Salinity Distribution Analysis in Estuaries

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論文内容要旨

Salinity intrusion has become a pressing issue for the preservation of estuary's natural situation as well as exploitation for agricultural and aquacultural production. The main objectives of this study are, therefore, to evaluate the characteristics of salt transport and to study the influence of morphological changes and wave set-up phenomenon on salinity intrusion into estuaries.

According to MRC (2004), during dry seasons saline water from the South China Sea and the Gulf of Thailand moves upstream along the rivers and canals of the Mekong Delta. The salinity intrusion into the Mekong Delta is very complicated. The highest salinity is usually observed in April. Currently, 1.77 million ha of delta lands are affected by saltwater intrusion, posing considerable difficulties for the development of not only irrigation but also domestic water supply system. Salinity worsens water quality and damages crop-lands. The most severe situations occur during the low flow season when there is insufficient flow to prevent seawater intrusion. Strong tidal waters encroach up to 50-70 km. The existing engineering infrastructure will be inadequate for coping with salinity intrusion if water abstraction increases in the delta. The affected area may increase to 2.2 million ha if no preventive measures are taken up. Therefore, salinity intrusion into the Mekong River delta is a problem of great importance for agricultural, aquacultural, and industrial development.

There have been many research on the Mekong River Delta conducted so far. However, most of these research have used one-dimensional model such as Nguyen (1986, 1991), Nguyen (1992), Czernuszenko and Pham (1993), Dao and

Nguyen (2000), Suphat et al., (2000), Nguyen and Savenije (2006) or two-dimensional width integrated model such as Nguyen et al. (1998). Recently, a new approach using water resource components to simulate salinity intrusion has been introduced by Tang (2002), Nguyen and Tang (2005). This approach appears to be interesting due to its capability of giving percentage of each water resource component. Moreover, all of these research only mentioned two main usual parameters, river discharge from the upstream and tidal level from the sea. Therefore, it would be of great benefit if there is a research using three-dimensional model and considering other parameter such as influence of morphology change.

The Nanakita river originates from the northern part of Sendai City in Miyagi Prefecture and goes through the Sendai Bay. There is a jetty on the left-hand side of the river mouth, which limits the migration of the mouth to the north direction, whereas the movement in the south is not limited. During winter season, the river mouth often closes due to small river discharge. The complete closures of the river mouth were observed in 1988 and 1994. The remarkable river mouth topographical changes pose flood problem in the low land area and the environment in the Gamo lagoon, where is well known as wild birds, the Teizan canal and many precious historic waterfront area. This is also a relaxation area for people who live near by Sendai City. They usually come here to play surfing, go fishing, and so on. According to Tanaka and Yamamoto (2000), due to the excavation in Nanakita river that leads to the increase of the tidal prism upward, and cause significant changes of hydraulic characteristics and benthos distribution in a tidal compartment at the Nanakita River mouth. Recently, the sediment intrusion and enhancement of salinity have been increased. It may be harmful for the environment. The question should be paid attention here thus is: how to reprocess the natural environment in this area so as to make it back to the primary status. The identification of characteristics of salinity in the Nanakita River is, therefore, also of great importance.

Consequently, details of research on this issue will be of outstanding interest to experts in the estuarine and coastal engineering fields.

Salinity intrusion into estuaries, in general, is mostly affected by river water discharge and tidal level. In addition, the change of salinity can also be influenced by other external forces such as wave height and river mouth morphology. The evolution of salinity in the Mekong River (a large scale) and the Nanakita River (a small scale) have been investigated by applying both Artificial Neural Network (ANN) Model and Estuarine Coastal Ocean Model (ECOM). The former model was used to preliminarily predict salinity evolution, whereas the later model was to represent more detailed and complicated phenomena of salinity intrusion in estuaries.

In ANN model, the weights are adjusted to obtain the desired results. This process is called learning or training. After the learning (or training) process, the weights are frozen. A data set that the ANN has not used before is presented to verify its performance, namely testing (or verification) process.

