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Excess load on ships and its effects on stability performance in Nigerian waterways

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Abstract: This research has been carried out to examine the impact of excess shipload on ship performance and stability. The objectives are to analyse the trend of sinking ships in Nigeria occasioned to ship excess load. Secondly, to examine the relationship between load size and ship stability and identify the various factors responsible for ship instability. Data were gathered from operators in the maritime industry using structured questionnaires and interviews as data collection instruments. Four significant stakeholders that can provide information based on their involvement across three strata of management, operation and general cadre were sampled. Pearson Moment Correlation technique has been used to examine the relationship between load size and ship stability, and Analysis of Variance-one was used to identify the various factors responsible for ship instability. The Pearson Moment Correlation technique analysis shows a significant relationship between load size and stability. The analysis of variance revealed that "hogging and sagging" is the most crucial factor among the factors identified for ship instability. It has the highest value of F-ratio of 17.837 with a significance at $p<0.05$. The research concluded that resultant accidents from the instability of vessels are caused majorly by hogging and sagging of vessels, and notably, the occurrence is much in riverine areas in Nigeria. Loading the vessel has a relationship with the vessel's stability, as depicted from the analysis in this research. Recommendations on how to enhance stability through boat construction, shipbuilding, loading and passenger's use of life jackets, among others were made.

Keywords: excess, waterways, load, Nigeria, ship and stability.

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1. Introduction

Ships are the objects used in maritime transport to convey goods on seas, oceans and other water bodies that can allow it from one geographical location to another. There are different types of ships primarily based on the type of cargo they carry, and often, oceanic vessels usually have larger earning carrying capacity to defray costs and accrue economies of scale. According to Maritime Newzealand (2011), ship stability is the ability of a vessel to maintain an upright position even when under external force. Ship stability is achieved by calculating the force of buoyancy which must be balanced with weight and pressure from the hull, equipment, fuel, stores and load. Themelis et al. (2018) noted that stability is crucial for a ship's performance and is determined even during the design of vessels. According to Wei (2016), the forces combating ships while in motion resulted in stability failures. In order words, understanding the basic necessity to guide against this mishap is critical for marine entrepreneurs.

Ships continue to experience variability instability due to differences in waves, currents, and winds. The three types of stability are initial, overall, and dynamic. It can be confirmed that level or angle of inclination, ability to resist capsizing in a loading condition and work done in healing differentiate them one after the other. Wei (2016) expressed two types of intact stability failure total and partial intact stability. He maintained that intact stability failure arises as a result of capsizing of ships and the partial instability roll angles that occur in ship operations which can cause damage to the vessel. Ships are put into danger by loading stress and many vessels have grounded as a result of instability. Ships encountered *"hogging and sagging"*, which used to cause various types of stress on the vessel. Ships will always experience variance instability because, at different times, the laden weight is different. For instance, ships will experience stability when fully laden, when fuel has reduced, half laden, and on different water densities. According to Clerk (2002), seafarers are responsible for the stability and strength of their vessels. The principles of stability go hand in hand with engineering, and it is a link in the study of Nautical Science and Marine Engineering. In order to balance the buoyancy and weight, which are interacting forces in ship stability, rigorous mathematical calculations with detailed plans and accuracies must be guarranteed. The essence of ship stability is crucial for ship manoeuvring, ship loading and unloading, and ship ballasting, among other safety precautions (Chandra, 2018). Ship stability precautions ensure the safety of the crew members, the safety of the ship and the safety of the cargoes. The maritime industry, over time, recognised the effect of overloading vessels, and as such, some countries like Britain declare it a criminal offence if a vessel is overloaded (Clerk, 2002).

