The effects of socioeconomic activities on water quality in Hainan Island, south China

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Abstract

Water quality is intimately related to the livelihood of the numerous people, and affects the development and operating benefits of various industries in society. This study clarifies the effects of human-driven economic activities on inland water quality in Hainan Island, and reveals relationships between water quality and tourism on the island. Based on previously monitored data, this study uses a static Bayesian network and radial basis function neural network (RBFNN) to model and predict the future water quality. From 2012 to 2015, water quality in the Nandu, Wanquan and Changhua Rivers was good (at level II, GB3838-2002). The static Bayesian network demonstrated that Gross Output Value (GOV) of agriculture, GOV of fishery, GOV of animal husbandry and chemical oxygen demand (COD) discharge will significantly affect water quality in the Nandu and Changhua Rivers. The effect of tourism on water quality in Wanquan River was significantly higher than that on the Nandu and Changhua Rivers. In the Wanquan River, the DO content fluctuated greatly in comparison to the other two rivers, and unexpectedly, increased tourism led to higher DO values. However, it remains necessary to closely monitor negative changes in water quality due to tourism, especially in Wanquan River and eastern Hainan province. The developed RBFNN showed that the changes in water quality were predicted accurately in comparison with experimental values in the present study and the water quality also is continuously improving. Overall, results suggest that current anthropogenic socioeconomic activities had a modest effect on water quality in Hainan Island. Agriculture, fishery, animal husbandry and COD discharge were relatively important factors affecting water quality, while tourism had a perceptible effect in eastern Hainan. Our findings provide a reference for the balance of water quality, people's livelihood and economic development (tourism and port construction) in Hainan province.

1. Introduction

With the rapid development of China's economy, increasing discharges of industrial and agricultural wastewater and domestic sewage are accelerating the eutrophication of lakes (Lin et al., 2021; Pu et al., 2021). Due to these human activities, aquatic water quality has declined to varying degrees (Luo et al., 2021). To date, the rate of damage to aquatic environments is far greater than their ability to recover (Hand et al., 2021). During eutrophication worldwide, excessive loading of the growth limiting nutrients nitrogen and phosphorus into slow flow water bodies (including lakes, reservoirs, estuaries and oceans) causes rapid propagation of harmful algal blooms, which decrease dissolved oxygen leading to increased mortality of resident fish and other organisms (Jane et al., 2021; Li et al., 2020a; Menberu et al., 2021; Mironga et al., 2012). Knowledge of environmental drivers and their impacts on water quality is essential to obtain a better understanding of mechanism of eutrophication and to allows for implementation of mitigation steps to protect inland freshwater resources.

The Nandu, Changhua and Wanquan Rivers are major rivers on Hainan Island, with a combined catchment area of more than 3000 km\(^2\), accounting for 47% of the island's area. The unique geographical factors, including marine erosion landform, volcanic activity, mineral spring activity, tectonic denudation, karst cave and stone forest, on Hainan Island lead to a relatively fragile ecosystem in the basin, rendering
the inadequate and inhomogeneous water resources (Li et al., 2020b), which can lead to imbalances of species distribution in aquatic ecosystems. Therefore, reversing eutrophication represents a major challenge. Jnh et al. (2020) investigated the distributional characteristics of chemical oxygen demand (COD), its influencing factors and pollution level of seawater. The spatiotemporal distributions of COD were affected by the pollutant inputs and hydrodynamic properties of receiving waters. Jia et al. (2012) reported that the Shamei lagoon in Hainan Island was transformed into a freshwater environment during 1900–1950. After 1950, due to anthropogenic activities, freshwater phytoplankton biomass increased and became the major source of buried organic matter (Jia et al., 2012). Beyond this finding, there are few studies concerning the investigation of inland water quality in Hainan province.

