A STUDY ON THE EFFECTIVENESS OF TSUNAMI WARNING SYSTEM IN SRI LANKA

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Abstract - The Indian Ocean tsunami of 26th December 2004 was the greatest natural disaster ever to hit Sri Lanka. This is considered as the world's first Internet-mediated natural disaster as it got extensive coverage with the power of satellite and Internet technologies. However, the tsunami warning message did not reach the respective coastal communities on time, resulting in massive damage to people and properties. Even though no more tsunamis hit Sri Lanka again, a few early warning and preparedness measures have been taken. Tsunami warningsare generated from tsunami towers and these must provide accurate messages. And the system is supposed to work effectively and accurately to avoid causing panic and unnecessary disruption. The purpose of this research is to identify what factors must be considered to make the tsunami warning system work more effectively. A descriptive research methodology has been used for this research, based on a selected sample from the coastal population in Galle that included 60 cases. The Study has been carried out over a period of eight months and it used a questionnaire as a survey instrument. This study proposes that technology, communication, administration and human resourcesare the most critical factors needed to put in place an effective tsunami warning system in Sri Lanka. This will support government agencies to deploy a wider range of response strategies.

Keywords- Tsunami warning system, Communication, Technology, Administration, Human resource

I. INTRODUCTION

Sri Lanka was the first country to receive the tsunami warning from Hawaii, US, several hours before the tsunami was about to hit the coastal areas of the Indian Ocean. But due to the lack of well-coordinated communication networks in these countries, Sri Lanka, India, and even Sudan (Northeast Africa) did not receive the Tsunami warning well in time to take the necessary action (Muggah, 2008). There was also the lack of a well-established natural disaster warning system in these countries (UNDP, 2005). On 26th December 2004 the Tsunami struck with great force wreaking havoc. It caused massive damage and killed tens of thousands of people living in coastal areas facing the Indian Ocean (Centre for Research on the Epidemiology of Disasters, 2005).

Sri Lanka was hit badly by this Tsunami, which was triggered by a Richter 9.0 magnitude earthquake off the coast of Sumatra on 26th December 2004. The tsunami was one of the worst disasters ever recorded in the history of the Island. It left thousands of people dead and many thousands more homeless,causing widespread of chaos (Pararas-Carayannis, 2003) throughout the Island. In addition to the social impact, the tsunami had a significant impact on Sri Lanka's environment and ecological systems. It caused severe long-term effects on the economy and the society (Samarajiva, 2005).

As of 1st March 2005, estimates stated that 35,322 people perished in the months following the Tsunami (UNDP, 2005). Nearly 800, 000 people who lived in the coastal areas of Sri Lanka have been directly affected (Nuwansi, 2005). The Eastern shores of Sri Lanka faced the hardest impact since they faced the epicenter of the earthquake. The Southern and Western shores were hit later, but the death toll was just as severe along those coastlines (UNDP, 2005). The South-Western shore is a hotspot for tourists as well as the fishing economy. Tourism and fishing industries created high population densities along the coast. The coastal lifestyle of people in Sri Lanka contributed to the high death toll. Besides the high number of fatalities, approximately 90,000 buildings were destroyed. Houses were easily destroyed since many of those were built mostly out of wood (Hettige et al., 2004).

The Meteorological Department of Sri Lanka receives Tsunami early warnings through the Regional Warning Centers, which in turn are transmitted to the Disaster Management Centre for the dissemination of that information to all as quickly as possible to ensure prompt evacuation to safety (DMC, 2005). No sooner an early warning of an impending Tsunami is received, required steps will be taken by the DMC to inform the general public through the Police, Radio broadcasts and TV telecasts (DMC, 2009). From the lessons learned from the 2004 Tsunami, the Disaster Management Centre has made arrangements to activate the Tsunami Warning alarm via 77 warning towers spaced along the coastal belt of Sri Lanka (DMC, 2009).

