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Numerical Modelling Of Initial Withdrawal of Ocean Prior To a Tsunami for the Kerala Coast

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1. INTRODUCTION

After the disastrous tsunami of December 26, 2004 the need for a tsunami warning system was badly felt. The main component of a tsunami warning system is the prediction of inundation and run-up along a coastline which can only be accomplished through the effective use of numerical models. Numerical modelling will be carried out involving all different possible permutations and combinations of tsunamigenic earthquakes and the result of it in terms of inundation /run-up characteristics will be converted and updated into vulnerability maps. The state /district level disaster management centres accelerate the mitigation activities by referring to such maps.

Initial withdrawal of Ocean (IWO) is an interesting phenomenon which occurs at some locations during tsunami events before the arrival of the main tsunami wave. The initial withdrawal of ocean prior to a tsunami is usually refereed as a harbinger of an upcoming tsunami wave at the coast. Due to lack of proper understanding about this phenomenon, in 2004 several people walked towards the sea when the sea receded which led to severe causalities. The IWO neither occurs at the same location for every tsunami nor at every location for the same tsunami (Nirupama et. al 2006).The tsunami of December 26 2004 also showed some withdrawal signatures along the Kerala coast. Kurianet. al (2006) carried out analysis on initial withdrawal along the Kerala coast and reported that the sites which witnessed IWO and the sites which do not witness IWO do not differentiate a particular causative factor. This paper analyses the extend of IWO for tsunamis arriving at the coast from various tsunamigenic sources in the Indian Ocean using numerical

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modelling. Three representative sectors in the Kerala coast were selected for model computations based on the varying topography. The sectors include Neendakara-Trikkunnapuzha the worst affected area during the 2004 tsunami, Pozhiyur-Thiruvallomand Mogral-Thalappadi pertaining to Southern Kerala and Northern Kerala.

2. DATA AND METHODOLOGY

The simulations were performed with the help of a numerical model (TUNAMI N2) which adequately models the physics of tsunami propagation from source to the coast using fixed computational grid using nested grids. The model was set-up and calibrated for the Kerala coast (Praveen et. al 2011). Numerical simulations for estimating tsunami inundation require two types of data inputs: 1) Source data, encapsulating the geology and seismology of the event and 2) Ocean Bathymetry and coastal topography. The model uses finite grids for the propagation of tsunami. The entire domain is divided into four grids A,B,C and D (Fig. 1). Almost the entire Indian Ocean is taken as the outer grid namely Grid A, and three sub-grids B, C and D each lie within the outer one. Grid D is the coastal area for which the run-up and inundation is computed. Starting from Grid D each outer grid will be expanding thrice the corresponding inner grid in terms of horizontal data spacing. The fine grid with lesser spacing and the spacing increases in the multiples of three starting from 3 arc seconds in the finest D grid (The topographic data for the D grid was taken from the survey conducted by CESS. The fault parameters used for the simulations are given in Table 1.

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Table 1. Seismic parameters considered in the present study for all the scenarios

Sl. No.	Source / Parameter	1945 Makran	1881 Carnicobar	1941 North Andaman	2004 Sumatra	*Hypothetical
1	Longitude (degrees)	63 E	92.43E	92.5 E	95.85 E	63E
2	Latitude (degrees)	24.5 N	8.52 N	12.1 N	3.32 N	24.5 N
3	Magnitude (M_w)	8.0	7.9	7.7	9.3	9.3
4	Slip (m)	15	5	5	15	15
5	Fault length (km)	200	200	200	680	680
6	Fault width (km)	100	80	80	150	150
7	Strike (degree)	270	350	20	342	270
8	Dip (degree)	15	25	20	15	15
9	Rake (degree)	90	90	90	90	90
10	Depth (km)	30	15	30	20	20

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***** Worst scenario:Sumatra like earthquake in the MakranSubduction Zone.