With the rapid economic development in Hainan, various sources of pollution, especially agricultural non-point source pollution, have increased pressure and impacts on its rivers’ water quality (Yu et al., 2020). Nevertheless, it has been demonstrated that river water quality can be improved through an increase of environmental investment, specifically to improve industry and agricultural practices (Barrington et al., 2014; Xiao et al., 2020). Zhou et al. (2017) have reported that during the past decade, water quality of Chinese inland waters has improved markedly since Chinese government financed investments in environmental restoration and reforestation. They found that GDP-normalized COD and ammonium concentrations was significantly and exponentially decreased. Zhou et al. (2020) showed that population size and agriculture declined to varying degrees at the end of the study period, although the urbanization level continued to increase challenging water quality. However, economic development leading to the deterioration of the water environment was alleviated. Ma et al. (2020) showed that water quality improved markedly and was maintained at acceptable levels nation-wide because of reduced discharges in the industrial, rural, and urban residential sectors. Unfortunately, growing discharges from the agricultural sector threaten to erase these gains. Moreover, the present status of water pollution is relatively severe in north and northeast China. Consequently, it seems that several indexes, e.g. industrialization, agriculture, population and per capita GDP, etc. may affect significantly the inland water quality. In this study, we will investigate on the relationship between these factors and water quality in the three major rivers of Hainan Island.

Artificial neural network is a mathematical model simulating biological neural network for information processing (Ma et al., 2020). It is based on the physiological connections within the brain, and its purpose is to simulate some mechanisms of the brain and achieve several specific functions (Wu et al., 2020). At present, ANN has been applied in numerous fields, including water environmental monitoring and assessment (Aghav et al., 2011; Wu et al., 2021). Shi et al. (2021) analyzed the back propagation artificial neural network, a self-adapting algorithm, proposed to assess cumulative risks to aquatic ecosystems. Daim et al. (2018) utilized that submerged biofilter media (plastic and gravel) under the influence of different variables such as temperature (18.00–28.50°C), flow rate (272.16–768.96 m³/day), and influent COD (55.50–148.90 ppm) combined with two radial basis function neural network (a conventional and based on particle swarm optimization) to accurately predict the removal of COD from polluted water streams. The objective of the present study is aim to 1) investigate the water quality of the three major
rivers on Hainan Island; 2) elaborate on the relationship between socioeconomic and inland water quality in the three major rivers of Hainan Island; 3) reveal water quality of water basin as affected by tourism from 2012 to 2015 a in Hainan Island; 4) simulate the inland water quality in the three major rivers of Hainan Island based on 2013–2015 to predict future changes.

2. Materials And Methods

2.1 Study area and field sampling

The Nandu, Changhua and Wanquan Rivers are the three major rivers on Hainan Island (Fig. S1). The Nandu River is the largest river in Hainan Island of China, originating at Nanfeng mountain in the south of Nankai Township, Baisha Li Autonomous County, Hainan Province, and flowing into the Qiongzhou Strait in the Sanlian community, Meilan District, Haikou City. Its total length is 333.8 km, a total drop of 703 m and a drainage area of 7033 km$^2$. The main tributaries are Longzhou River, Datang River, Yaozi River, etc. There are two peaks in water level per year; one in May, the other in September-October.

Changhua River is the second largest river on Hainan Island, originating from Kongshiling in Limu mountain forest area of Qiongzhong, Hainan, and flowing into the South China Sea from Dongfang City through the west of Changhua port in Changjiang County. The main segment of the Changhua River is 232 km long, with a drainage area of 5150 square kilometers and a total drop of 1270 meters. Finally, the Wanquan River, the third largest river on Hainan Island, originates from Nanling, Linbei village, Wuzhishan, with a total length of 157 km and a drainage area of 3683 km$^2$. The Wanquan River Basin has a tropical monsoon climate, and the rainfall can be divided into dry and wet seasons. Generally, the wet season is May to October, with ~1900 mm rainfall, accounting for about 80% of the annual rainfall. Annual rainfall is 5526 mm at Zhongping station (1964), and the minimum annual rainfall is 1522 mm at Chengpo station (1959).

2.2 Inland water quality datasets in Hainan province

DO, COD, and NH + 4-N were selected for evaluating water quality in the present study. They were sampled on a weekly basis in the Nandu, Changhua and Wanquan Rivers of Hainan Island from January 2012 to December 2015. The survey data for this study were from the Department of ecological and environmental protection of Hainan Province (http://hnsthb.hainan.GOV.cn/). Among them, low, high and normal water seasons were examined from March to April, July to August and October to November, respectively. Based on the water quality standards for surface waters in China (GB3838-2002), these indices were graded in Table S1.