However, on the night of 28th March 2005, three months after the 2004 Tsunami, there was a big earthquake measuring 8.7 on the Richter scale at the Sunda Pit near Nias Island, Southeast of the epicenter of the previous earthquake.Tsunami warnings were issued andmillions of people living along the coasts of the Indian Ocean ran out of their houses in the dark. It was not a destructive tsunami though. Unfortunately, some people died while attempting to evacuate, or just out of shock (Nuwansi, 2005). This incident illustrated the problem with the tsunami Warning system which issued false alarms 75% of the time (Associated Press, 2005) resulting in additional costs to the country. DMC (2009) confirmed that as the steel towers are situated near the coastal areasboth the towers andeven the associated systems are prone to corrode at a fast rate due to the salty air. Servicing and functional tests of these sirens mounted on the towers are not carried out at regular intervals. Therefore, sometimes when the Tsunami warning was activated, the systems had failed to function as they were not in a serviceable condition to be used even in an emergency (Samarajiva, 2005). Also, casualties have occurred during evacuation due to the lack of a proper evacuation plan and/ or failure to educate the public about an orderly evacuation process. (Repetition) These drawbacks are considered to be critical weak points of the Tsunami warning systems in Sri Lanka.

By considering all the problems affecting the existing Tsunami warning system, the purpose of this study is to overcome theexisting drawbacks by identifying theremedies that might be appliedto improve its effectiveness in the long run. It has been fifteen years since the Indian Ocean Tsunami hit Sri Lanka. Since then the Sri Lankan government has been focusing intently on disaster prevention and initiating several projects at various levels to educate the public and protect them from natural disasters including tsunamis (DMC, 2009). The desired results could be achieved by introducing regular maintenance programs, monitoring them assiduously, linking them with a proper evacuation plan and by educating the public.

II. LITERATURE

A.Tsunami Warning Systems in the European Region and Western Countries

The Tsunami Warning System is a method that was devised to help minimize the loss of life and property during a tsunami strike. The National Tsunami Warning Center at Palmer, Alaska, monitors worldwide earthquakes and tsunami events. If a tsunami is original, they issue advisories, watches, and warnings, as well as information about it to the United States of America, Canada, and Puerto Rico (Titov et al.). The Pacific Warning Center in Hawaii provides similar services to all other US territories in the Pacific Ocean. They also serve some countries in the Pacific Ocean, Indian Ocean and the Caribbean basin. These two tsunami warning centers use the earthquake information, tidal gauges and also a new tool now from the NOAA (National Oceanic and Atmospheric Administration).This is known as the Appropriate detection device, developed by NOAA Pacific Marine Environmental Laboratory. A total of 39 buoys are currently deployed in the North Pacific with nearly two dozen scientists to analyze their data and determine if a tsunami has been generated and crossed the Pacific, well before it reaches the North American coast. Another tool in the tsunami warning centers helps to avoid false alarms. The buoys in the dense network supplement each other and act as mutual backups.

The Intergovernmental Oceanographic Commission (IOC) is coordinating the implementation of the global Tsunami warning system, building upon its experiences in the Pacific to establish warning centers for the Indian Ocean, Caribbean Sea, and the Mediterranean Sea. The Pacific Tsunami Warning Center (PTWC) serves as the international warning center for the Pacific. This international warning effort became a formal arrangement in 1965 when the PTWC assumed responsibility as the operational center for the Tsunami Warning System in the Pacific (TWSP). The ICG/ITSU, presently comprised of 26 international Member States, oversees warning system operations and facilitates coordination and cooperation in all international Tsunami mitigation activities (Dacis, 2008). Until a regional warning center is permanently established in the Indian Ocean, the PTWC and the Japan Meteorological Agency (JMA) will cooperatively provide interim warning services (Dacis, 2008).

The US agency responsible for Tsunami warnings is the National Oceanic and Atmospheric Administration (NOAA) and its predecessor agencies, including the US Coast and Geodetic Survey and the Environmental Science Services Administration (NOAA, 2005). The Pacific-wide Tsunami warning system took advantage of the islands scattered within the vast expanse of the Pacific Ocean and organized international cooperation among these nations at risk to create a "if you detect a Tsunami, alert everyone" movement. Tsunami detectors are tide gauges located around the Pacific 'ring of fire,' and the telephone-based communications systems are tested monthly to ensure reliability in alerting all nations requesting Tsunami services. Tsunami travel-time maps are provided to all participants, so times of Tsunami arrival could be easily determined. This international cooperation initiative benefited affected nations by providing access to a large Tsunami monitoring network and arrival forecasting system for the cost of investing in and operating a portion of the system. This shared cost system worked, but the inaccuracies of the forecasts led to a false alarm rate of 75%. A false alarm isdefined as a Tsunami evacuation accompanied by a non-flooding Tsunami. The inaccuracies and high false alarm rate were due, in part, to Tsunami measurements at tide gauges being greatly influenced by local bathymetry. As such, using these data to predict the Tsunami impact at other locations was of little quantitative value. Also, the US earthquake-centric system suffered the same inaccuracy problems as Japan in using earthquake magnitude to estimate Tsunami impact.