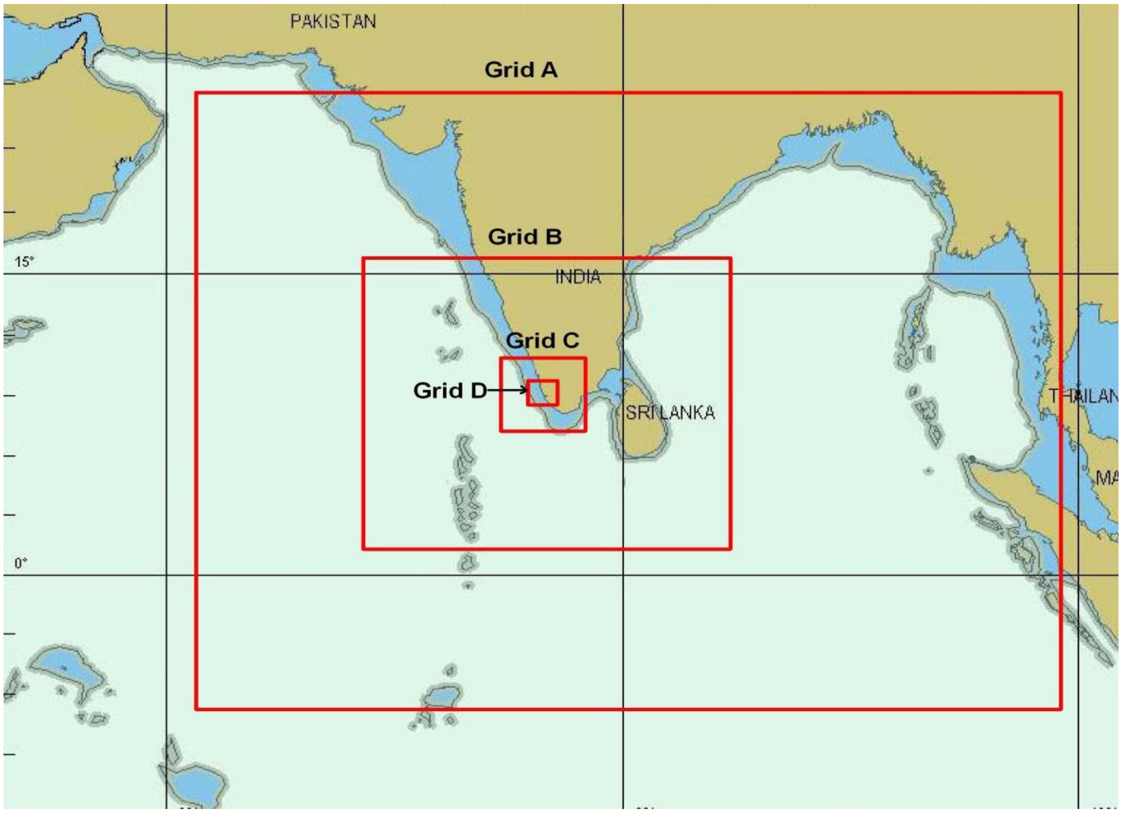

Fig. 1The four depth grids used for Sumatra simulation

3. RESULTS AND DISCUSSION

The IWO during the 2004 Sumatra tsunami for the Kerala coast was analyzed by Kurianet. al (2006). So the results of the model were compared with the field observations for the worst affected part of Kerala during 2004 Sumatra tsunami (Fig. 2).

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The model while projecting the maximum extendof withdrawal gave some over estimates for this sector while on comparison with the field data.