2.3 Data on human-driven economic indexes

The Nandu River flows through Baisha, Qiongzhong, Danzhou, Chengmai and Haikou (https://baike.so.com/doc/6607929-6821716.html). Gross industrial and agricultural outputs, population and per capita GDP in the present study used the sum of the single indices for the through cities by a
water basin. The Changhua River flows through Qiongzhong, Wuzhishan, Ledong, Changjiang and Dongfang (https://baike.so.com/doc/6209923-6423193.html). Similarly, the Wanquan River flows through Wuzhishan City and Qionghai City (https://baike.so.com/doc/6229629-6442958.html). The methods for calculating the four indices for Changhua and Wanquan River were consistent with Nandu River. Data on the Population, GDP by region, WW discharge, COD discharge, NH4 +N discharge, Total AABM, ECPU GDP, Cultivated land, GOV of agriculture, GOV of forestry, GOVAH, GOV of Fishery, GIO and PDUA from 2012 to 2015 were obtained from the website of Hainan Provincial Bureau of Statistics (http://stats.hainan.GOV.cn/)

2.4 Radial basis function neural network for predicting water quality

The number of hidden layer nodes of Radial basis function neural network (RBFNN) is equal to the number of input samples M = N (Fig. 1). The activation function of hidden nodes is a Gaussian Green function, and all input samples are set as the center of radial basis function (Ayala et al., 2019; Hong et al., 2020).

\[ \sigma = \frac{d_{\text{max}}}{\sqrt{2M}}, \quad d_{\text{max}} = \max \left\{ |\mu_i - \mu_j|, 0 \right\}, \quad i \neq j \]

\[ F(x) = \sum_{j=1}^{P} w_j G(x_i, x_j) \]

\[ G(x_i, x_j) = G(||x - x_j||) = \exp \left( -\frac{1}{2\sigma^2} ||x - x_j||^2 \right) \]

Where \(d_{\text{max}}\) is the maximum distance between center points, and M is the number of center points.

Because it is easily affected by noise and may be overfitting, it is necessary to add a constraint containing prior knowledge of the solution to control the smoothness of the mapping function

\[ \min E(F) = \frac{1}{2} \sum_{j=1}^{P} (y_j - F(x_j))^2 + \frac{1}{2} \lambda ||D F||^2 \]

where \(\lambda\) is the regularization parameter, D is the linear differential operator, representing the prior knowledge of \(F(x)\). After determining the central position of the hidden layer neurons, we only need to solve the linear equations to obtain the analytic solution of \(w\) to determine the RBFNN model.

\[ W = (G + \lambda I)^{-1} Y \]

2.5 Statistical analyses

Statistical analyses, including mean values, standard deviation, t-test, and linear correlations, were conducted using Origin 2017. Spatial distribution of water quality related parameters was determined
with ArcGIS 10.1 software. The Bayesian neural network was used to determine the relationship between the macro index and water quality using Python 3.6.0. The RBFNN was performed by MATLAB R2012a software.

