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Evaluation of Salinity Intrusion through Periyar River Estuaries using Mathematical Models

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Abstract **- The salinity dispersals of estuaries display novel attributes as a result of the effects of diverse outside forces including freshwater discharges and topographic effects. To perceive the salinity intrusion of Periyar River Estuary, Kerala the surface salinity of Aluva Head works area were seen from 2008 to 2010. Monthly variations of salinity were studied. In addition, the salinity firmly lessened when additional freshwater was discharged in appreciation to the dry period. The characteristics of the salinity flow in the Periyar estuaries were considered using data from the Water Resources Department and Central Water Commission. The salinity intrusion length was computed based on the measure of freshwater discharge, and topographic effects. An association between's the saltwater intrusion length at the Periyar River, the freshwater discharge rate was imparted using an observational scientific proclamation. The salinity intrusion length was workedout using Brockway model (2006) and Byuing II Yoon model (2013) and found that the intrusion length was inversily proportional to the estuarine river discharge. The two mathematical models utilized were evaluated to opt on the best suitability. The developed relationship between river discharge and salinity intrusion length was verified and conducted regression analysis which provides better strength between its variables.**

Keywords- Discharge, Empirical Model, Estuaries, Evaluation, Intrusion Length, Periyar River, Salinity Intrusion

I. INTRODUCTION

The studies [1] established that the salinity intrusion processes of estuaries are dominantly governed by the amount of fresh water discharge and the estuarine salinity concentration. At the same time the depth governing geometrical factors and the velocity of fresh water discharge also plays active roles in the salinity intrusion process. Due to this fact, it was decided to study the salinity intrusion length also in the salinity intrusion processes.

Estuaries, where fresh water from rivers mixes with salt water from the oceans, are among the most productive environments on Earth. The estuary is not a part of the coast but is a coastal feature with a continuous exchange of water between land and the sea [2]. The intrusion of seawater in estuaries is an interesting phenomenon which occurs naturally and affects the quality of the water for different purposes [7]. In addition to morphological characteristics of an estuary, salinity intrusion depends strongly on the salinity difference between sea and river water and the amount of riverine flow [1], [4]. Combinations of above factors determine the mixing mechanism in an estuary and the salinity intrusion length [7]. Salinity intrusion may decrease the estuarine water quality so that its water becomes unsuitable for some uses such as drinking and agricultural purposes. Therefore determination of the salinity distribution along an estuary is a main interest for water engineers in coastal regions. Since the physical modelling of seawater intrusion in an estuary is time-consuming and expensive, it is preferred to use tools like emperical models [7]. This paper deals with such an attempt of Periyar estuaries in Kerala. The Periyar estuaries have free connections with the Arabian Sea is the most important water resource for Kochi City, the commercial capital of Kerala. Along this estuary some intake stations have been made to supply various water needs and it is important to keep the water salinity below a certain level at these intake stations. Here for Kochi City, the intake point situates at Aluva.

The initial studies for this work have been carried out using both Numerical Analysis and Harleman Emperical Model [6]. This was explained in our earlier papers [8], [9]. Aim of this paper is for the Evaluation of Emperical Models [3], [7] to assess the suitability of Periyar River Estuaries for prediction of salinity intrusion.

To achieve this aim, a one-dimensional model prepared by J.Parsha et,al (2007) based on an established model of the famous researcher Savanaji(1993) to calculate the salinity intrusion length was used [5]. Another researcher named Mr. Brockway from Washington University in 2006, has developed an emperical Model which is easier and giving axial mixing which is more suitable for the analysis of drinking water sources. The model established by Byung II Yoon and Seung-Buhm Woo is also used to compute the salinity intrusion length of Periyar River estuaries. The above models were evaluated to assess the suitability for predicting salinity intrusion through Periyar River Estuaries. In addition, an emperical model was formulated to predict the salinity intrusion lengths in the same conditions and which was tested using regression analysis to affirm its strength and relationship.