Therefore, a British politician (Samuel Plimsoll) reassured people to ensure that the illegal loading of ships would stop in Britain. This decision later led to the International load line convention of 1930, and the convention enacted that a ship's draft and permissible load line must be postioned with marks on the vessel. Ship stability is a concern for insurance companies engaging in maritime covers. The marine surveyors and classification societies have a severe role in ship stability, and their roles are to ensure that the ship is seaworthy and safety standards are not compromised. Stability is assured by ensuring that the ship's Centre of Gravity (CG), ship's Centre of Buoyancy (CB), and ship's Meter Centre (MC) are well calculated. There are stipulated load line rules for different water. The Summer (S) load line has been used as the maximum permitted draft. Others are Tropical Forest (TF), Fresh Water (F), Tropical Water (T), Winter (W) and Winter North Atlantic (WNA).

2. Literature review

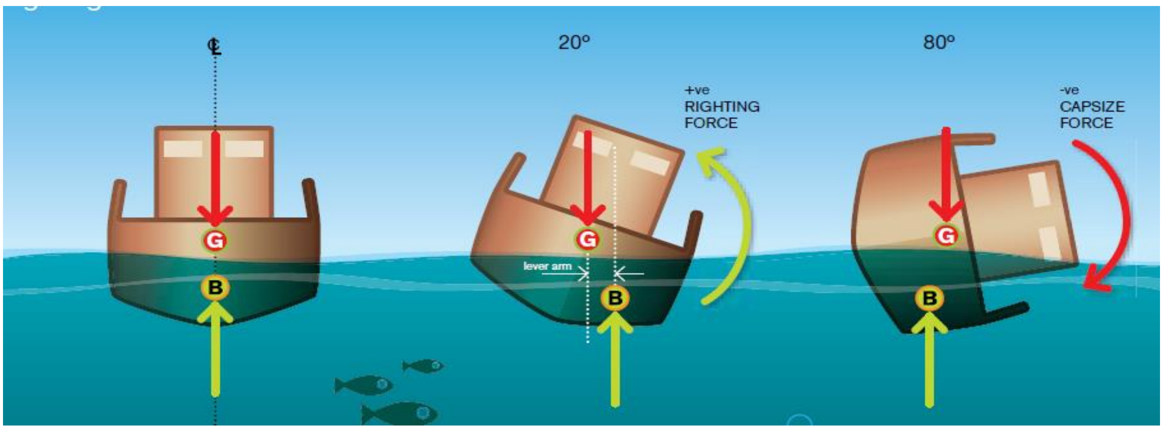
According to Barrass and Berret (2006), stability can exist when a vessel is rolling or trimming; it is the ability to remain in a stable equilibrium or otherwise. Hence there is a link between Ship Stability and Ship Motion. Stability can also exist in ship structures via the strength of the material from which the ships are built. Ship's material may be stressed or strained and not return to its initial form, thereby losing its strength of stability. Hence there is a link between Ship Stability and Ship Strength. Another type of Ship Stability that deals with course-headings and course keeping are called Directional Stability. The one most important thing for the safety of ships is stability. Stability is crucial for the design, construction, and loading of vessels throughout their life span. Ari (2009) explained that stability is concerned with subjection of a vessel to certain inclination on water and its ability to return to its balanced position after being heeled by an external force, such as wave or the strain from its gear or the wind.

There seems to be a constraint in the shipping trade where the maximum revenue for ship owners is to load vessels to earn through the ship's maximum Earning Carrying Capacity as against the permissible drafts, especially in international voyages. Loading vessels beyond the freeboard is not allowed, but to generate revenues, many used to circumvent the standard procedures to load vessels beyond permissible drafts. Ballasting is about the liquid or solid placed on the ship to increase its draft, change the trim, regulate the stability, or maintain stress loads within acceptable limits (National Research Council, 1996). The problem is that, while ballasting is meant to stabilise the vessel, the discharge of ballast water has been a serious concern. The discharge of ballast water into the ocean or river has can affect the living organism and cause other environmental effects. Wind and other environmental conditions can cause ships to sway, roll or pitch. In any of these conditions, if proper navigation and safety precautions are not maintained; crew, cargo, and ships are in danger (Parok & Umeda, 2006). The stability conference STAB 2012 identified the cargo shift as one of the challenges of ship stability