3. Results And Analysis

3.1. General water quality conditions in the Nandu, Changhua and Wanquan Rivers.

Figure 2 shows the concentrations of pH, COD, DO and ammonia nitrogen in Nandu, Changjiang and Wanquan Rivers from August 2012 to December 2015. During the investigation period, the pH of the surface layer of Nandu River was 7.36 ± 0.29, ranging from 6.95 to 7.94, with the maximum values occurring in January and February 2015. The DO content in surface of Nandu River ranged from 5.29 to 8.44 mg/L, with an average of 6.64 mg/L ± 0.83 mg/L, with the maximum and minimum appearing in February 2014 and July 2015 respectively. For COD, the range of COD in the surface layer of Nandu River is 1.95–4.60 mg/L, and the average value is 3.18 ± 0.58 mg/L, with the maximum and minimum appearing in February 2014 and July 2015, respectively. Ammonia nitrogen concentration in the surface layer of Nandu River ranged from 0.085 to 0.295 mg/L, with an average value of 0.16 ± 0.05 mg/L, with the maximum and minimum occurring in January 2014 and September 2012 respectively. For the Changhua River, the average surface pH was 7.49 ± 0.23, ranging from 6.97 to 8.07, with the maximum values in July 2013 and March 2014. The COD content in the surface layer of the Changhua River ranged from 1.13 to 3.53 mg/L, with an average of 1.94 ± 0.60 mg/L, with the maximum and minimum appearing in October 2014 and March 2013 respectively. The DO content in the surface layer of the Changhua River ranged from 5.41 to 8.10 mg/L, with an average value of 6.88 ± 0.590 mg/L, with the maximum and minimum occurring in November 2013 and may 2015 respectively. The range of ammonia nitrogen content in the surface layer of Changjiang River is 0.105–0.265 mg/L, with an average of 0.16 ± 0.04 mg/L in September 2013 and July 2015, respectively. The surface pH of the Wanquan River was 7.22 ± 0.34, ranged from 6.39 to 8.13, with the maximum values in January and February 2014. The DO concentration in the surface of the Wanquan River ranged from 5.56 to 8.66 mg/L, with an average of 6.86 mg/L ± 0.91 mg/L, with the maximum and minimum appearing in January 2014 and August 2013 respectively. For COD content, the range of COD content in the surface layer of Wanquan River was 1.05–2.96 mg/L, with the average content 1.98 ± 0.49 mg/L, and the maximum and minimum appearing in November 2014 and February 2015 respectively. The surface ammonia nitrogen content of Wanquan River ranged from 0.13 to 0.43 mg/L, with an average of 0.24 ± 0.06 mg/L, with the maximum and minimum values occurring in December 2015 and August 2015 respectively.

Overall, water quality of Nandu, Wanquan and Changhua River was level II. For pH of the three rivers, Changhua River > Wanquan River > Nandu River. Among the three main rivers in Hainan Province, the order of COD content is Nandu River > Wanquan River > Changhua River; The DO contents of Changhua
River and Wanquan River were similar, but higher than those occurring in the Nandu River. The content of ammonia nitrogen in Wanquan River was highest, followed by Nandu River and Changhua River.

3.2 Relationships between water quality and human-driven socioeconomic indexes

Figure 3 shows the degree of impact on water quality under socioeconomic indexes by Bayesian network. The weight value that GOV of agriculture, GOV of fishery, GOV of animal husbandry and COD discharge greatly influence DO content, with their weight values being 0.352, 0.352, 0.204 and 0.194 respectively. GOV of fishery, GOV of agriculture, total AABM and GOV of animal husbandry strongly influenced COD content in Nandu River, and their weight values were 0.603, 0.603, 0.409 and 0.406 respectively. The weight values of GOV of fishery, GOV of agriculture, total AABM and GOV of animal husbandry were 0.601, 0.61, 0.407 and 0.404, respectively. In general, GOV of fishery, GOV of agriculture, total AABM and GOV of animal husbandry strongly influenced water quality of the Nandu River. Annual changes of the above indicators are analyzed in Fig. 4a. GOV of agriculture has been increasing each year, GOV of animal husbandry and GOV of fishery showed little change, and total AABM decreased on a yearly basis. Figure 4b and 4c show that the correlations of GOV of agriculture, GOV of fishery, GOV of animal husbandry and total AABM to the annual increasing trend were 0.88, 0.85, 0.62 and 0.77, respectively.

Figure 5 shows the impact of various macro indicators on water quality of Changhua River, and the weight values were obtained. The major impact on DO content was ammonia nitrogen discharge, GOV of animal husbandry, GOV of forestry, GOV of fishery, and the weight values were 0.789, 0.635, 0.616 and 0.605 respectively. Cultivated land, population density of urban area, and GDP by region and EC per unit of GDP have great influence on COD content in Changhua River, and their weight values were 0.594, 0.400, 0.399 and 0.393 respectively. The weight values of cultivated land, waste discharge, population density of urban area, ammonia nitrogen discharge, total AABM and GOV of agriculture were 0.388, 0.386, 0.384, 0.376, 0.376 and 0.376 respectively. In general, cultivated land, GOV of fishery, GOV of agriculture, total AABM and GOV of animal husbandry strongly impacted water quality of Nandu River. Fig. S2a analysis the annual changes of the above indicators. GOV of agriculture is increasing year by year, GOV of animal husbandry, GOV of fishery and cultivated land changed slightly, and total AABM is decreased on a year by year basis. Fig. S2b and S2c show that the correlations of GOV of agriculture, GOV of fishery, GOV of animal husbandry, total AABM and cultivated land to the annual growth trend were 0.88, 0.85, 0.62, 0.90 and 0.77, respectively.