II. STUDY AREA

Periyar River estuaries, located in the central-west of Kerala are one of the main inland waterways in Kerala. The back water of this portion is known as Venbanad Kayal. It has a length of 96.5km and 14km width with an average area of 2033 Sq.km. The first upstream dam of the estuary is Bhoothathankettu. The averaged cross-sectional area, width and depth of Periyar estuary are about 3980 m^2, 920 m and 4.2 m respectively. The annual average discharge through the estuaries is noted as 206 m^3/sec. During dry season, usually

in summer, when the Periyar discharge is very low, the salinity intrusion influences the drinking water production, even though the intake is more than 20 km upstream of the estuary. However, under different riverine flow, depth of water and salinity concentrations, water surface elevation and water quality of Periyar River along its entire course are strongly affected. As the salinity in Periyar River estuaries is high in its initial portions, it is not suitable for agricultural use and also affecting the intake of drinking water source at 20 km upstream. The salinity of the Periyar estuaries varies between 2000 and 4500 mg/l, with maximum salinity of 4500mg/l [4].

III. METHOD OF STUDY

Based on the studies of Mr.Savaniji, a famous researcher on estuaries, from DELFT, Netherlands, another researcher named Mr. Brockway from Washington University in 2006, has developed an emperical Model for the analysis of drinking water sources. In view of these facts this work has been carried out using Brockway Model and found that it is suitable for Periyar estuaries also.

The Brockway Model is given to find out the Salt Water Intrusion Length,

That is; the intrusion length,

$$X_L = [1/\beta] \ln [(4.6\ A_0\ \beta K_x/Q)+1] \text{ –(1) for 2 ppm}$$

Here, A_0 is the cross-sectional area of the entrance of estuary and β is the reduction factor or the extent of topographical convergence of the estuary.

In our study, the A_0 is (the sum of two estuaries A1 and A2)

It is measured that the total Area of Cross-section

$A_0 = 3980\ m^2$

At the head works portion the average area of Cross Section, A3= 700 m^2

Topographical Convergence, β = 0.17588

Slope of the River stretch is 7.14 mts per one Kilometre,

i.e; = 0.00714

As the salinity intrusion is high during low fresh water discharge, so for this calculation the fresh water discharge is considered as, Q = 2 m^3/sec

Mixing Coefficient for the axial Direction,

$$K_x = (-Q/(\beta A_0 \text{Slope}))$$

$$K_x = 0.40016$$

Applying the above values in the Brockway Model, Salt Water Intrusion Length, $X_L = [1/\beta] \ln [(4.6\ A0\ \beta Kx/Q)+1]$

A salinity concentration of 2 units will be at the intrusion length of 36.7846 km

As mentioned above another researcher, named Mr.Byung II, in 2013 has developed a relationship between the salinity intrusion length and river discharges through the estuaries. It was noticed that a Relationship between fresh water discharges through the estuary and the salinity intrusion length was established by Byung II Yoon and Seung - Buhum Woo through their research work on Han River Estuary, South Korea. The study revealed that a very good relation between the coefficients as its Correlation coefficient obtained was 0.89.

The Byung II Model, find the Salt Water Intrusion Length given as,

$$L = 234.6\ Q^{(-1.6/10)} \text{ –(1) for 2 ppm}$$

Here, L is the salt water intrusion in km and Q is the fresh water discharge in m^3/sec

Mr. Byung II, has given an indication of flexibility in using the relationship for other estuaries that by refixing the constant and the power values to suit the river under selection if required.

IV. RESULTS AND DISCUSSIONS

Keeping the above limitations and other constraints of power values, in our studies for Periyar River estuaries a detailed iteration work has been carried out to reach the values of constants and the power values. The iteration works revealed that a constant of 80 during summer (December to May) and 63 during monsoon (June to November); and a power value of (-1.7/10) throughout the year are the most suitable emperical values. The summer relationship and monsoon relationship has been separately worked out. Finally, the best consistancy results were obtained for 80 during summer and 63 during monsoon seasons. Similar itiration works have beeen carried out for obtaining the power values also. The optimum and best results are obtained with consistancy for a power value of (-1.7/10) throughout the year.

Accordingly the intrusion length using both methods has been worked out for 3 years and computed the relationship. It is found that Byung II Model is more easy, workable and dependable. Further, an emperical relationship has been developed for the study.

Salt Water Intrusion Length was further obtained using the Emperical relationship developed based on the Byung II Model for Han River Estuary.

