INUNDATION OF TSUNAMI WAVES AND ITS RELATION TO THE TSUNAMI RUNUP.

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Abstract:

Natural hazards like tsunami cannot be avoided but efforts can be made to minimize their demolition. The devastating tsunami of 1945 caused a severe damage of lives and infrastructure across the coastal areas of Pakistan particularly the Makran coast. Any kind of preemptive measures to reduce the after effects of tsunami and its destruction needs proper assessment of risk areas and more precisely to how much threat certain areas are likely to be exposed in case of any such incident. The previous study was based on the amount of possible destruction that coastal areas of Pakistan are likely to suffer in case of tsunami generated in the Arabian Sea for which a tsunamagenic earthquake along Makran Subduction Zone is the most likely cause [3]. Present study does not focus on any particular location of the globe instead an effort is made to explore various factors that will affect the inundation of tsunami waves across the coast and more precisely its relation with run-up height. An effort has also been made in this document to highlight and point out various efforts that are needed to be done in this regard to predetermine the possible loss in case of tsunami generated along the Makran Subduction Zone and to establish an effective "Tsunami early warning system".

Introduction:

Tsunami is one of the most destructive coastal hazards generating in deep oceans by volcanic activities, submarine land slides and more usually by an earthquake particularly generated by a subduction zone. Makran Subduction Zone that is located 100 Km from Makran coast is a major source of tsunami threat particularly to Pakistan's coastal cities. Initially the intensity of tsunami depends upon the size of hump created due to the deformation of sea floor as a result of triggering source. Than the potential energy of the tsunami is transformed into the kinetic energy of tsunami waves that propagate in the oceans at steady speed and as it reaches coast, the kinetic energy of tsunami waves transforms back into potential energy creating giant waves at the coasts hence causing enormous damage to the coastal zones. One such incident took place in December 1945 as a result of an earthquake of magnitude 8.5 at Richter scale that was responsible for loss more than 4000 lives and immeasurable property along the coast of Makran.

Run-up height is the maximum elevation of tsunami waves above mean sea level and the inundation distance is the amount of horizontal distance tsunami wave travels landwards from the coastline (Figure 1.). In current study, the run up and inundation data of Madghaskar and India has been used because of non-availability of the data of only recorded tsunami that struck coastal areas of Pakistan in 1945.

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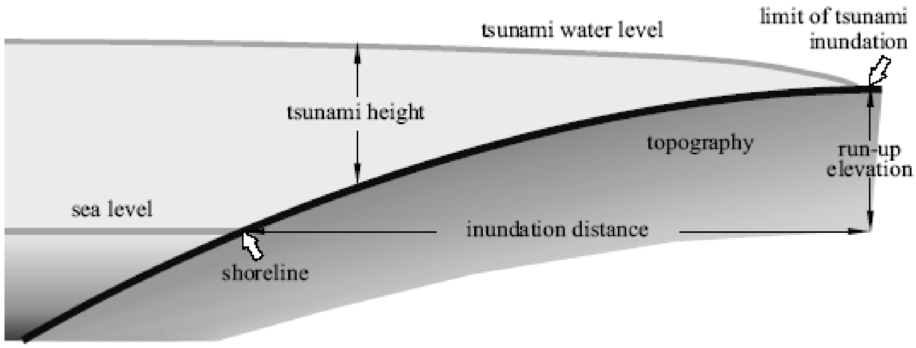

Figure 1: **Measurement of run up height and inundation distance of tsunami.**

Inundation Distance:

Table 1 and table 2 is the database showing the run up height and inundation distance of different location in Madghaskar and India respectively collected after the devastating tsunami of December 26, 2004.