With the level advancemenpt of available technology to predict weather, to determine the waves by wind's movements and quality training receieved by the crew; ship accidents still occur. In other words, the indication is that advancement in technology can fail. According to Hasanudin and Jeng (2015), IMO is the regulator of maritime industry almost all over the world and it provides guidelines for ship's intact stability, bulkhead arrangement, installment of bilge keel, usage of U-Tank Stabilizer and application of IMO's stability requirements. IMO used to conduct survey on ships that are safely navigated and those that are involved in one challenge or the other for the purpose of determining the best way to promulgate standard practice for safety and stability of vessels**.** There are 160 accidents caused by collision, 20 caused by contact, 745 caused by foundered, 199 caused by fire, 85 caused by hull damage, 7 caused by missing, 109 caused by machinery, 6 caused by piracy, 312 caused by wrecked and 30 caused by miscellaneous. 45% ship's accidents caused by foundered in bad weather were due to extreme ship motions caused ship to capsize (Hasanudin and Jeng, 2015).

Newzealand (2011) noticed changes in stability of vessels as depicted in the Figure 2.1 below. In Figure 2.1, the first vessel by the left is upright because the forces from G and the reaction from B upward balances at the centre line of the vessel and as such the vessel is in stable position. The loading position on the vessel was well calculated and positioned to achieve the level of upright stability. In the second diagram, if the load is shifted and the buoyancy changed at 20^0 for instance, one side of the vessel becomes too heavy , the ship may finally capsize. There is a misalignment between G and B at this point. Lastly on the third diagram, at 80^0 the ship, the centre of gravity moves higher and there will be roll of severe instability which will sink the vessel.

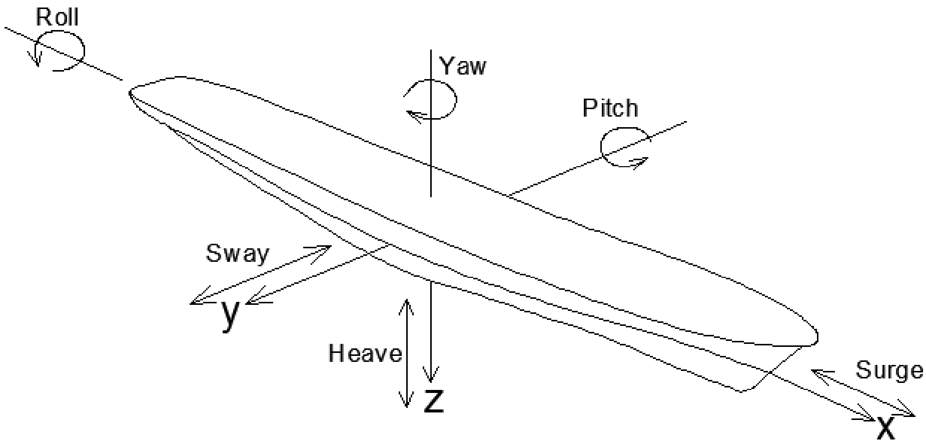
Figure 1: Changes in vessel's stability



Source: Maritime Newzealand (2011)

The forces and direction of movement in the process of either loading or weather challenge described in Figure 2. Ideally, ship owners prefer to complete all voyages with cargo. However, many trades and voyages require passage without cargo or in a light-cargo condition. For example, a crude oil tanker or iron ore carrier typically transports a single cargo load between two ports, it then returns to its point of origin or another port without cargo. In this empty condition, the vessel requires ballast to operate safely- a condition referred to as being "in ballast. In contrast, a container ship may be fully loaded between two ports but may thereafter proceed with only a partial load between the next two ports. This vessel, therefore, sails with some cargo and some ballast, that is, "with ballast." Since fuel costs usually increase with displacement, ship owners tend to use as little ballast as is necessary for the ship's safe, efficient passage when operating either with ballast or in ballast (National Research Council, 1996).