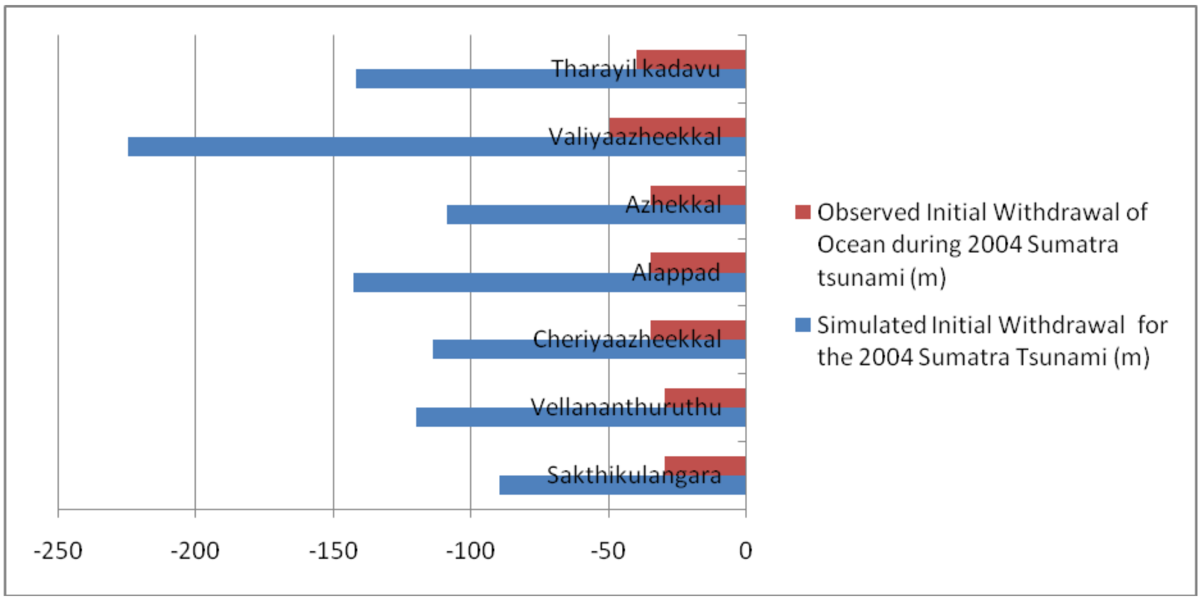

Fig.2 Comparison of Simulated and Observed IWO for the Neendakara-Trikkunnapuzha coastal stretch

The results of numerical modelling carried out for the three representative sectors are shown in figures3 to 5.

The simulation result shows varying results along the Kerala coast. The Pozhiyur-Thiruvallom coast pertaining to the southern Kerala coast showed huge withdrawal of ocean for the 2004 Sumatra source (Fig. 3). A maximum withdrawal of 480 m was observed at Chowara and a minimum of 100 m at Adimalathura. The other locations like Pachalur, Vazhamuttam, Puthiyathura, Karimkulam and Pozhiyur showed withdrawals of

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253 m, 311 m, 239 m, 360 m and 320 m respectively. The simulation showed no withdrawal for the other sources like Carnicobar, North Andaman in the east and Makran in the west. Even the hypothetical potential worst case cannot make a withdrawal for the southern Kerala. The huge withdrawal for the Sumatra source can be attributed towards the role of several physical oceanographic processes like reflection, refraction, total internal reflection and diffraction. Apart from that the proximity of the southern Kerala coast with the Sumatra source also contributed in steering the tsunami to this location and causing considerable withdrawal of the ocean. The other sources like Carnicobar and North Andaman could not make much of an impact due to the large distance between epicentre and study area. Moreover the west coast of India and especially Kerala coast fall in the shadow zone with reference to these two sources. Whereas Makran by virtue of its fault orientation and low rupture intensity could not make much of an impact, but it is clear that the hypothetical case originating from the same location had undergone some attenuation prior to the reaching of its waves in the south coast leading to no withdrawal at the southern Kerala coast.