For the weight value, population, GDP by region, waste discharge, gross industrial output and population density of urban area strongly influence DO content, with their weight values being 0.391, 0.390, 0.389, 0.389 and 0.389 respectively (Fig. 6). GOV of animal husbandry, GOV of fishery, total AABM and ammonia nitrogen discharge strongly influenced COD content in Nandu River, with their weight values being 0.649, 0.647, 0.442 and 0.640, respectively. The weight values of gross industrial output, waste discharge, population density of urban area and GDP by region were 0.645, 0.643, 0.641 and 0.629, respectively. In general, GOV of fishery, GOV of agriculture, total AABM and GOV of animal husbandry
influenced water quality of the Nandu River. The annual changes of the above indicators are analyzed in Fig. S3a. GOV of agriculture is increasing year by year, GOV of animal husbandry and GOV of fishery showed little change, and total AABM decreased year by year.

3.3 Annual average of NOV, Gross value of AO and Gross value of fishery in 2012, 2013, 2014 and 2015

An obvious increase for annual average of NOV occurred from 2012 a to 2015 a (Fig. 7abcd). Among them, Haikou city and Sanya city accounted for the highest proportion for the entire province of annual average of NOV in 2012 a, corresponding to 29.80% and 31.92%, respectively. Thereafter, the proportion of Haikou city for the entire province of annual average of NOV in 2013, 2014 and 2015 decreased year after year, being 28.47%, 27.94% and 27.28%, respectively. However, the ratio of Changhua county was improved during the survey period, reaching 5.44%, 5.67%, 5.94% and 6.22%, respectively. The proportion in Qionghai city to the entire province of annual average of NOV was between 1.48–1.80% from 2012 to 2015. In general, the annual average of NOV in the east of Hainan province was higher than of the west. For the annual gross value of agricultural output, the proportion in Haikou to the entire province was gradually reduced during the study period, and their respective values were 7.71%, 7.70%, 7.08% and 6.74% (Fig. 9abcd). The ratio in Changhua county to the entire province varied little from 2012 to 2015, corresponding to 3.22%, 3.23%, 3.21% and 3.30%, respectively. The proportion in Qionghai city changed slightly, ranging from 10.34–10.90% during the investigation period. Generally, the gross value of AO successively focused on Qionghai city, Ledong county, Sanya city, Chengmai county, Wenchang city, Haikou city, Danzhou city and Dongfang city, and their sum of proportion in the gross value of AO reached at 74.38%. In addition, the proportion of gross value of fishery is relatively less in comparison with the Hainan province between 2012 to 2015, and reached at 3.21, 3.09, 3.01 and 3.14, respectively (Fig. 10abcd). The ratio of gross value of fishery in Changhua county to Hainan province gradually increased in 2012 to 2015 a, and ranged from 3.24–3.31%. Similarly, the proportion for Qionghai city increased little during the study period, being 4.31%, 4.63%, 4.66% and 4.65%, respectively. On the whole, the gross value of fishery in the west of Hainan province was higher than that of east, especially for the higher ratio for gross value of fishery in Lingao county and Danzhou city to the entire province.