Figure 2: Directions of forces on ships



Source: Hasanudin and Jeng (2015)

The rotatory forces on the ship as shown in the Figure 2 are what stability standards and measures guide against. The different shifts in position can be seen at the centre to yaw, rolling at the centre in forward direction is pitch, the rolling perpendicular at the aft or rear is rolled, the surge is immersion from the front part and heave is condition of moving vertically downward at the centre while sway is shift experienced from the starboard side.

Ship's stability and forces

Barrass and Berret (2006) reported that the solution of many of the challenges concerned with ship stability involves an understanding of the resolution of forces and moments. Meanwhile, a force has been defined as any push or pull exerted on a body. The S.I. unit of force is Newton and one Newton being the force required to produce in a mass of one kilogram an acceleration of one metre per second. When considering a force, the following points regarding the force must be known viz:(a) the magnitude of the force (b) the direction in which the force is applied and (c) the point at which the force is applied. The resultant force is produced when two or more forces are acting at a point, there combined effect can be represented by one force which will have the same effect as the component forces. Such a force is referred to as the “resultant”, and the process of finding it is called the 'resolution of the component forces'. The resolution of forces occur when resolving forces acting towards a point will have the same effect as an equal force acting away from the point, so long as both forces act in the same direction and in the same straight line. Thus a force of 10 Newtons (N) pushing to the right on a certain point can be substituted for a force of 10 Newtons (N) pulling to the right from the same point. Moreover, resolving two forces which act in the same straight line and in the same direction the resultant is their sum, but if the forces act in opposite directions the resultant is the difference of the two forces and acts in the direction of the larger of the two forces. Similarly, two forces act in parallel directions, their combined effect can be represented by one force whose magnitude is equal to the algebraic sum of the two component forces, and which will act through a point about which their moments are equal. Moreover, *moment of a force* is a measure of the turning effect of the force about a point. The turning effect will depend upon the following: (a) the magnitude of the force. (b) the neasurement of the lever to which the force acts on (c) The magnitude of the moment is the product of the force and the length of the lever.

The Meter Centric height (G.M) is very important to ship stability. For example, different ships have different stability criteria as captured in Table 1. Metacentric height (GM) is the vertical distance between the Centre of Gravity (G) and the Metacentre (M). If M is above G the vessel will want to stay upright and if G is above M the vessel will want to capsize. i.e. GM positive is Stable, GM negative is Unstable**.**

Table 1: Types of ship and stability allowance

Types of Ship	Stability when loaded
General cargo	0.30-0.50 m
Oil Tanker	0.50-2.00 m
Double hull super tanker	2.00-5.00 m
Container Ship	1.50-2.50 m
Ro-Ro vessels	1.5 m approximately
Bulk ore carriers	2.3 m

Source: Barrass and Berret (2006)

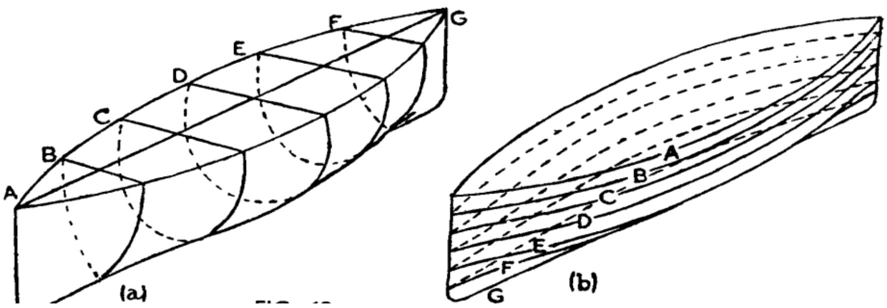
When a tank is completely filled with liquid, the liquid cannot move within the tank when the ship heels. For this reason, as far as stability is concerned, the liquid may be considered as static weight having its centre of gravity at the centre of gravity of the liquid within the tank.

