scale water storage projects based on natural terrain. Most of the rain in the rainy season directly flows into the sea in the form of sloping currents. Lagoon water is shallow, so it is difficult to regulate and use effectively.

Figure1. Topographic map of Jaffna Peninsula (UNIT: ft, from PIDNP)



(2)Climate

1) Temperature

The multi-year average temperature is about 27°C; the highest average temperature is in April and May; the average monthly temperature is 29°C; the lowest average temperature is in December, and the average monthly temperature is 24°C. The highest and lowest temperature in the historicalstatistical range is 36°Cand 16°C respectively.

2) Rainfall

The multi-year average precipitation is about 1270 mm. The main rainfall month is from October to December, which accounts for about 68.5% of the annual rainfall. It is more common for single-day rainfall to be more than 25 mm. There is a brief rainfall period in April and May, and the average rainfall is about 90 mm.

The other five months of the year are the dry season, with a total average rainfall of about 110 mm, which only accounts for about 8.7% of the annual average rainfall. The least average monthly rainfall is in June and the average rainfall is only 10 mm. The total average rainfall days are only 9 days, of which the average rainfall days in June and July are only 1 day.

3) Humidity and dew point

The multi-year average relative humidity is about 79%, the lowest monthly average is in February and March, the average relative humidity is 74%, and the highest monthly average is in November, with an average relative humidity of 84%. The average monthly relative humidity from May to December is relatively stable, all above 80%. The multi-year average dew point temperature is 22°C, and the average dew point temperature of each month is all lower than or equal to the corresponding monthly minimum temperature, and there are fewer occurrences of fogging and condensation.

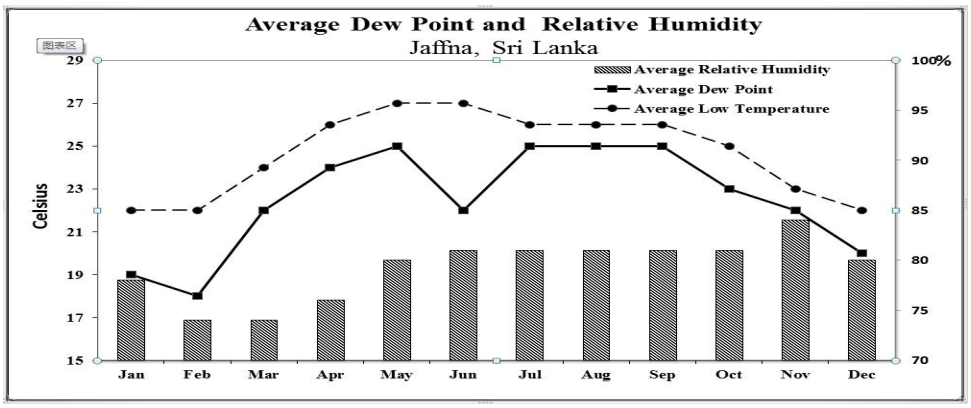


Figure 2. Meteorological statistics of Jaffna Peninsula [2]

III WATER RESOURCES STATUS

A. Overview

There is no stable surface runoff in Jaffna Peninsula, and groundwater resources also depend on the recharge of rainfall. According to data provided by Sri Lanka ' s Northern Province Irrigation Department (PIDNP), the average annual total water resources of the Jaffna Peninsula is approximately 1,250 million cubic meters (MCM, million m3, commonly found in the Jaffna region statistics). Excluding evaporation loss and surface runoff loss, the available water resources are about 250 million cubic meters. The department estimates that the total agricultural and domestic water storage capacity of the peninsula in 2050 will be about 171 million cubic meters, accounting for about 70% of the available water resources. This shows that the water resources of Jaffna Peninsula are relatively abundant. The current water crisis is mainly caused by the following two reasons:

(1) Rainwater resources utilization issues: The peninsula has a gentle terrain and concentrated rainfall, and it is difficult to use natural terrain to collect and store rainwater. At current stage, there are no effective measures to make full use of rainwater resources in the rainy season.