3.4 Water quality prediction by radial basis function neural network

RBFNN can approximate any nonlinear function, dealing with laws that are difficult to analyze in the system, and is also of excellent generalization ability and fast learning convergence speed. In the present study, the goal value of mean square error was set as $1 \times 10^{-10}$ and the spread value was set as 0.8. Figure 8a exhibits that the training process is terminated when the mean square error was reached at 0.0141958 with 100 iterations. Additionally, the determination coefficient ($R^2$) between the experimental and predicted values was 0.97744 after the training the developed RBFNN (Fig. 8b). For Nandu River, Fig. S6a shows that only the predicted water quality of 4th and 8th weeks is not consistent with the correspondingly predicted values. Fig. S6b shows that the non-conformity between experimental and
predicted values is merely at 6th week for Changhua River. Fig. S6c demonstrates that the predicted water quality of 2nd and 7th weeks differed from the experimental values.

4. Discussion

The degree of variation of pH values in Wanquan River was relatively higher in comparison with Nandu River and Wanquan River. The higher and lower pH values were found at annual November to February and annual May to July, respectively. Generally, in Hainan province, March and April, July and August and October and November are dry, wet and normal seasons, respectively. Zuo et al. (2015) reported that the pH value of water quality in the tourism development zone and the control zone was high water period > low water period > normal water period and the pH value of tourism development zone was significantly higher than that of control zone (p < 0.05), which coincided with the present study. Haraguchi et al. (2008) reported water utilization by local inhabitants responding to seasonal changes in water quality of river water in Central Kalimantan, Indonesia. River water chemistry showed little difference between the dry season and the rainy season in the Sigi area, whereas river and canal water in the rainy season in Paduran and Pangkoh showed lower pH than in the dry season due to a high concentration of sulfuric acid in the rainy season (Haraguchi et al. 2008). Zhang et al. (2012) exhibited spatial and temporal characteristics of hydrochemistry in typical inland river basins of middle Tianshan Mountains. The pH value of the water body is weakly alkaline, and the pH change is clearly seasonal. The pH value is higher in dry season and lower in wet season. Generally, water quality in the wet season is better than that in dry season. The above-mentioned studies are roughly in accord with the present study.

Overall, GOV of agriculture, GOV of fishery, GOV of animal husbandry and COD discharge have large influences on water quality in the Nandu and Changhua Rivers in the present study. However, GDP by region, waste discharge, gross industrial output and population density of urban area strongly influence water quality. The proportion of agricultural non-point source pollution is approximately 20% ~ 30%, which is mainly due to the release of pesticides, chemical fertilizers from farmland with runoff and the discharge from farms, etc. (Hou et al. 2021). Yang et al. selected the Yangtze River Basin and the Yellow River Basin as research areas. They used a combination of canonical correlation analysis and a distance-based influence assessment method to quantitatively assess the influence of socioeconomic development on river water quality. Their results revealed a strong correlation between socioeconomic development and river water quality. The average degree of influence in the Yangtze River Basin was between 0.22 and 0.27, and that in the Yellow River Basin was between 0.2 and 0.36. Moreover, the degree of influence in the Yangtze River Basin in the wet season was greater than that in the dry season, whereas the opposite pattern was observed in the Yellow River Basin. By analyzing the influences of various socioeconomic indicators on water quality, we found that the main factors that influence water quality are per capita GDP and urbanization rate in the Yangtze River Basin and urbanization rate in the Yellow River Basin. Elhatip et al. (2003) demonstrated the influences of human activities and agriculture on groundwater quality of Kayseri-Incesu-Dokuzpınar springs, central Anatolian part of Turkey. The results showed that agricultural activities directly and indirectly affected the concentrations of a large number of
inorganic chemicals in groundwater, e.g. \( \text{NO}_3 \), \( \text{N}_2 \), \( \text{Cl} \), \( \text{SO}_2\text{4} \), \( \text{H}^+ \), \( \text{K} \), \( \text{Mg} \), \( \text{Ca} \), \( \text{Fe} \), \( \text{Cu} \), \( \text{B} \), \( \text{Pb} \), and \( \text{Zn} \), as well as a wide variety of pesticides and other organic compounds. According to the website of Hainan Provincial Bureau of Statistics, the agricultural output value was sharply increased between 2012 to 2015 a. Rice is the main crop in Hainan province, and is seeded approximately in April and October, respectively. A large amount of fertilizer is needed in the process of rice sowing, and thus decreasing the water quality in approximately June and January every year, especially for Nandu River.