B. Tsunami Warning System in Asian Region

A massive earthquake of magnitude 9.0 on the Richter scale struck off the coast of Sumatra Island in December 2004, setting a record as the most devastating tsunami in modern times, and affecting 18 countries in Southeast Asia, Southern Africa, and Sri Lanka.It caused enormous damage in terms of life and property along the coasts of the Indian Ocean (USGS, 2004). The number of deaths and missing persons was estimated at 300,000, and almost 1.2 million people were affected by the event (OCHA, 2005). The scale of the damage that occurred has been attributed to the absence of an Indian Ocean early warning system such as that which exists in the Pacific Ocean, and a lack of knowledge about tsunamis (Gregg et al., 2006; Colombage, 2006).

The chairman of the National Disaster Warning Council, Ranong Branch, Thailand has mentioned that many towers were not functioning properly, as thieves had stolen and removed loudspeakers and other equipment from the towers in Ranong, Thailand. There were 13 warning towers in Ranong, one of the six southern provinces hit by the 2004 Tsunami. The chairman also complained that the signboards were rather confusing and so people might not have been able to find safe evacuation routes in times of emergencies (Nations, 2012).

In 2007, the Indonesian Parliament passed Law No. 24/2007 on Disaster Management, which explicitly stated that the government of Indonesia was responsible for disaster response, including mitigating disaster risks and protecting the society from natural hazards. In 2008, Badan National Penanggulangan Bencana (BNPB) was established as a new National Disaster Management Agency responsible for disaster coordination and management of all natural hazards. The BNPB is responsible for coordinating other government agencies assigned with specific disaster response functions and operations (Morin, 2008). Other existing disaster agencies were also institutionally empowered. A mechanism was established to issue the first Tsunami warning alarm within 5 minutes of an earthquake event. However, in practice this has not performed well,thereby proving that the TEWS ideally needs an additional 500 accelerometers (devices that measure the proper acceleration of Tsunami waves) distributed around the Indonesian coasts to predict a Tsunami within two minutes after an earthquake.

This is because the earthquake epicenter, on average, is located from 250 to 400 km away from the nearest coast of Indonesia. This reduces the amount of time available to warn citizens living near the coastsvulnerable to Tsunami hazards and also gives them less time to evacuate (Chatfield, 2013). The warning messages have also been disseminated through social media like Twitter.

C. Tsunami Warning System in Sri Lanka

The tsunami of December 2004, caused by a 9.0 magnitude earthquake, is the most devastating tsunami of modern times with the consequences being felt in many areas. In response, since December 2004, the Meteorological Department of Sri Lanka has announced Tsunami warnings on three occasions, specifically on 29/ 03/ 2005, 17/ 09/ 2007 and 11/ 04/ 2012, resulting in evacuation in all three occasions. However, no disastrous situations were experienced. It must be noted that all undersea earthquakes can give rise to a tsunami. It depends on the magnitude of the earthquake and the depth of water at that location. If the earthquake occurs near the Indonesian shores, then the meteorological Department of Sri Lanka will be rather concerned about the possibility of its effect on Sri Lanka. However, it was found in 2012 that some of the Tsunami towers set up in the coastal areas of Sri Lanka had not functioned properly due to technical failures when a Tsunami alert was issued during a drill (DMC, 2012).

The Meteorological Department of Sri Lanka gets data about earthquakes through the Global Telecommunication System (GTS) and this includes details like magnitude and depth of earthquake with reference to sea level. Then the Meteorological Department analyzes the information and if necessary, alerts thepopulation. They will analyze mostly earthquakes of magnitude above 6.5 Richter scalethat occur at depthsof 100 meters below the seabed. They will also consider the weather forecast, and the IOTWS is responsible for passing along such warnings. However, when an earthquake capable of triggering a Tsunami occurs nearby Sumatra, it will take a minimum of one and a half hours to reach Sri Lanka;but if an earthquake occurs on the nearest fault line towards the West of Sri Lanka, then it will take around five hours for the waves to reach Sri Lanka (DMC, 2009).