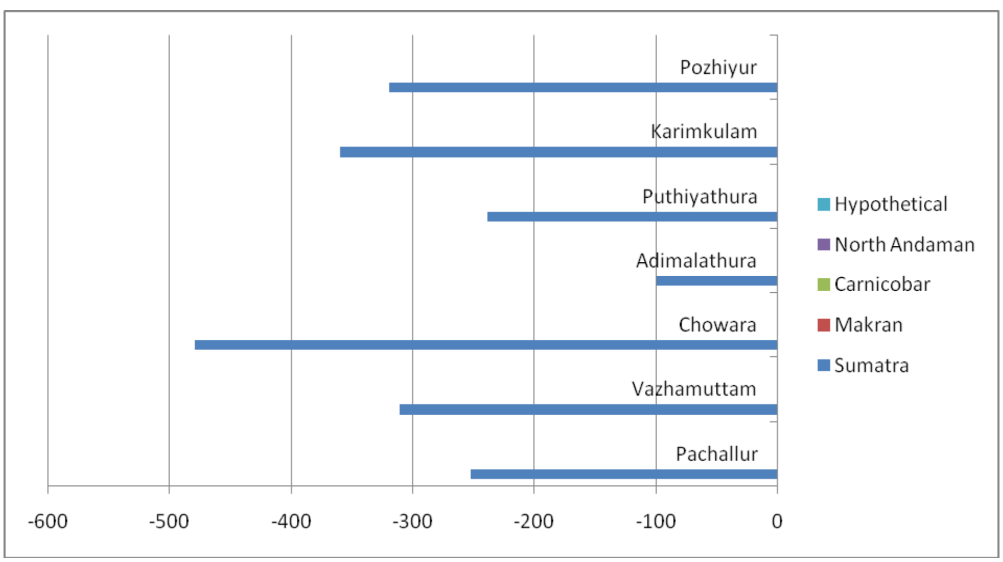

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Fig.3 Comparison of Simulated IWO of Southern Kerala for different tsunamigenic sources in the Indian Ocean

The simulation for the Mogral-Thalappadi sector pertaining to the northern Kerala shows some distinctive result. Unlike Southern Kerala, Sumatramodelling results shows no withdrawal along this stretch except a 227 m withdrawal at north of Uppala (Fig. 4). The model showed no withdrawal for the sourcesCarnicobar, North Andaman and Makran. The highest withdrawal was simulated for the hypothetical source. The hypothetical source showed a maximum withdrawal of 500 m at the south of Uppala and a minimum of 154 m at the north of Ankadi. The other regions like south of Ankadi, North of Uppala and Manjeswaram showed a withdrawal of 203 m, 252 m and 160 m. The huge withdrawal for the Northern Kerala for the hypothetical case can be mainly due to the rupture intensity and proximity of the location with the source. When a tsunami from Makran was unable to produce any kind of withdrawal for the Northern Kerala ,the hypothetical source produced some withdrawalwhich underscores the fact that the increased rupture intensity can definitely lead to huge withdrawal .