With regard to aquaculture, in order to increase the output of aquatic products, fishermen add a lot of feed, or cultivate rotifers and other live bait by fertilizing, resulting in a large number of residual bait. These substances are mainly carbohydrate (18%), fat (14% ~ 17%) and protein (46% ~ 51%), as well as a small amount of phosphorus, vitamins and pharmaceuticals (Duan et al., 2010). A large number of residual food enter into the water body, which aggravates the eutrophication of the water body. In addition, excreta from aquaculture products also has an important impact on water quality. Residual food and feces accumulated on the surface of sediment, and continuously oxidized and decomposed, consuming a lot of oxygen, resulting in the decrease of DO in aquaculture water (Duan et al., 2010). Shen et al. (2005) reported that the comprehensive quality of ecological environment in the Yangtze River Estuary has obvious seasonal variation, and the quality of ecological environment in summer is poor than that in spring. Fortunately, with the acceleration of the construction of Hainan International Tourism Island and ecological island, the coastal aquaculture land in Hainan Province will be greatly reduced, and the coastal aquaculture space will be reduced. Additionally, the excrement of livestock and poultry can pollute the surface water after being washed in by precipitation, and form the pollution of groundwater as leakage. After livestock manure enters the surface water, it is easy to form the eutrophication in the water quality, resulting in the excessive propagation of algae in the water, making the water black and smelly due to lack of oxygen, and eventually causing the death of fish and shrimp in the water (Li, 2017).

Tourism has become the pillar industry of Hainan’s economic development, and it is beginning to affect the environment. In general, the annual average of NOV in the east of Hainan province was higher that of west. Therefore, the \( \text{NH}_4^+ - \text{N} \) content in Wanquan River was significantly lower than of Nandu River and Changhua River, and the DO content was relatively fluctuation in comparison with the other two river. The \( \text{NH}_4^+ - \text{N} \) content in the Wanquan River was relatively high in November to January, which is coincidentally is the hight of the tourist season. Surprisingly, the more tourists there are, the higher DO value is, especially for Nandu River and Wanquan River. Jiang et al. (2016) studied the impact of ecotourism on the water body of Qilian Mountain National Nature Reserve. Their result indicated that with the increasing tourist interference intensity, the \( \text{pH} \) value and DO content of water in the reserve decreased, the electrical conductivity and \( \text{BOD}_5 \) increased, and thus increasing pollution degree in water body. Aminu et al. (2015) evaluated the suitability for recreational activities and conservation in Bertam River. Seven sampling points were selected in the river and tributaries: DO, BOD and COD, TSS, \( \text{NH}_3 - \text{N} \) and \( \text{pH} \) were measured and the water quality index (WQI) was computed during high and average water flow. Results show that TSS, BOD and \( \text{NH}_3 - \text{N} \) contribute most to water pollution. Juma et al. (2014) reported the dynamic response of water quality change to human tourism disturbance in Liupan
Mountain Ecotourism area. They indicated in the tourism season, the main indices of water quality in the tourism area are within the scope of class II water quality standard, and some indices reached at class III. However, the degree of pollution in some sections reached at the level of grade 3 and grade 4. With the change of tourism mode, the interference increased gradually, and the folk village and hotel changed the most acutely. Lin et al. (2013) exhibited the impact of water quality changes on tourism capacity at Golden Lake, China. Tourism activities of 500–600 thousand people each year over last few years have greatly increased pollution to the lake, with serious negative water quality impacts. Although water quality in Hainan province is acceptable from 2012 to 2015 a, it is necessary to pay close attention to water quality degraded by tourism, especially in Wanquan River and eastern Hainan province.