The Disaster Management Centre of Sri Lanka plays a vital role in broadcasting the warning message in liaison with relevant authorities to assist the public in evacuation. There are two types of evacuation namely horizontal and vertical evacuation. For horizontal evacuation, locations 2km from the sea shore are considered as safe. Vertical evacuation refers to the process of selecting hilly areas. Evacuation routes are marked clearly to enable easy retreat by the public (DMC, 2009).

Once the DMC receives the warning message about an earthquake under the seabed, the Meteorological Department in turn, will send a facsimile message to the Disaster Management Centre (DMC). As soon as the DMC receives such a message it will be passed on to the general public by following the Standard Operation Procedure practiced at DMC. This is done via 77 Tsunami towers situated in the coastal areas. Before sounding the warning, the operational staff of DMC will inform about the situation to the Director General of DMC and then to the Hon. Minister of Disaster Management at the ministry. The DMC activates the Tsunami warning system mounted in towers through satellite communication.

The DMC will follow up by passing the warning message through Police (119 division), Army, Navy & Air Force, SMS alerts, a committee appointed in Tsunami vulnerable areas and through the DMC sub units established in the district divisional secretariats.

D. An Effective Early Warning System

Early warning is thestrategy that is considered as the main element in Disaster risk reduction. It helps a country's administration to prevent loss of life and significantly reduce economic losses to a minimum. 'Communication saves lives' stated Dr. Zavazava in his presentation at the World Conference on Disaster Reduction held in Kobe (United Nations, 2005). An efficient and effective early warning system comprises four elements – (1) Risk awareness: prior knowledge of the likely risk scenarios that communities face (UNISDR, 2006; Chatfield, 2013;Izadkhah, 2008). (2) Monitoring and warning service: monitoring for early signs of these risks and engaging in rapid and reliable decision-making processes for issuing early warning (UNISDR, 2006; Chatfield, 2013;Izadkhah, 2008). (3) Communication: dissemination of understandable warnings and preparedness information to those at risk (UNISDR, 2006; Chatfield, 2013;Izadkhah, 2008). (4) Response capability: knowledge, preparedness and capacity to act by all partners of the information chain (UNISDR, 2006; Chatfield, 2013; Izadkhah, 2008). Failure in any one part of the chain can result in the breakdown of the whole system (United Nations, 2005). Developing information communication technologies is needed to facilitate information sharing and dissemination. Such information must be accurate and fully compatible with the needs of developing countries.

1) Response Capacity (Communication, Human resource, Technology and Administration controls)

Response Capacity includes public reaction to the warning and the response to the disaster itself. The local population must understand the risks, respect the alert and know how to react. Education and preparatory programs play a key role, and it is essential that proper disaster management and preparedness plans are put in place,well-practiced and tested. Disaster Preparedness Plan describes the activities and measures taken in advance - before the disaster strikes to ensure an effective response, including the issuance of timely and effective early warnings and temporary evacuation (Chatfield, 2012;Jahangiri et al., 2011; Basher, 2006; Vilagran De Leon, 2000).

The community must be well briefed on the safe behaviors and practicesthat should be adopted to avoid damage and loss of property. There are five major areas that come under Response Capacity and they are,i) Warnings and Guidance Instructions Respected, ii) Evacuation Plans Developed, Disseminated to the Community and Practiced, iii) Disaster Response Plan Established, iv) Community Response Capacity Assessed and Strengthened, v) Public Awareness and Education Enhanced (Izadkhah, 2008).

2) Risk Knowledge (Administration and Human resource controls)

The risk of a tsunami comes from the combination of tsunami hazards and vulnerabilities at a particular location. Tsunami risk assessment requires systematic data collection and analysis and should take into account the dynamic nature of hazards and vulnerabilities arising from processes such as urbanization, rural landfills, degradation ofenvironment and climate changes. A Tsunami risk assessment map helps and motivates people to set up an early warning system and guide disaster preparedness, prevention and response (UNISDR, 2006; Izadkhah, 2008).