The buoyancy forces are calculated for ship designs with Simpson's rule. Simpson's Rules may be used to find the areas and volumes of irregular figures. The rules are based on the assumption that the boundaries of such figures are curves which follow a definite mathematical law. When applied to ships they give a good approximation of areas and volumes. The accuracy of the answers obtained will depend upon the spacing of the ordinates and upon how near the curve follows the law. The first rule assumes that the curve is a parabola of the second order. A parabola of the second order is one whose equation, referred to co-ordinate axes, is of the form $y = a0 + a1x + a2x^2$, where $a0$, $a1$ and $a2$ are constants.

$$\text{Area of figure} = \int_0^{2h} y\,dx$$

However, ships are uniformly built about the centre line, it is only paramount to calculate the area of half the water-plane and then double the area found to obtain the area of the whole water-plane. The Simpson's second rule can be used to find the area when the number of ordinates is such that if one be subtracted from the number of ordinates, the remainder is divisible by 3. The third rule of Simpson is used to find the area between two consecutive ordinates when three consecutive ordinates are known. The rule states that the area between two consecutive ordinates is equal to five times the first ordinate plus eight times the middle ordinate minus the external ordinate, all multiplied by 1/12 of the common interval (Barret & Derret, 2006). Pursey (1996) showed in diagrams (Figure 3a and 3b below) that the stability is about balancing the sectioning of a ship.

Figure 3a & 3b: Ships area and volume determination



Source: Adapted from Pursey (1996)

Figure 3a reveals the transverse section of the ship and 3b the longitudinal section of the ship. The area of a water-plane by Simpson's Rule is the half-breadth of ordinates. The total moment area of any point can be derived with the understanding of its half ordinate. However, when there is division of total moment by total area, the centroid of the area can be derived.

The density on draft of ship increases when the water decreases and vice versa. However, if increase change is not in proportion and its calculation is more complicated. The way to go about it is giving each vessel a "Fresh Water Allowance" when her load lines are assigned. This allowance is approximately the amount by which the ship will decrease her draft on going from Fresh water to salt water (Pursey, 1996). Pursey (1996) also maintained that; ordinary load line shows the draft at which a ship can safely remain at ocean. In the smooth water of harbor or river, it is better to load the ship a little below these marks, provided that she rises to them when or before she reaches the open sea. For instance a ship loading in a harbor of Fresh water could submerge her load line by the amount of her fresh water allowance, because she would rise to her proper load line on reaching salt water.

3. Methodology

There are 101 shipping companies in Nigeria as of 2008. In Lagos and Port Harcourt, the population of shipping companies that are perhaps involved in this study are as follows:

Blue Star Hipping Ltd, 3MO Shipping & Trading Company Limited, Antwerp Shipping Nigeria Limited, Ayoolas Cargo and Services, China Shipping and Container Line (CSC), P&O Nedloyld and Tran Oceanic Shipping. Many of these companies do not own ship, but they are charterers in many cases.

Table 2: Sample population

	Niger Dock	Insurance	Ship-owners	Captain	Total
Management	32	21	18	4	75
Operation	14	46	48	3	111
General	32	62	62	0	156