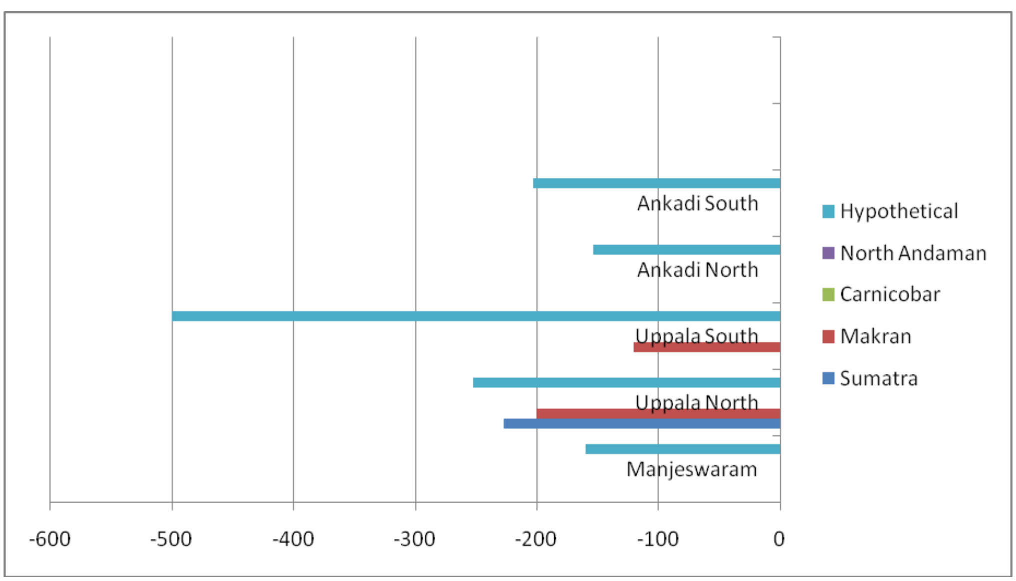

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Fig.4 Comparison of Simulated IWO of Northern Kerala for different tsunamigenic sources in the Indian Ocean

The Sumatra source dominated in terms of IWO for the Neendakara-Trikkunnapuzha stretch which was the worst affected area during the 2004 Sumatra tsunami (Fig. 5). A maximum withdrawal of 225 m was observed at Valiyaazheekkal whereas Sakthikulangara showed a minimum withdrawal of 90 m. The other areas like Vellanathuruthu, Cheriyazheekkal, Alappad, Azhekkal and Tharayilkadavu showed withdrawals of 120 m, 114 m, 143 m, 109 m and 142 m respectively. The simulation for Makran 1945 showed some negligible withdrawal for this coast while comparing with that of Sumatra 2004, whereas the simulation for the hypothetical source showed marginalincrease in the withdrawal on comparison with Makran.

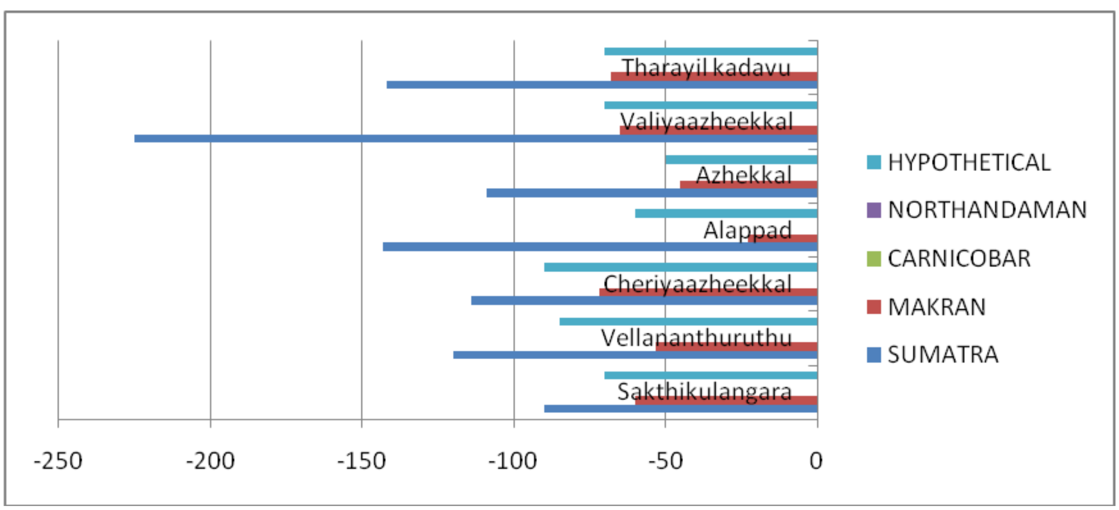

Fig.5 Comparison of Simulated IWO of the Neendakara-Trikkunnapuzha stretch for different tsunamigenic sources in the Indian Ocean