3) Monitoring and Warning Service (Human resource, Administration and Technology controls)

Most of the communities living in tsunami-prone areas are at risk of tsunamis. Locally generated tsunami waves may reach the coast in a very short time. For that reason, local communities should pay special attention to natural warning signs (Vilagran De Leon, 2000). The first warning sign that communities may receive is the tremor felt from a strong but distant earthquake; this is barely detectable when the epicenter is far away. Unfortunately, ground shocks are not a very reliable tsunami indicator, and this is subjective. There is also the possibility that the earthquake occurred on land, andtherefore, no tsunami danger exists. There have also been reports of local tsunamis, preceding which people did not notice any ground shaking. Earthquake data are generated by many different countries collaborating in an international network of seismic stations.New seismic data is compared with a Tsunami Simulation and the existing Database to estimate the probability of a tsunami, the expected wave height, and areas that would be affected. Based on this information a first warning will be issued. A second component monitors the ocean processes and determines whether a tsunami was generated. Monitoring and Warning service operates 24 hours a day (Izadkhah, 2008).

4) Dissemination and Communication (Communication, Human resource, Administration and Technology controls)

A communication method will be selected to disseminate the early warning message at the national level or the community level. Public media (radio, TV) are used to inform the general public. Additionally, warnings will be conveyed to selected institutions and persons by SMS. Special radio and Internet-based communication technologies will be applied to disseminate warnings directly to people and institutions in risk areas. There are three major themes related to Dissemination and Communication to be considered at the local level: i) Organizational and Decision-making Processes Institutionalized, ii) Effective Local Communication Systems and Equipment Installed, iii) Warning Messages Recognized and Understood (Izadkhah, 2008; Basher, 2006; UNISDR, 2006).

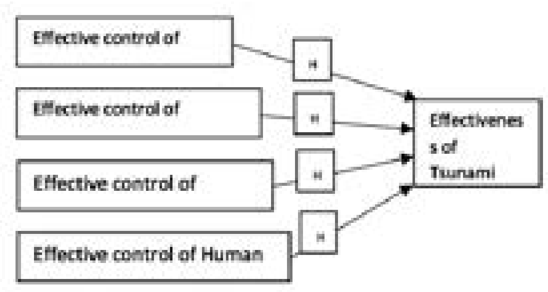

Figure 1. Conceptual framework
Source: Developed by the authors

5) Emergency Operations (Communication, Human resource, Administration and Technology controls)

Emergency Operations Centers (EOCs) are facilities set up in one location to implement the execution of three key tasks: multi-agency coordination, decision-making, and management of information (Izadkhah, 2008). An EOC is physically arranged to facilitate coordination and information-sharing among all those involved in its operations.

The EOCs normally carry out their operations using EOC SOPs and generate the information that is later disseminated to the media and the public via bulletins or through press conferences. A lack of inter-institutional coordination can lead to the duplication of effort, or give rise to gaps or voids in response and cause costly delays in decision making. The use of EOCs in conjunction with contingency plans helps emergency managers to minimize such inefficiencies (UNESCO, 2015).

By considering all the important points discussed in the previous studies (Izadkhah, 2008; Vilagran De Leon, 2000; UNISDR, 2006; UNESCO, 2015) and the inputs of the Sendai Framework (2015) on Early Warning System, the authors of this study developed four independent variables that can be described as "Effective control of Communication, Effective control of Human resource, Effective control of Administration and Effective control of Technology" to measure the dependability of an effective Tsunami warning system.

H1. Effective control of Technology has a positive impact on the effectiveness of Tsunami early warning system

H2. Effective control of Communication has a positive impact on the effectiveness of Tsunami early warning system

H3. Effective control of Administration has a positive impact on the effectiveness of Tsunami early warning system

H4. Effective control of Human resource has a positive impact on the effectiveness of Tsunami early warning system