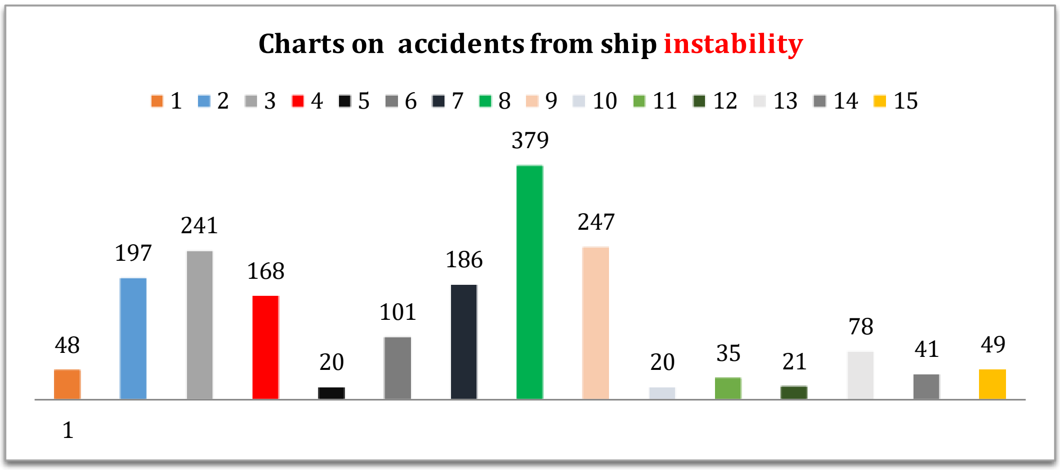
Source: Authors' computation (2020)

Table 3 shows the population of the respondents. Majorly, regarding ship stability and direction-the shipyard is concerned, the insurance company, the ship owners and captain of the vessels. Four major stakeholders that can provide information based on their involvement across three strata of management, operation and general cadre were sampled.

4. Result and discussion

This segment deals with the result and analysis of data collected in the field. In this case, each objective that solved corresponding research questions is looked into and analysed. The first objective which is to analyse the trend of sinking ships in Nigeria. The descriptive analysIs is histogram chart. The accidents rate per annum from 2006 to August, 2020 were also analysed.

Figure 4: Histograms of accidents from boat's instability in Nigeria

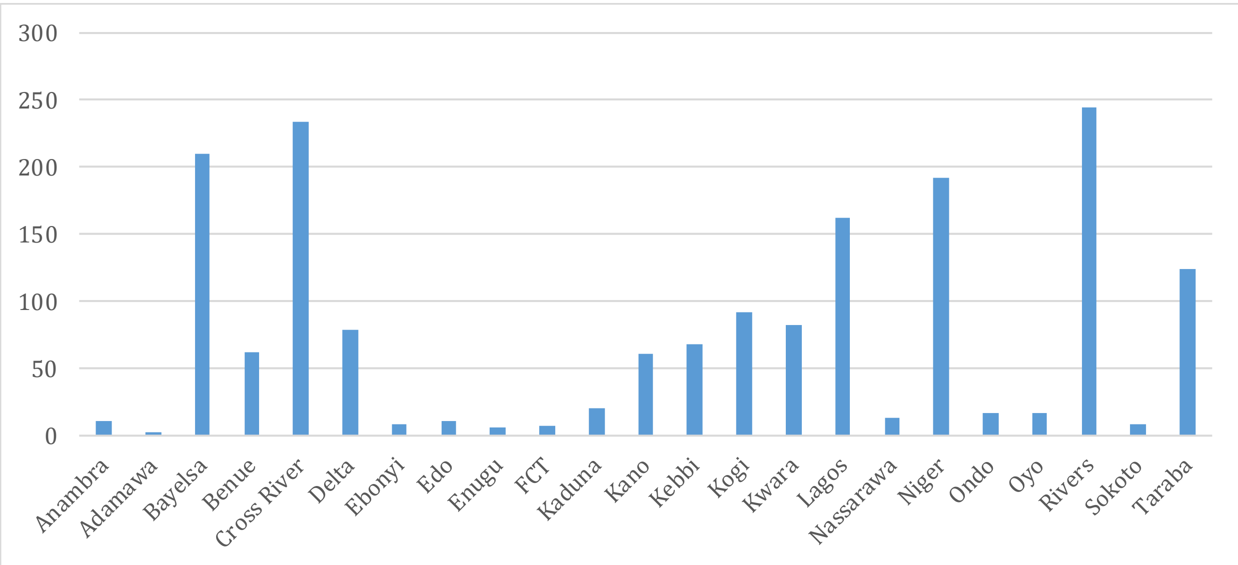


Source: Authors' computation (2020)