(2) Management issues: Lack of comprehensive and effective management measures by local governments to use and protect water resources has caused problems such as seawater intrusion, agricultural non-point source pollution, and non-point source pollution, and has further worsened the water resources situation on the peninsula.

B. Lagoon

a. Geographical location and distribution of water conservancy facilities

There are four large-scale lagoons on Jaffna Peninsula, of which Jaffna Lagoon is the largest lagoon in the region; Elephant Pass Lagoon is located at the junction of the peninsula and main island, which almost separates the two and connects with Jaffna Lagoon on the west side; The remaining two lagoons are lagoons inside the peninsula, and water conservancy facilities are constructed at the connection with the Indian Ocean. Jaffna Lagoon has a large entrance to the ocean, making it difficult to construct water conservancy facilities, and its internal water quality is strongly affected by seawater. The lagoon is actually similar to a bay. Therefore, the main consideration in the existing lagoon protection and utilization plan in Jaffna is the remaining three lagoons. The area of the three lagoons in wet seasons and the catchment area are shown in Table 1. Except for Jaffna Lagoon, the area of each lagoon decreases significantly in the dry season. Among them, Upparu Lagoon almost dries up except for the southern offshore area; Vadamarachchi Lagoon almost ceases to flow in the Midwest and becomes two basically independent lagoon systems. That' s why Jaffna Peninsula is mentioned to have five lagoon systems in some materials.

Table 1. Lagoon's area in wet season and the corresponding catchment area (unit: square mile)

Lagoon	**Area in wet season** [3]	**Catchment area** [3]
Upparu Lagoon	10	85
Vadamarachchi Lagoon	30	115
Elephant Pass Lagoon	40	363

Upparu Lagoon and Vadamarachchi Lagoon are connected to the ocean with small entrances, and each has only one connection. Ariyalai Barrage and Thondamanaru Barrage are constructed respectively. Among them, repair works are carried out for Ariyalai Barrage and Thondamanaru Barrage recently, and their operating conditions have improved compared to that in the past, but the phenomenon that lagoons are invaded by seawater in dry seasons has not been changed. Barriers have been constructed on both sides of the Elephant Pass Lagoon, but the operating conditions are not ideal, especially due to ground subsidence and seawater erosion on the east side, the collapse occurred shortly after completion [3]. The Mulliyan Channel linking Vadamarachchi Lagoon and Elephant Pass Lagoon was an important part of the River for Jaffna scheme proposed by the Irrigation Department of the Northern Province of Sri Lanka in 1983, but finally it was not implemented.

Figure 3. Lagoon's location and distribution of hydraulic projects of Jaffna Peninsula (base map is from Bing Map)

b.Upparu Lagoon

Upparu Lagoon, also known as South Lagoon, is the smallest one in the Jaffna Peninsula lagoon system, with a high population density in surrounding areas. After the completion of the Ariyalai Barrage renovation project, the lagoon is relatively less affected by seawater and its water storage capacity is relatively small. A series of independent ponds have formed in some areas. At present, the lagoon is greatly affected by human activities, and there are salinization problems in some waterfront areas.

According to data provided by the National Water Supply & Drainage Board (NWSDB) in Sri Lanka, the conductivity of water bodies in lagoons has increased significantly during the dry season (approximately from May to October), up to 80,000 μ s/cm. It is approaching the seawater quality outside the barrage, which is caused by the strong evaporation during the dry season.