Table 1: **Run up and inundation distance of different locations of Madghaskar**

City	Run up (m)	inundation (m)
Antalaha	2.30	28
Ampahana	2.53	50
Sambava	1.77	71
Sambava	1.91	30
Vohemar	1.60	10
Vohemar	1.48	9
Vohemar	3.19	24
Benarevika	3.51	29
Ambila	2.35	30
Soanierana-Ivongo	2.00	46
Soanierana-Ivongo	1.30	12
Manafiafy (Sainte Luce)	3.10	34
Ankaramany	2.70	35
Ampasimasay	3.20	29
Betanty (Faux Cap)	4.40	34
Betanty (Faux Cap)	2.30	30
Betanty (Faux Cap)	4.80	37
Benaiky	2.90	19
Tolagnaro (Fort Dauphin)	4.10	36
Manakara Be	3.80	58
Manakara North	2.0	25
Manakara Be	3.5	59
Manafiafy (Saint Luce)	3.1	34

Study related to the tsunami inundation has revealed that tsunami inundation mainly depends upon the geomorphologic settings of the coastal areas. The degree of inundation was controlled by coastal geomorphologic features such as sand dunes, cliffs, coastal vegetation, nature and configuration of the beach and most effective of all is the angle of elevation of the coastline and the velocity of the invading tsunami surge. The angle of elevation of a coastline plays a major role in assessing the possible inundation distance. It has been observed that elevated coastlines are less prone to high degree of inundation as there is difficulty for the up-rushing tsunami waves due to increasing gradient and exposure to the rocks as compared to the low lying coasts that are prime victims of the tsunami inundation and low lying coasts are unable to put up considerable resistance to the inundating tsunami wave. Narayan et al. (2005a) found that the elevated landmass played a key role in preventing inundation and minimizing damage along the coast of Tamilnadu India. Narayan et al. (2005b) found that the degree of inundation was strongly scattered in direct relationship to the morphology of the seashore and run-up level on the Kerala coast. Kurian et al. (2006) investigated the inundation characteristics and geomorphologic changes resulting from the 26December 2004 tsunami along the Kerala Coast, India. They noted that river inlets had been conducive to inundation; the devastation was extremely severe there, as the tsunami had coincided with the high tides. Chandrasekar et al. (2006b) reported that the extent of inundation depends mainly upon the nature of the coastal geomorphology.

Table 2: **Run up and inundation distance of different locations of India**

City	inundation (m)	Run up (m)
Azhakappapuram	40	1–2
Kanyakumari	50	1–2
Agastheeswaram	50	1–2
Tamaraikulam	375	4–6
Thengampudur	100	3–4
Madhysoodhanapuram	50	2–3
Dharmapuram	50	2–3
Rajakkamangalam	350	3–4
Kadiapatnam	75	2–3
Manavalakurichi	250	3–4
Lakshmipuram	300	4–5
Colachel	450	5–6

Correlation between Run-Up and Inundation:

Although inundation distance is affected by the geomorphology of the coastal area, gradient of coastline and nature of the coastal area but run up height is the main factor that affects the inundation distance. The run-up height and inundation distance seems to be directly proportional to each other. Narayan et al (2005a) reported the inundation distance of 20 to 7000m with the run-up height of 1to 12m at Tamilnadu coast of India. Rasheed et al (2006) reported the inundation distance of 60 to 600m as a result of 2 to 5m run up height at Kerala coast of India.

Figure 2, is showing the relationship between run up height and inundation distance at different locations at Madghaskar and it can be noted that the extant of inundation distance is directly proportional to the amount of run up at the respective coasts.

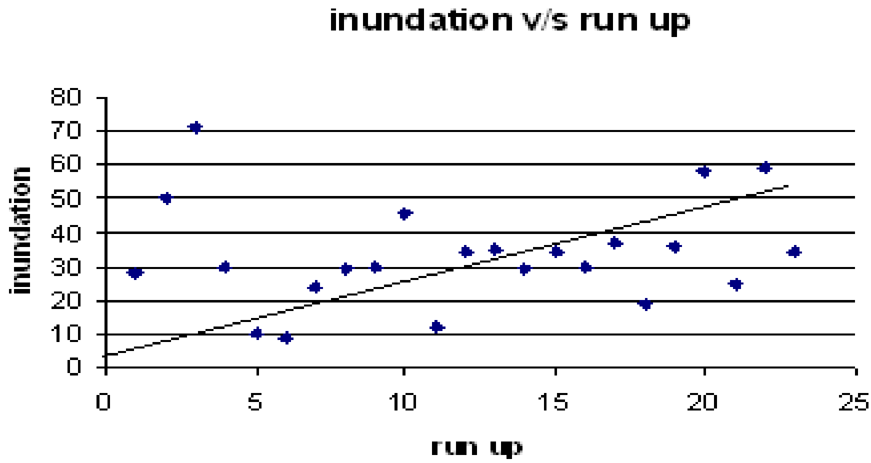

Figure 2: **Run-up v/s inundation distance at Madghaskar**

Figure 3, is the plot of inundation distance v/s run up height at several cities of India. It also shows a direct relationship between run up height and inundation distance. As we can observe that as run up height increases inundation distance also increases.