III. METHODOLOGY

Quantitative research was conducted to meet the aim of this study, which is to identify drawbacks of the existing Tsunami warning system and identifying those elements that would improve its effectiveness in the long run. Based on the descriptive nature of the research which is dictated by the aim of this research, a quantitative research methodology was selected to test the relationship between the effective control of communication, technology, administration and human resource and an effective Tsunami warning system (Saunders, Lewis, & Thornhill, 2009). From the research objectives perspective, this research can be classified further as a correlational study also, since it attempts to discover/ establish the existence of a relationship/ association/ interdependence between the variables and support for the overall effectiveness of the system (Saunders, Lewis, & Thornhill, 2009). This is presented in Figure 01. The reliability of the research instrument (questionnaire) was tested using the reliability analysis of SPSS. The questionnaire was adjusted after calculating the Cronbach's alpha value using SPSS reliability analysis. The questionnaire was adjusted until it reached 0.80 of Cronbach's alpha value. To ensure validity at the data analysis stage, validity checks that are unique to qualitative methodologies were applied. Descriptive, interpretative, theoretical, and external validity tests were conducted to ensure the validity of the qualitative study (Kumar, 2012).

The primary data were collected from a questionnaire answered by people in the coastal areas, engineers, and designers of the warning towers/systems and management of DMC. The questionnaire consisted of 19 items to measure all four variables and their correlation with the effectiveness of tsunami warning system. The sample was selected based on the Simple Random sampling method, by ensuring each person was actually living in the coastal area and could provide reliable information. As indicated in the following table, the Population was 6,639 persons, representing three Grama Sevaka Divisions in Galle District, that are highly vulnerable to a Tsunami. Numbers were assigned to the members of all the families and then each second person was selected from 20 families out of each G.S. Division to arrive at the total 60 cases in the sample.

Table 1. Details of the Population and Sample size

District	Divisional Secretariat	GramaSevaka Division	Families vulnerable to Tsunami		No. of questionnaires	Percentage
Galle	Four Gravets		Families	Members		
		(96) China Garden 99 B	307	1993	20	1 %
		Pettigalwatta	337	1318	20	1.5 %
		99 Magalle	418	3328	20	0.6 %
Total		03	1062	6639	60	0.9 %

Source: Developed by the authors

IV. FINDINGS

Using the SPSS, the Cronbach's α value is generated for the latent factors in the hypothesized theoretical framework. This was carried out during the pilot study using seven datasets. The questionnaire items were readjusted until they reacheda Cronbach's α value of approximately 0.80 within a grouped variable set on par with the hypothesis. The least significant factors (variables) were ignored when carrying out real data collection.The Pearson correlation coefficient was calculated for each combination of the independent and dependent variables; this result is presented in Table 02. Each independent variable consists of two or more indicators. Item definition is given in Annexure 01.

Table 2.Correlations

Effective control of Technology	**Q1**	**Q2**	**Q3**	**Q4**	**Q5**	**Q19**
Pearson Correlation	1	0.150	0.314*	0.141	0.142	0.020
Sig. (2-tailed)		0.253	0.014	0.283	0.281	0.882
Effective control of Communication	**Q6**	**Q7**	**Q8**	**Q9**	**Q19**	
Pearson Correlation	1	279*	0.242	0.126	0.141	
Sig. (2-tailed)		0.031	0.063	0.338	0.283	
Effective control of Administration	**Q10**	**Q11**	**Q12**	**Q13**	**Q14**	**Q19**
Pearson Correlation	1	0.252	0.124	0.315*	0.371**	0.267*
Sig. (2-tailed)		0.052	0.345	0.014	0.004	0.039
Effective control of Human resource	**Q15**	**Q16**	**Q17**	**Q18**	**Q19**	
Pearson Correlation	1	0.468**	0.452**	0.496**	0.496**	
Sig. (2-tailed)		0.000	0.000	0.000	0.000	
N	60	60	60	60	60	60

* Correlation is significant at the 0.05 level (2-tailed).
** Correlation is significant at the 0.01 level (2-tailed).

Source: Survey data

There is a linear relationship between the effective control of technology, communication, administration and human resource and the overall effectiveness of the tsunami warning system. The influence of all four variables on the dependent variable represents a positive correlation though it is not very strong. However, the influence of independent variables on the dependent variable can be accepted as significant.

Linear regression analysis was used in hypothesis testing in this research. In this analysis the dependent variable is tested against the independent variables by looking at the model fit"ANOVA"first. The last column denotes the significance of the model ("It is the model to explain the deviations in the dependent variable")and also shows the goodness of fit of the model.