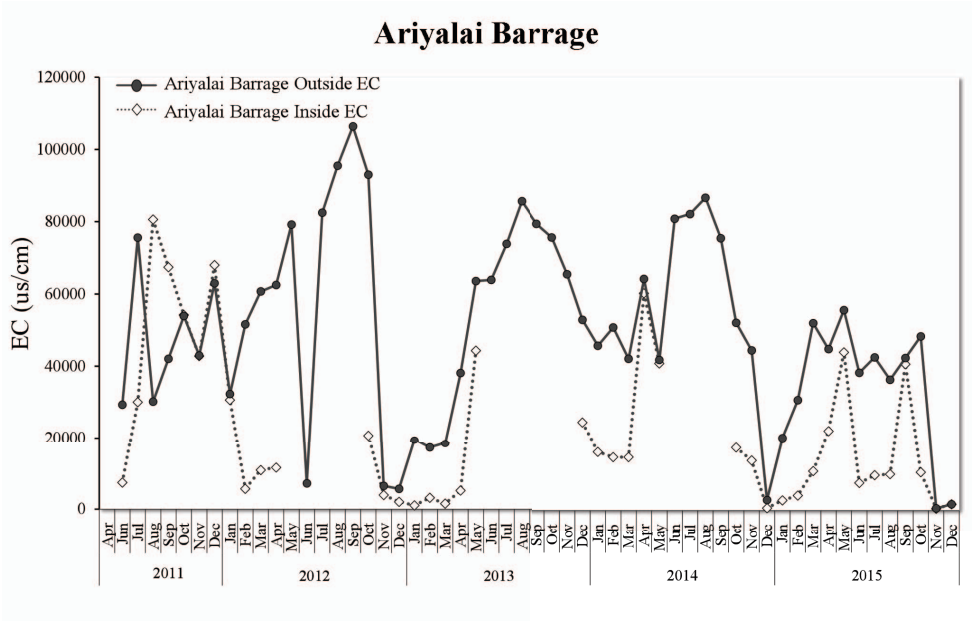


Figure 4. EC Inside and outside Ariyalai Barrage

c. Vadamarachchi Lagoon

Vadamarachchi Lagoon is almost cut off in the Midwest during the dry season and will form two relatively independent lagoon systems. Therefore, the west seafront part of the lagoon is also called Thondamanaru Lagoon in some literatures. This part of the lagoon system is relatively affected by seawater. While the narrow and long lagoon system on the southeast side is relatively closed, the conductivity of the water body in the lagoon increases greatly in the dry season (approximately from May to October), up to 56000 μ s / cm, which is about 50% of the seawater conductivity outside the barrage. It is caused by strong evaporation during the dry season. In recent years, the conductivity of the water in the dam is basically stable, which indicates that the renovation project of Thondamanaru Barrage has played a certain role.

Due to its special geographical location and environmental conditions, there are frequent fishing activities in the western region of Vadamarachchi Lagoon. According to historical information provided by the irrigation department of the Northern Province of Sri Lanka, the total fishery production in the lagoon area in 1993 was approximately 46 tons per year.

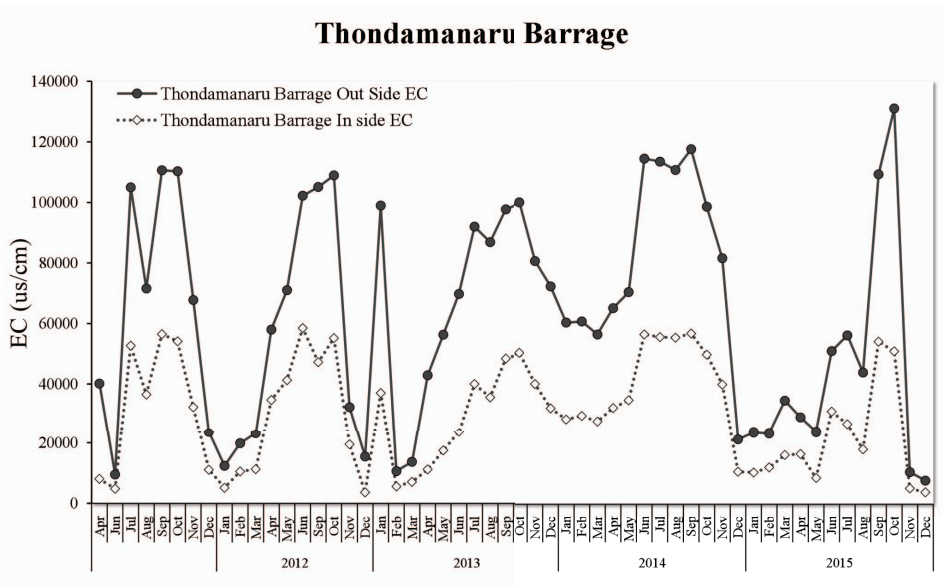


Figure 5. Inside and outside EC of Thondamanaru Barrage (from NWSDB)