Salt Water Intrusion Length,

$$L = 80\ Q^{(-1.7/10)} \text{ for summer season, and}$$

$$= 63\ Q^{(-1.7/10)} \text{ for monsoon season}$$

TABLE 1. Salinity Intrusion Length for Periyar Estuaries using Byung-II Model

2008		2009		2010	
Discharge, Q in m^3/sec	Intrusion Length, L in km	Discharge, Q in m^3/sec	Intrusion Length, L in km	Discharge, Q in m^3/sec	Intrusion Length, L in km
13.24	51.57	3.48	64.72	18.66	48.64
6.76	57.81	6.00	58.99	20.93	47.70
13.42	51.45	3.70	64.05	26.38	45.86
31.91	44.40	20.57	47.85	23.17	46.89
68.84	38.96	36.05	43.49	35.78	43.55
212.96	25.32	402.44	22.73	353.18	23.24
475.88	22.09	1660.86	17.86	511.99	21.82
489.34	21.98	994.38	19.49	422.89	22.54
1069.91	19.25	1879.00	17.49	329.60	23.51
303.12	23.85	308.85	23.77	597.44	21.25
256.17	24.54	214.07	25.30	375.39	23.00
15.61	50.15	46.00	41.73	149.32	34.16

As explained, the Discharge verses Salinity intrusion length for the year 2008, 2009 and 2010 are computed and tabulated below.

The salinity intrusion length was worked out using Byung II Model vide Table 1for the years 2008, 2009 and 2010 and found that the results obtained are matching with the values obtained through Brock way Model.

The salinity intrusion length using Brockway Model and the Byung II Model has been worked out and its relationship was obtained using linear Regression Method. The strength of the relationship obtained during the year and during summer season separately, which is described vide Table 2 and Table 3 respectively.

TABLE 2. Details of the General Relationship (with Brockway Formula)

Year	a= Y-Intercept	b= slope	S=Standard error	r= correlation Coefficient	r^2= Coefficient of determination
2008	5.54923	0.84256	3.11104	0.97161	0.94404
2009	14.08748	0.62127	4.06987	0.94705	0.89691
2010	3.00322	0.99856	5.99307	0.90274	0.81494

TABLE 3. Details of Summer Relationship (with Brockway Formula)

Year	a=Y-Intercept	b= slope	S=Standard error	r=correlation Coefficient	r^2=Coefficient of determination
2008	1.24599	0.00898	0.00516	0.99691	0.99384
2009	1.28057	0.00824	0.00431	0.99898	0.99796
2010	1.15523	0.01101	0.00284	0.99906	0.998129

V. EVALUATION OF EMPERICAL MODELS FOR PERIYAR RIVER ESTUARIES

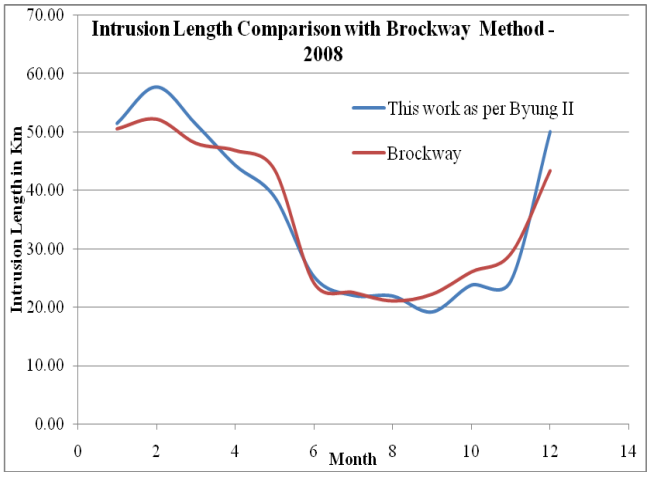

Fig 1 Intrusion Length Comparison with Brockway Method – 2008

An evaluation work has been carried out by comparing Brockway Model and Byung II Model based on the worked out values. The relationship between the values obtained through both models for the year 2008, 2009 and 2010. The results are given vide the Fig 1. Fig 2 and Fig 3 depicted below for a detailed evaluation to assess its accuracy and validity.