In the present study it has been observed that extant of inundation distance is directly proportional to the run up height and substantial inundation coupled with run up resulted in the heavy devastation. It has been found that in addition to the amount of run up height, coastal geo morphology and elevation of the coastal area, river inlets and canals also proved to be very conducive for substantial amount of inundation.

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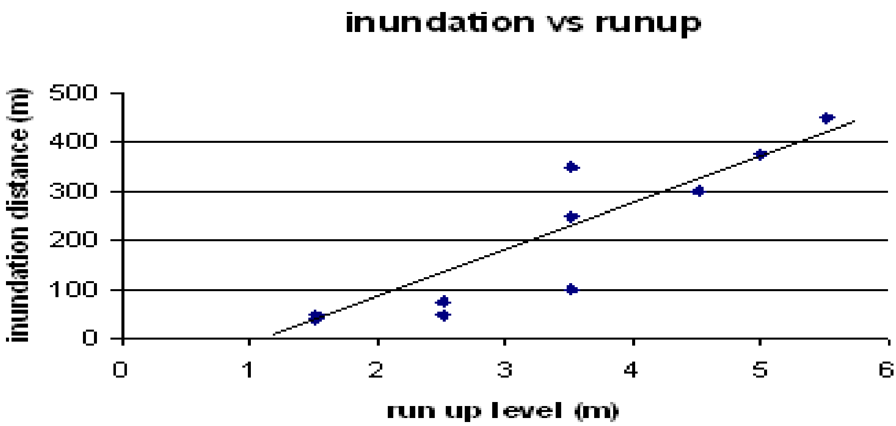

Figure 3: **Run-up vs. inundation distance at India**

Results and Discussions:

It has been observed that although inundation distance is directly proportional to the run up height but it does not depend solely upon the run up height, it also depends upon the type of coast encountered. Low lying coasts are often prime victims of the tsunami surge as they are unable to present sufficient amount of resistance to the path of invading tsunami waves. Elevated coasts especially with rockey exposure normally recieve minimal inundation due to the resistance they are able to put up in the way of accelerating tsunami surge because of their steep slope and rocky behaviour as it is evident from figure 3 and table 2 that Agastheeswaram and Kadiapatnam being rockey and steep coastal areas recived very low inundation as compared to the low laying shallow coast of Thengampudur.

River inlets and canals also contribute heavily to the amount of inundation that a particular area recieves. In figure 3 and table 2, the anormously inundated Rajakkamangalam and Manavalakurichi lie at the mouth of the river Panniyar and Valliyar respectively and hence these rivers also contributed to such a huge amount of inundation.

In case of any damage assessment or risk mitigation efforts these two factors must be considered side by side to grasp the complete picture of the scenario. The voulnerability of any coast depends upon the run up height at that particular coast as well as its location and geomorphologic setting also.

Recommendations:

For future work in the field of tsunami science and for the development of some kind of the early warning system following steps are unavoidable and without these no sustainable efforts in this regard can be realized.

A detailed survey in particular of the coastal cities of Pakistan may be conducted to find out complete data of the fault lines adjacent to these cities as well as the slope and elevation of the coastlines to carry out future research and risk mitigation efforts in the field of tsunami.

A data bank comprising of the complete fault parameters and locations may be established for near future “Tsunami early warning system” in Pakistan.

For the development of “tsunami early warning system”, seismic data, tidal gauge data and tsunameter data should be made possible at the earliest for an alert signal in shortest possible time to minimize the risk of tsunami destruction.

A tsunami warning system should be built on the foundation of international cooperation in the principal of open, free and unrestricted exchange of data and information.

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