d. Elephant pass Lagoon

Elephant pass Lagoon is one of the largest lagoons in the Jaffna Peninsula lagoon system. It receives surface runoff from the main island on the south side and has a considerable amount of freshwater supply. Therefore, the lagoon has long been regarded by local scholars as the best starting point for solving the peninsula's water problem. The River for Jaffna plan is to use the lagoon's freshwater runoff supply to flush and dilute the interior of Vadamarachchi Lagoon Water body. The conductivity data of this lagoon is relatively few. It can be seen that under the freshwater runoff recharge in the rainy season, the conductivity of the water body in the lagoon is generally low, and a large amount of fresh water that has not been stored is discharged into the ocean through the lagoon, resulting in a dramatic downward trend of the conductivity of the seawater outside the dam during the same period. Under the strong evaporation in the dry season, the conductivity of the water body in the lagoon is higher; but the highest conductivity generally occurs from September to December, mainly due to lateral intrusion into the lagoon caused by the tropical storm in the rainy season. Since Elephant pass Lagoon is a relatively open lagoon system, the conductivity of its internal water body varies greatly. In addition, the lagoon has high connectivity with the ocean. There are large mangrove forests and abundant seafood such as shrimp and crab. A large number of residents engage in fishery activities in the lagoon.

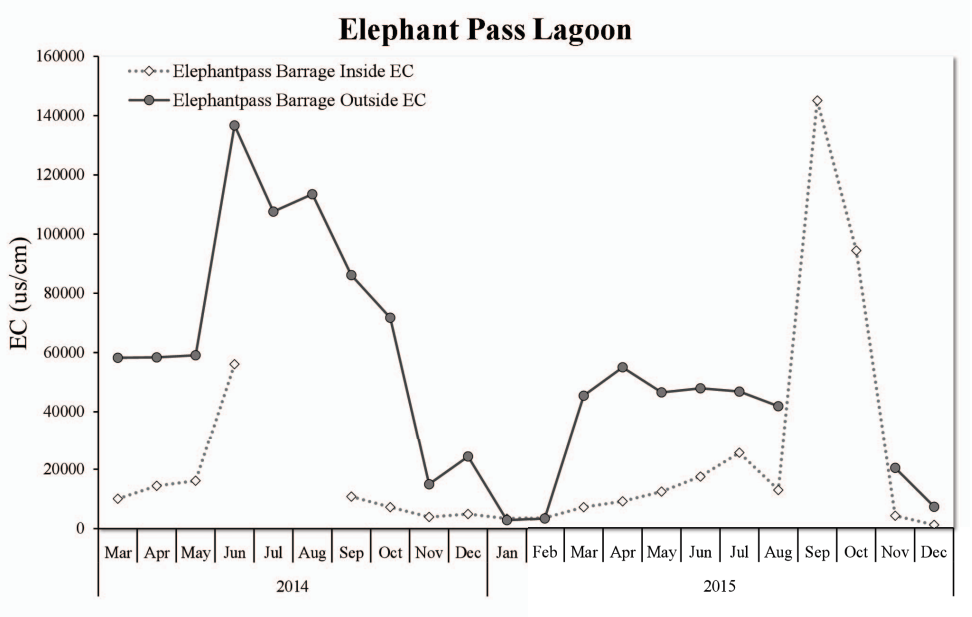


Figure 6. Inside and outside EC of Western Closer Barrage

C. Underground water

(1) Hydrogeological overview

Bedrocks in Jaffna Peninsula are limestones from the early Miocene [4]. This group of limestones is usually compact and hard, with some crystalline rock bodies [5]. There are a large number of coral limestones along the northern coastline of the peninsula, some of which were formed during the Quaternary period [5]. The thickness of limestone in the Jaffna is usually greater than 75 meters, and the karst landforms are relatively developed. There are rectangular faults that run in the direction of NW-SE and NE-SW. The main aquifer is fissure water aquifer [5]-[7].