The data used consists of two sets: one for training and the other for testing the model. As the back propagation neural network model uses logistic activation function in which its output based on the interval [0, 1] (Nguyen and Tanaka, 2004); the original data is linearly transformed to the interval [0.1, 0.9] before inputting to the network. The interval [0.1, 0.9] is chosen instead of the interval [0, 1] because logistic activation function is an asymptotic function, so it reaches the value of neither 0 nor 1.

In order to establish the input data set, we use input data and output data processing as follow:

- For discharge, we use the equation:

$$Q^* = 0.4\left[\frac{2.Q-(Q_{\max}-Q_{\min})}{Q_{\max}+Q_{\min}}\right]+0.5$$

- For tidal level and wind velocity, we use the equation:

$$\eta^* = 0.4\left[\frac{2.\eta-(\eta_{\max}-\eta_{\min})}{\eta_{\max}+\eta_{\min}}\right]+0.5$$

- For salinity concentration, river mouth width and wave height, we use the equation: $S^* = S_i/S_{max}$

In which $\eta_{max}(Q_{max}, V_{max}, B_{max}, H_{max})$ and $\eta_{min}(Q_{min}, V_{min}, B_{min}, H_{min})$ are the maximum and minimum values of tidal level (discharge, wind velocity, river mouth width and wave height) data series, respectively; η^*, Q^*, S^*, V^*, B^* , H^*) are transformed values of tidal level, discharge, salinity, wind velocity, river mouth width and wave height, respectively. After training and testing, the salinity output resulted from ANN model will be transformed back into its original value by the formula as follow: $S_i = S^* . S_{max}$

In this study, to assess accuracy of computation, efficient index (EI) and root mean square error (RMSE) will be used. The formulas of EI and RMSE can be written as follow:

$$EI = 100.\frac{SST - SSE}{SST} \text{,and} \quad RMSE = \sqrt{\frac{\sum_{i=1}^{n}(F_i - S_i)^2}{n}}$$

Where, SST is the initial variance for salinity concentration, and SSE is the residual model variance. SST and SSE can be given by: $SST = \sum_{i=1}^{n}(S_i - \overline{S})^2$,and $SSE = \sum_{i=1}^{n}(S_i - F_i)^2$

In which, S_i, F_i, $\overline{S}$ is observed, model estimated, and mean salinity concentration (psu), respectively; n is the number of observed data.

The second model used in the present study is hydrododynamic module of ECOMSED. It is a three-dimensional, time-dependent, and finite difference. The ECOMSED has a long history of successful applications to oceanic, coastal, and estuarine waters (Blumberg et al., 1999). A turbulence closure model, which enable us to determine the turbulent viscosities and difusivities, must be included to fulfill the governing equation system. The model incorporates the Mellor and Yamada (1982) 2.5 level turbulent closure model to provide a realistic parameterization of vertical mixing. A system of curvilinear coordinates is used in the horizontal direction, which enable a smooth and accurate representation of variable shoreline geometry. In the vertical scale, the model uses a transformed coordinate system known as the σ coordinate transformation to achieve better representation of bottom topography and flow near the bottom (Ahsan et al., 2005). The mode split technique allows the 2D calculation of the free surface elevation and the velocity transport in barotropic approximation to be separated from the 3D calculation of velocity and thermodynamics (Blumberg, 1977). Water surface elevation, water velocity, temperature, salinity, and water turbulence are calculated in response to morphological changes data, wind data, river discharge from the upstream, water level in the mouth, salinity, and temperature in open boundaries connected to the river mouth.

By using the above mentioned two models, the author come up with the following conclusions:

➢ *Artificial neural network model*

For the Mekong River of Vietnam, reasonable results in both mean daily and hourly salinity simulation have been achieved. Furthermore, the missing salinity data in the Hau River estuary are interpolated to determine. The results may become necessary data for calibration or verification process of the conventional model.

For the Nanakita River of Japan, there has been a very good correlation between external forces and salinity concentration. Apart from two main usual forces affecting the transport of salinity such as river discharge from the upstream and the tidal level from the ocean, the river mouth width and wave height also have influenced on the salinity distribution. In addition, based on the sensitivity analyses of the combined two external forces (the river mouth width and wave height), it can also be concluded that the morphology change is predominant over the wave height.