Although the most of water quality was predicted precisely in comparison with experimental values using the developed RBF-ANN in the present study, however, the minor parts predicted value was not absolutely match. The situation may be due to its shortcoming, e.g. the poor interpretation, unable to proceed due to insufficient data, the difficult to determine the number, center and width of hidden layer nodes, etc. However, it was also reported that RBF-ANN could well recognized the complex nonlinear relationship between Haloketones occurrence and the related water quality, and paved a new way for Haloketones prediction and monitoring in practice (Deng et al., 2021). Hameed et al. (2017) reported that the radial basis function neural network and back propagation neural networks models were used to examine and mimic the relationship of WQI with the water quality variables in a tropical environment (Malaysia). Their results are promising with high performance accuracy belonging to RBFNN model for both scenarios. Rahnama et al. (2021) compared the forecasting of SAR of water in Aras, Sepidrud, Karun, and Mond Rivers, Iran, using autoregressive integrated moving average (ARIMA) time series and RBF neural network. They also compared forecast errors of the ARIMA time series and RBF neural network for SAR forecasting of Sepidrud, Karun, and Mond Rivers; the results presented that RBF neural network is more reliable than ARIMA for the predicting of SAR. Zhang et al. (2012) exhibited a new PSO-RBF model for groundwater quality assessment, which was employed in the ten monitoring points of the black dragon hole. The results of this evaluation corresponded with the actual conditions, and are basically in accord with those obtained by other evaluation methods, which was also showed the practicability to groundwater quality assessment. Hong et al. (2020) proposed a radial basis function artificial neural network (RBF ANN) as well as the hybrid method of RBF ANN and grey relational analysis (GRA) to predict trihalomethanes levels in real distribution systems. This result demonstrates that GRA can be an effective technique to facilitate the generation of sound RBF ANN models with fewer factors. Therefore, future studies should develop RBF-ANN that is of the more accuracy and speed to employ the water quality.

**Conclusion**

(1) The present study showed that water quality of Nandu, Wanquan and Changhua Rivers is II level from 2012 to 2015. The content of NH4+ -N in Wanquan River was the highest, followed by Nandu and Changhua Rivers. GOV of agriculture, GOV of fishery, GOV of animal husbandry and COD discharge significant influence on water quality in Nandu and Changhua Rivers in the present study. However, GDP
by region, waste discharge, gross industrial output and population density of urban area significant influence water quality.

(2) In general, the annual average of NOV in the east of Hainan province was higher than that of west. In the Wanquan River, DO content fluctuated in comparison with the other two rivers, and inexplicitly, the more tourists is, the higher DO value was. However, it is still necessary to pay close attention to the water quality declines due to tourism, especially in Wanquan River and eastern Hainan province. The developed RBFNN exhibited that most of water quality were predicted precisely in comparison with experimental values in the present study, and also indicated the water quality will continue to improve. Our results suggest that the anthropogenic socioeconomic activities moderately affected the water quality in Hainan Island. Agriculture, fishery, animal husbandry and COD discharge were relatively more important factors affecting water quality on Hainan Island, while tourism can also have an effect in eastern Hainan.

**Abbreviations**

GDP by region  Gross Domestic Product by region

WW Discharge Wastewater Discharge

Total AABM  Total Afforested Area in Barren Mountain

ECPU GDP  Energy Consumption per Unit of Gross Domestic Product

GOVA represents  Gross Output Value of Agriculture

GOVF  Gross Output Value of Forestry

GOVAH  Gross Output Value of Animal Husbandry

GOV of Fishery  Gross Output Value of Fishery

GIO  Gross Industrial Output

PDUA  Population Density of Urban Area

Annual average of NOV  Annual average of number of overnight visitors

COD  Chemical oxygen demand

NH+ 4-N  Ammoniacal nitrogen

DO  Dissolved oxygen

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**Data availability:** The present study data are available from the corresponding author on reasonable request.

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**References**


Figures
Figure 1

The structure of RBFNN model in the present study.
Figure 2

The pH, DO, COD and NH₄⁺-N in Nandu River (a), Changhua River (b) and Wanquan River (c) from 2012 to 2015.
Figure 3

Bayesian static graph in Nandu River for predicting water quality

Figure 4
The output value of GOV of agriculture, GOV of Fishery, Total AABM and GOV of Animal Husbandry

Figure 5
Bayesian static graph in Changhua River for predicting water quality
Figure 6

Bayesian static graph in Wanquan River for predicting water quality
Figure 7

Annual average of NOV in 2012 (a), 2013 (b), 2014 (c) and 2015 (d).
Figure 8

The relationship between iterations and mean square error (a), and between trained and experimental values (b).

Supplementary Files

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