The surface is mainly covered by soil, widely distributed on the peninsula, with a thickness of about 0.6-2.1 meters. The sandy sedimentary layer is generally about 3-6 meters thick, mainly distributed along the coastline on the north east side of the peninsula, and the thickness can reach 20 meters. A sandy aquifer with good water content is formed in this area [5].

Rainfall recharge is the main source of groundwater recharge in the peninsula. The recharge process mainly occurs during the rainy season (usually from September to December). The groundwater level rose from the lowest value in August (about 0-1 meters below sea level) to January, with the highest value of about 0-2.5 meters above sea level [5]. After the rainy season, there is a sudden drop in the groundwater level, and a large amount of fresh water is discharged into the sea through the fissure system [8][9]. According to historical data, although the maximum water level will vary with changes in rainfall during the rainy season, the minimum water level in August

remained basically stable, indicating that groundwater storage in Jaffna Peninsula remained relatively stable for a long time [5].

(2)Aquifer type

The main type of aquifers in Jaffna Peninsula is fractured aquifer. In addition, there are two different types of sandy aquifers.

1) Imestone fractured aquifer

This aquifer is distributed in most areas of Jaffna Peninsula, especially in the Midwest. It is the most important aquifer in Jaffna region. Due to lack of research on the petrological characteristics of the limestone of Jaffna [5], the distribution law of limestone fractures and karst caves within the peninsula is not clear. Aquifers are closely connected to seawater and surface sandy soils through widely distributed fracture systems. It is easily affected by seawater intrusion or surface pollution. It has caused some difficulties in development and utilization of groundwater resources [10]. The fracture rate of this aquifer varies greatly, ranging from 4.5% to 27%, with an average fracture rate of about 15% [11].

2) Sandy aquifer in coastal area

It is mainly distributed in coastal areas on the north east side of the peninsula, located between the coastline and the north shore of Vadamarachchi Lagoon. It starts from Point Pedro and extends to the southeast to Chundikkulam. It is about 50 kilometers long and is mainly composed of coastal sand dunes overlying limestone. It has a thickness of up to 20 meters and good water abundance. It is one of the main aquifers on the peninsula that can provide a stable water source. A small water plant is built near Point Pedro.

3) Sandy aquifer in central loess area

This aquifer is mainly distributed between Vadamarachchi Lagoon and Jaffna Lagoon and extends westward to the east of Upparu Lagoon. The thickness of this aquifer is uneven, and the thickness gradually increases from west to southeast [10].

(3) Groundwater salinity

Seawater intrusion is common in Jaffna Peninsula, especially in coastal and island areas and during the dry season. Groundwater salinization caused by seawater intrusion is more serious. Affected by seawater intrusion, almost half of the wells in Jaffna Island become salted. There are many ways for seawater to invade groundwater, including infiltration through sandy aquifers, intrusion through limestone fissures, and lagoons. However, the root cause is the disorderly exploitation of groundwater, the obsolescence of lagoon water conservancy facilities, and lack of a reasonable operation and management mechanism. Only in a few years, seawater intrusion in coastal areas caused by extreme meteorological activities or geological disasters becomes serious.

1) Disorderly groundwater extraction

The quality of the water obtained from different wells is different. Unreasonable locations and depths of well not only fail to obtain fresh water, but also exacerbate seawater intrusion. Unreasonable well location selection and over-exploitation are the main reasons for seawater intrusion in this area.

The main direction of the groundwater flow in Jaffna Peninsula is from the middle of the island to the north and south sides, but the population of the peninsula is mainly distributed in the southwest coastal area, and the corresponding groundwater mining activities are also concentrated in this area. The agricultural irrigation water intake location in the densely populated area of the peninsula is located in the area where freshwater lenticle is relatively thin in the direction of groundwater runoff, while domestic water intake location is located in the coastal area. Generally speaking, water intake locations are relatively concentrated, and it is not the region with the most abundant freshwater resources on the peninsula. The unreasonable groundwater exploitation plan has aggravated the local seawater intrusion phenomenon, especially caused severe damage to the groundwater resources in the coastal area.