➢ *Three-dimensional model*

For the Lower Mekong River, satisfactory results in salinity simulation have been obtained. The correlation between river mouth width and averaged salinity concentration is directly proportional. It, therefore, the influence of morphology change on salinity distribution should not be ignored when simulating salinity.

For the Nanakita River, firstly, the effect of morphology and wave set-up on salinity concentration has been confirmed through the detailed results of field investigation. Secondly, a three-dimensional model to deal with phenomena of salinity intrusion into estuaries. It can be recognized that the model results are in good agreement with the measurement data. Both calibration and verification processes indicated that the model is able to predict the saltwater intrusion into the river with a reasonable accuracy. Thirdly, the influence of morphology change and wave set-up on salinity distribution has been elucidated. It has been confirmed that the change of salinity is not only influenced by usual parameters as river discharge and tidal level, but also another external force such as morphology and wave set-up.

Beside these conclusions, this study also made significant contribution. The author have built a great and systematic data set for the Mekong River which can be significantly contribute to the calibration and verification processes of reproducing the real phenomena in estuaries. These data sets are expected to be of great interest to researchers and experts in estuarine and coastal engineering field. In addition, the dissertation's findings may further advance the understandings of the salinity evolution in estuaries.

論文審査結果の要旨

河川末端部が海に注ぐ河口部においては海水と淡水が接することから，その混合に伴い複雑な流れや物質の分布が見られる．また，それに応じて独特の環境・生態系が維持されている．このような感潮域における塩分変動過程を明らかにすることは，利水・環境などの観点から重要性がきわめて高い．感潮域の塩分変動を支配する要因としては，その主要なものとして潮汐，河川流量の二つが挙げられる．しかし，地形変動を伴う河口部においては特に閉塞の影響も無視できないものと考えられる．さらに，活発な漂砂移動により河口部が浅化した時には，河口前面での砕波が塩分輸送を助長することが考えられる．そこで，本研究においては，大河川としてベトナム・メコンデルタ，中小河川として仙台市・七北田川を選び，その塩分変動機構を定量的に評価することを目的としている．

第１章では本研究の背景，目的およびその意義について述べている．

第２章においては，感潮域塩分変動に関する研究事例のレビューを行い，さらに，塩分変動の支配要因に関する考察を行っている．また，数値計算手法のレビューを行っている．

第３章においては，研究対象であるメコンデルタ，七北田川について概説し，また現地調査の内容，使用する数値計算手法に関する記述を行っている．

第４章では，現地調査結果について述べている．メコンデルタにおける調査では水温・塩分の鉛直・縦断分布特性を明らかにしている．また，七北田川においては塩分の河口地形依存性が示された．これまで，このような現地資料は得られておらず，貴重な成果である．特に，メコン川においてはこれまで継続的な計測がほとんどなされておらず，将来的にも活用され得る貴重な現地データである．

第５章では，感潮域塩分変動の支配要因に関する検討を行うために，ニューラルネットワークによるシミュレーションを行った．学習過程の計算精度を確認した後に，河口地形・wave set-up 高さを変えて塩分に関する感度分析を行い，両者の影響を定量的に評価した．これは，工学上重要な成果である．

第６章では，物理過程を考慮した三次元モデルを用い，検証計算の後に河口地形と wave set-up を仮想的に変化させたケースに関して数値シミュレーションを実施した．その結果，メコン川，七北田川のいずれについても塩分の河口地形に対する依存性が確認された．また，wave set-up の効果については七北田川で顕著であった．同様な現象が，同規模の河川において生じているものと考えられる．これは，工学上重要な成果である．

第７章は結論と今後の課題を示したものである．

以上要するに，感潮域の塩分変動に及ぼす河口地形，波浪の影響を定量的に明らかにしており，河川・海岸工学分野の発展に寄与するところが少なくない．

よって，本論文は博士(工学)の学位論文として合格と認める．