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From the modelingresults , it is seen that IWO varies to a greater extend with reference to the tsunamigenic sources, its rupture parameters, intensity and directivity of propagation. For the northern Kerala coast only the hypothetical case generates some kind of withdrawal. The withdrawal is not visible for the sources Sumatra, Makran, Carnicobar, and hypothetical, whereas for southern Kerala the withdrawal is exclusively for Sumatra 2004 alone. The worst affected part of 2004 Sumatra tsunami shows withdrawal for Sumatra, Makran and Hypothetical but the extend of withdrawal is mostly dominated by Sumatra source. It should be specifically mentioned that the other two sources in the east,Carnicobar and North Andaman cannot produce even a feeble withdrawal for any of the sectors pertaining to entire Kerala coast. This can be attributed towards the distance of the source from the study area sectors and the role of various physical oceanographic processes leading to the dispersion and attenuation of tsunami waves. Apart from that the earthquake rupture parameters coupled with the directivity of tsunami propagation also played a major role in not causing withdrawal for the Kerala coast. The withdrawal for the southern Kerala was much dominant for Sumatra case due to the directivity of propagation, role of diffraction, reflection, total internal reflection and refraction. Moreover the proximity of Sumatra source location with the Kerala coast also aggravated the IWO. But the Makran source due to its low rupture intensity and the orientation of the fault was unable to produce a withdrawal along the entire coast. But the hypothetical source, by virtue of its intensity caused considerable withdrawal for the northern Kerala coast with values further decreasing towards the coast.

4.0 CALIBRATION OF INITIAL WITHDRAWAL

The calibration of IWO was done for the Kerala coast. The field observations were taken from Kurianet. al(2006) . The model calibration results for Southern Kerala and Northern Kerala are shown in the figures 6 and 7.

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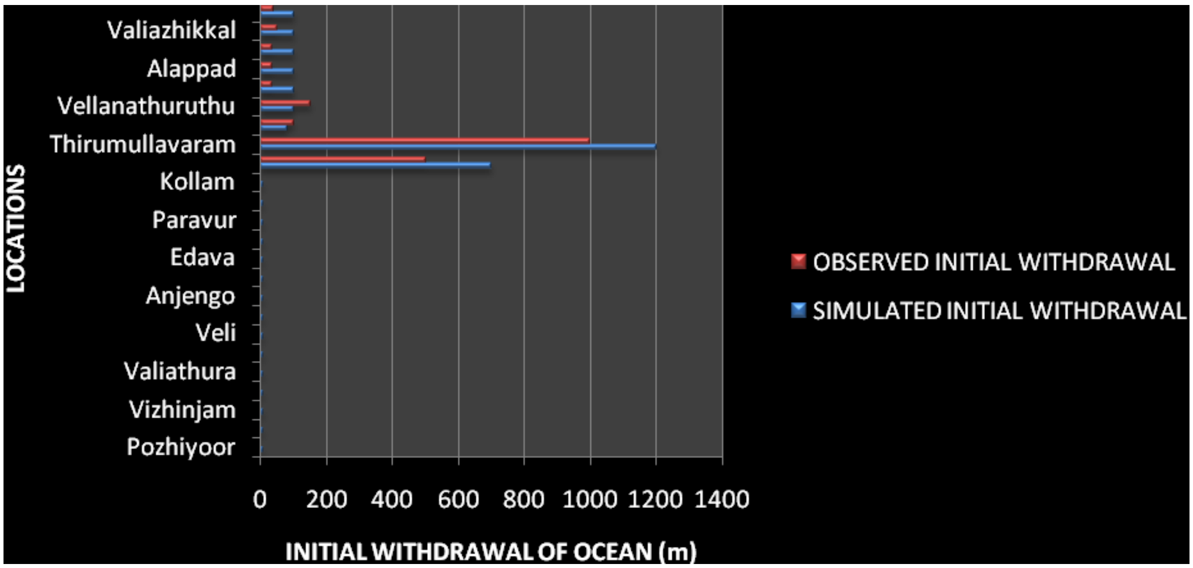

Fig. 6 Comparison of simulated and observed IWO along Southern Kerala coast

In southern Kerala and northern Kerala the modelling results shows a similar pattern of IWO which was observed on field during December 26, 2004. Though the pattern is similar there is change in the extend of withdrawal for both southern and northern Kerala.