Table 3. Model Summary for H1

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.736a	0.599	0.329	1.005

Source: Survey data

Table 4. ANOVA for H1

Model	Sum of Squares	Df	Mean Square	F	Sig.
Regression	23.394	4	5.848	5.785	0.001b
Residual	35.381	35	1.011		
Total	58.775	39			

Source: Survey data

Table 03 explained that Ris 0.736 and therefore the correlation between the effective control of technology and the effectiveness of the tsunami system is positive. Thevariance explains the R Square (0.599). Table 4illustrates that the regression is statistically significant at the 0.001 level. This indicates that effective control of technology has significantly explained 59.9% of the variance in the effectiveness of tsunami warning system. Thus, the relationship between the effective control of technology and the effectiveness of the tsunami system is statisticallysignificant.Hence H1 is accepted.

Table 5. Model summary for H2

Model	R	R Square	Adjusted R	Std. Error of the Estimate
1	0.632_a	0.583	0.244	1.067

Source: Survey data

Table 6. ANOVA for H2

Model	Sum of Squares	Df	Mean Square	Sig.
Regression	30.850	4	7.712	0.001
Residual	0.000	55	0.000	
Total	30.850	59		

Source: Survey data

Table 5 explained that R is 0.632 and therefore the correlation between the effective control of communication and the effectiveness of tsunami warning system is positive. In table 6, the R Square (.583) explained the variance and the results of regression are significant at the 0.002 level. This indicates that the effective control of communication has significantly explained 58.3 % of the variance in the effectiveness of tsunami warning system. Thus, the relationship between the effective control of communication and the effectiveness of tsunami warning system is statistically significant. Therefore, H2 is accepted.

Table 7. Model Summary for H3

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	0.429a	0.184	0.109	0.683

Source: Survey data

Table 8. ANOVA for H3

Model	Sum of Squares	Df	Mean Square	F	Sig.
Regression	5.686	5	1.137	2.440	0.46b
Residual	25.164	54	0.460		
Total	30.850	59			

Source: Survey data

Table 7 explains R is 0.429 and R square is 0.184for the correlation between the effective control of administration and the effectiveness of tsunami warning system. Table 8 shows that the regression is statistically significant at the 0.046 level. This indicates that the effective control of administration has significantly explained 42.9% of the variance in the effectiveness of tsunami warning system. Accordingly, the correlationbetween the effective control of administration and the effectiveness of tsunami warning system is statistically significant. Hence H3 is accepted.

Table 9. Model summary for H4

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	1.000a	1.000	1.000	0.013

Source: Survey data

Table 10. ANOVA for H4

Model	Sum of Squares	Df	Mean Square	F	Sig.
Regression	16.644	2	8.32	7.309	.00b
Residual	42.131	37	1.13		

Source: Survey data

Table 9 shows the result of the correlation between the effective control of human resource and the effectiveness of Tsunami warning system by indicating that R and R square are the same (1.000). Table 10 explains that the regression is statistically significant at the 0.013 level. This indicates that effective control of the human resource has significantly explained 100% of the variance in the effectiveness of tsunami warning system. Therefore, the correlation between the effective control of human resource and the effectiveness of Tsunami warning system is statistically significant. Hence, H4 is accepted.

V. DISCUSSION

Based on the analysis and testing of the hypotheses on the correlation between independent variables and the dependent variable, the effective control of Technology, Communication, Administration and Human Resource factors were identified as the most critical factors (UNISDR, 2006; Chatfield, 2013;Izadkhah, 2008) affecting the overall effectiveness of the Tsunami Warning System in Sri Lanka.

During the study, it was revealed that in the 2004 tsunami disaster, most of the deaths could have been avoided if an early tsunami warning had been issuedabout 03 hours before the Tsunami waves hit the coast of Sri Lanka. This indicates clearly that the early warning message was not transmitted in time. Later on in 2005, a few incidents occurredfrom time to time, when some tsunami warning towers issued false warnings that led to some bad situations (Samarajiva, 2005). This happened due to the malfunctioning of some towers.