2) Backward water conservancy facilities of lagoon

Although the local government in Jaffna has repaired water conservancy facilities at many lagoon-ocean junctions in recent years, the problem of seawater intrusion into lagoon has not been completely solved. Under such conditions, the continuous infiltration of salt water will have a certain impact on groundwater, and the lagoons are located close to the main aquifers in the peninsula, further magnifying the impact of seawater intrusion, especially when extreme meteorological events such as tropical cyclones occur.

3) Impact of extreme weather events and geological disasters

Jaffna Peninsula is located in a tropical monsoon climate zone. Affected by tropical cyclones and plate movements, coastal areas will be affected by natural disasters such as storms and tsunamis. T. Illangasekare and others once paid attention to the impact of the tsunami disaster caused by earthquake in 2004 on groundwater resources in the coastal areas of Sri Lanka, and found that tsunami caused widespread short-term impacts on the groundwater along the coast, which resulted in that a large number of wells are salted within a few months. Although salinity of most wells returned to normal after a few months,

salinity of some wells remained at a level that could not be supplied to residents for a long time [13].

Similarly, extreme weather events such as tropical storms can cause similar seawater intrusions. In addition, when the above-mentioned meteorological events occur in Jaffna Peninsula, seawater will also flood into the lagoon, causing salinity of the lagoon water to rise significantly. This was the case with Elephant pass Lagoon in September, 2015. High salinity lagoon water will continuously recharge groundwater through limestone cracks or sandy bottom layers, which will have a long-term impact on groundwater quality.

IV Fresh water shortage

Jaffna Peninsula is rich in rainwater resources. The groundwater aquifers are mainly limestone fissure aquifers and sandy porous aquifers. The total amount of water resources is not scarce, but there are certain difficulties in development and utilization, mainly due to the following reasons:

(1) Although the rainfall is relatively concentrated, with scattered catchment surface and strong evaporation, it is difficult to use for a long time. The flat natural terrain determines that it is impossible to build a water storage project based on the terrain, and the backward economic situation in the local area determines that it is not feasible to build large-scale water conservancy facilities.

(2) There is a lack of research on groundwater resources and insufficient geological survey data to describe the distribution law of freshwater lenticle on the peninsula, making it impossible to formulate a reasonable groundwater exploitation plan; the local drilling capacity is poor, and effective hydrogeological surveys cannot be conducted.

(3) The level of social management is low. There is basically no water supply network and sewage network. The direct discharge of domestic sewage and lack of control over agricultural and fishery non-point source pollution have led to water resource pollution. Excessive exploitation of groundwater has led to groundwater salinization. Lack of management of salinized or contaminated abandoned wells has further exacerbated groundwater pollution.

Water shortage in Jaffna Peninsula is a complex systemic problem. A plan only focusing on lagoon desalination cannot solve the fundamental problem. Based on a comprehensive study of surface water, groundwater, rainwater collection and utilization, and sewage treatment, the comprehensive management system for sustainable development of water resources is of great significance to Jaffna Peninsula.

V Conclusions and suggestions

The gross amount of water resources in Jaffna Peninsula is abundant, but replenishment period is relatively concentrated. The water shortage generally emphasized by local governments and scholars is essentially a “water quality-induced water shortage” problem. That is, the existing water resources cannot meet needs of local residents for their lives and production due to water quality problems. It is specifically manifested in difficult to effective storage and utilization of rain in the rainy season, frequent occurrence of seawater intrusion, and increasingly serious water pollution. However, the existing research work and solutions mainly focus on desalination of lagoon water resources, and ignore rainwater collection and utilization, groundwater resource exploitation planning, water pollution prevention and control. Water shortage problem in Jaffna Peninsula cannot be solved fundamentally. Therefore, a comprehensive water resources development and management system is of great significance to this region. It is recommended to comprehensively consider factors such as water resources utilization zones, exploiting plan, water supply channels, and carry out in-depth research on the comprehensive management system for sustainable development of water resources, under the principle of “partitioned water supply, abundant water sharing, exploitation and protection in parallel”.

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