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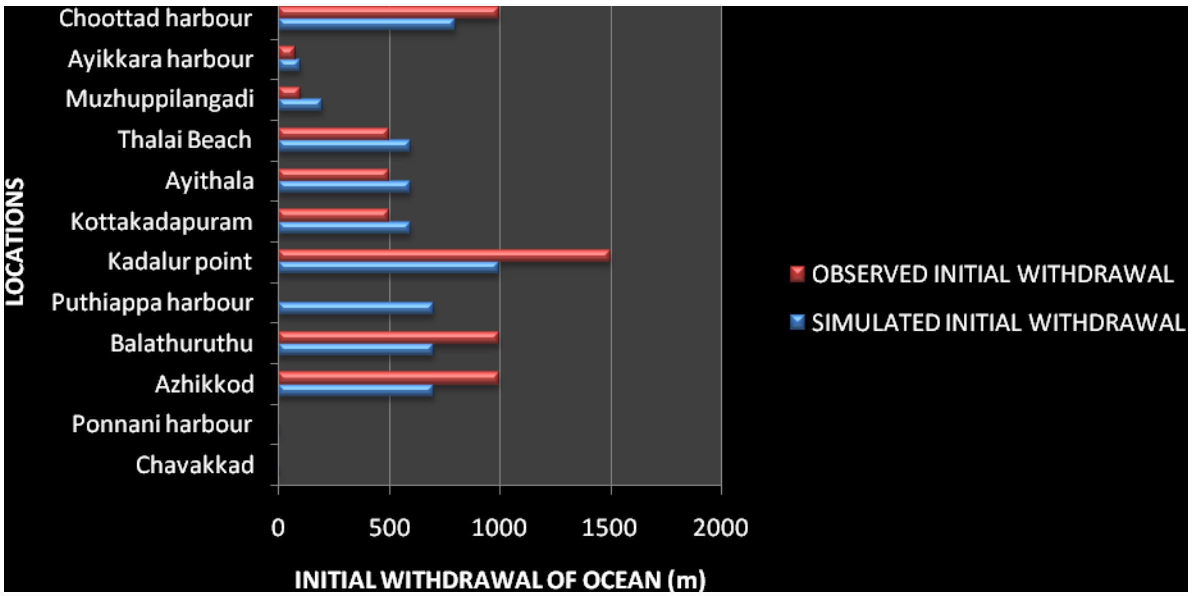

Fig. 7 Comparison of simulated and observed IWO along Northern Kerala coast

However the simulation results for IWO show a marginal high value in the southern Kerala sector and a marginal decrement value along northern Kerala sector which can be attributed towards the bathymetric variations represented by the data which was used for this numerical modelling investigation.

5.0 SUMMARY AND CONCLUSION

The modelling result unraveled the fact that IWO is not a uniform processes. It may or may not happen. Moreover it is not mandatory that the ocean should withdraw prior to a tsunami. Even though bathymetry has some contribution towards initial withdrawal it can be said that bathymetry alone is not a major factor which determines the withdrawal of ocean prior to a tsunami. The main difficulty with tsunami researchers is that IWO is not a process which occurs universally.

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From the results of numerical modelling it is seen that the Sumatra 2004 will be dominant in causing withdrawal for the southern Kerala coast, whereas this source is not effective in causing withdrawal for the northern Kerala coast. The hypothetical source from Makran with Sumatra rupture intensity can cause effective withdrawal for the northern Kerala coast but not in the southern Kerala coast. When Makran source did not give rise to much withdrawal , the other sources in the east like Carnicobar and North Andaman could not even generate a feeble withdrawal due to its shadowness and directivity of the propagation with the coast. The calibration of IWO shows a marginal increase in southern sector and a marginal decrement in the northern sector of Kerala attributed as bathymetric variations in the near shore.

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