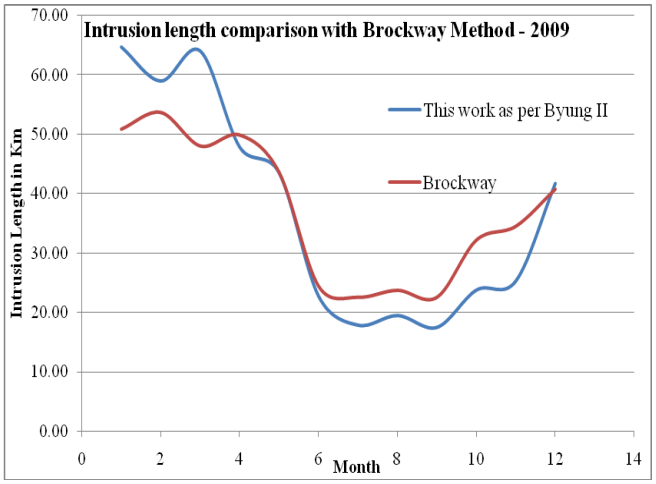

Fig 2 Intrusion Length Comparison with Brockway Method – 2009

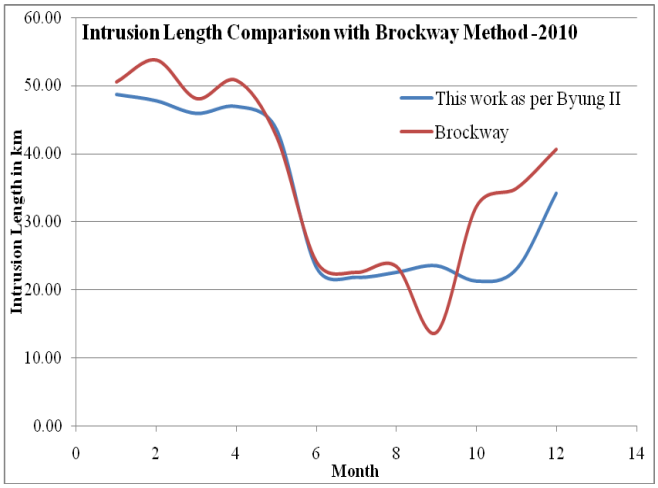

Fig 3 Intrusion Length Comparison with Brockway Method - 2010

As both the methods, Brockway Model and the Model formulated based on the Byung II Model are seen able to provide good results for the Periyar estuaries, it is now decided to compare the results of both and to ascertain its strength. The linear regression analysis is used as the tool for correlating between the values of intrusion lengths obtained for same discharges for both methods.

TABLE 4. Details of Relationship between Brockway Model and Byung Model

Year	a= Y-Intercept	b= slope	S= Standard error	r= correlation Coefficient	r^2=Coefficient of determination
2008	1.27638	0.35580	0.01411	0.97866	0.95778
2009	1.35600	0.30344	0.01639	0.97422	0.94911
2010	1.21749	0.39967	0.01454	0.97666	0.95386

The regression analysis works has been carried out for the three years as such and also for the summer and monsoon seasons separately, exhibited vide Table 4, Table 5 and Table 6 respectively.

TABLE 5. Details of Summer Relationship between Brockway Model and Byung Model

Year	a=Y-Intercept	b= slope	S=Standard error	r= correlation Coefficient	r^2=Coefficient of determination
2008	1.71457	0.09807	0.00288	0.91304	0.83365
2009	1.73001	0.08905	0.00325	0.93418	0.87269
2010	1.76929	0.06628	0.00133	0.95639	0.91469

TABLE 6. Details of Monsoon Relationship between Brockway Model and Byung Model

Year	a=Y-Intercept	b= slope	S=Standard error	r= correlation Coefficient	r^2=Coefficient of determination
2008	1.61201	0.10552	0.00313	0.8594728	0.7386934
2009	1.56864	0.13865	0.00253	0.9729759	0.9466821
2010	1.34900	0.30000	0.00273	0.8944272	0.8000000

The emperical relationship formulated shows a good relationship among its variables. The coefficient of correlation is obtained as 0.9 in all cases except during monsoon.

VI. CONCLUSION

1. The Salinity Intrusion length was computed using Brockway Model and Byung II Model and compared the results, found good relationship among them.
2. The Brockway Model was tested using the measured Salinity to obtain the Salinity Intrusion Length and the results are compared with the intrusion length computed using the Emperical relationship formulated based on the Byung II Model.
3. The Empirical relationship formulated will assist in predicting the salinity Concentration at Head Works and to obtain the Salinity Intrusion Length.
4. The developed model will assist for a better flow control so as to maintain an uninterrupted water supply.
5. The Brockway Model and Byung II Model are evaluated and found that both models are useful to Periyar River Estauries.
6. Emperical relationship formulated based on Byung Model and the Brockway model are correlated and found stron relationship between the variables with the correlation coefficient above 0.900 and Coefficient of Determination aabove 0.850

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