It is important to note that among all four critical factors, the effective control of human resource is identified as the most important aspect to be considered in improving the effectiveness of the tsunami warning system in Sri Lanka. This finding supports the outcome of an earlier study that also identified the same elements (Chatfield, 2013;Basher, 2006).The staff at the operational level in the management of a disaster is supposed to play a vital roleby managing all other aspects such as administration, technology and communication. For example, effective communication prevails only if the respective staff receives, interprets and responds to the international warning messages by disseminating it to the public within the predetermined timeline. Effective control of the human resource is the foundation on which the other three factors such as administration, communication and technology rest.

People presently tend to use mobile phones and the Internet more often to get news updates on the imminent disasters, while the media also play a timely and active part in responding to same. Both mass media and social media (Sorensen, 2000) expect the authorities to issue the necessary warningand people are now getting used to checking on their phones frequently during a disaster period. This finding shows that corrective actions have been taken by the government,was and this has been pointed out by research (Samarajiva, 2004). However, the telecommunication systems may easily get disrupted when disaster strikes as experienced recently during flood situations.This supports the research findings of Basher (2006). The electricity supply may also get disrupted leading to communication failures during a disaster.

Further, Tsunami warning towers do not always send accurate messages sometimes as experienced during some of the drills. The local government authorities frequently provide tsunami drills and evacuation mapsso that people will become familiar with the preparedness measures and evacuation routes; but there does not appear to be a high level of understanding (Gregg et al., 2006; Colombage,

2006) and therefore,it is important to encourage community participation in disaster response further (Kogami, 2007). The continued maintenance of tsunami towers is necessary as it is the most critical element in the tsunami warning system. According to previous research (Kogami, 2007; Basher, 2006; Gregg et al. 2006),different countries may use different types of Tsunami warning systems with different technologies. Currently,the most advanced and efficient Tsunami warning system is the Pacific system that serves theInternational Tsunami Warning Centerthat networks with over two dozen member countries in the Pacific and Indian Ocean Basins as well as theCaribbean.

The administration and the staff who are working in tsunami-prone areas need to be trained and strengthened further in numbers as well as with the requisite tools. Though no massive tsunami warning has been receivedin years, it is nevertheless important to continue with training and knowledge building since Sri Lanka continues to be vulnerable to earthquakes and tsunamis (DMC, 2009).

VI. CONCLUSION

This study intended to explore the importance of communication, technology, administration and human resource factors on running an effective tsunami warning system in Sri Lanka. As per the findings of this study, it was found that Human resource is more critical than other factors to run an effective tsunami warning system. However, the other three factors also contribute significantly to an effective tsunami warning system, though they work on top of the human resource factor, which acts as the foundation for all of them. The findings of this study could contribute to more effective management of the tsunami warning system as they point out how to improve the response capacity of government agencies, intergovernmental organizations and other international organizations. Technology, Communication, Administration and Human resource are the critical factors to consider in developing a new framework to maintain a proper tsunami warning system. Further, this supports the Sri Lanka government to extend its existing strategies and measurements on tsunami response.

This research directs future researchers to measure the efficiency of the tsunami warning system as that will enable an increase in the speed and accuracy of issuing warnings in future. Also, it is important to explore to what extent people have taken mitigation and preparedness measures by learning from the lessons of the 2004 Tsunami. The level of understanding regarding the consequences of the tsunamiis still not adequate among the communities. Therefore, future research can come up with strategies to improve the community's understanding of Tsunamis and participation in preparedness measures.

Annexure 1. Description of items

Q1	Availability of Mobile technology
Q2	Warning received from Internet technology
Q3	Available social media and technology
Q4	Delivery speed
Q5	Nearby tsunami warning towers and technology
Q6	Accuracy and the pitch of the message
Q7	Delivery in three languages
Q8	Accuracy of the message during drill
Q9	Evacuation directions in three languages
Q10	Training programmes from the government
Q11	Sufficient education on preparedness by the government
Q12	Safety of the designated locations to which people should evacuate
Q13	Installation of adequate signage indicating evacuation routes
Q14	Maintenance of tsunami towers by the staff
Q15	Government agencies to conduct frequent training and drills
Q16	Importance of drills and community participation
Q17	Commitment of the staff who conduct drill
Q18	Staff on duty on 24/7 basis in the tsunami vulnerable areas
Q19	Satisfaction level of the system

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