Figure 4 above shows the instability of boats resulting to a number of accidents in Nigeria from year 2006 to year 2020. The year 2013 was the worst incident of instability of ships till date as it recorded 379 accidents and only reduced by 32 in 2014 subsequent year. 241 cases of accidents were recorded in 2008, and the preceding year of 2007 was 197.The year 2011 recorded 101 accidents and 2018 recorded 78 accidents. Though the data for 2020 stopped at August, the recorded incidents have been up to 49. The year 2006, 2019 and 2016 respectively have 48, 41 and 35 numbers of accidents in Nigeria. The lowest recorded are in 2010, 2015 and 2017 with respective numbers of 20, 20 and 21 accidents.

Figure 5 below expresses the presentation of boat accidents resulting from vessel's instability in Nigeria from year 2006 to August, 2020.

Figure 5: Boat instability accidents in Nigerian states



Source: Extrapolated data from Ukoji and Ukoji (2015)

Examining the graph in Figure 5, the descending order of ranking for boats' instability accidents are as follows: Rivers State is leading with second position by Cross River state, the third by Bayelsa state, fourth by Niger, Lagos State came sixth, Taraba and Kogi came seventh and eighth positions respectively. Kwara State came ninth and the tenth position to Delta. Benue state came eleventh while Kaduna and Ondo States came twelfth and thirteenth positions respectively. Oyo State came fourteenth among the states for the boat accident mishap and Anambra State came fifteenth position.

Edo is slightly higher than Nassarawa with sixteenth position. Eboyin and Sokoto States nearly had the same figure with the two coming seventeenth and eighteenth positions respectively. FCT, Enugu and Adamawa are the least states on the account of boat accidents in Nigeria. From this analysis, it is obvious that, states that are closer to the sea like Rivers, Cross River, Bayelsa, Niger and Lagos are at the fore front of boat mishap in Nigeria. Therefore, efforts must be taken to reduce the menace through various measures.

The second objective of this study examined the relationship between load size and ships stability. In order to examine this, Pearson Product Moment Correlation analysis was used. If a ship floods, the loss of stability is caused by the increase in *KB*, the center of buoyancy, and the loss of water plane area - thus a loss of the water plane moment of inertia - this decreases the metacentric height. This additional mass will also reduce freeboard (distance from water to the deck) and the ship's angle of down flooding (minimum angle of heel at which water will be able to flow into the hull). The range of positive stability will be reduced to the angle of down flooding resulting in a reduced righting lever. When the vessel is inclined, the fluid in the flooded volume will move to the lower side, shifting its center of gravity toward the list, further extending the heeling force. This is known as the free surface effect. There are different types of ship and the stability varies according to different size.

Based on the responses gathered from the respondents on load size(s) the followings are noted in the analysis:

a) *Ships and Boat without cargo*

The relationship between the ship and no cargo onboard in anaylsed thus:

Table 3: Load size and Stability relationship (No cargo)

Correlations

		loadssize	**stability**
Loadssize	Pearson Correlation	1	.063
	Sig. (2-tailed)		.474
	N	132	132
Stability	Pearson Correlation	.063	1
	Sig. (2-tailed)	.474	
	N	132	132

Source: Authors' computation (2020)

Table 3 shows the Correlation Analysis of relationship between load size and ship stability. Examining the table 3, there is no significant relationship between load size and stability for ships/boat as the case may be. The result for correlation analysis shows correlation value of 0.474 which is greater than acceptable 0.05. Therefore, the null hypothesis will be rejected and alternate hypothesis upheld.

In this case, it has been revealed that, cargo must be onboard vessel to maintain its balance and this is the essence of ballasting. If a vessel gets lower in the water, from loading, too much weight is experienced and likely that its freeboard is reduced. However, when the vessel then rolls, the deck edge goes underwater sooner and reduces the righting lever more quickly. The effect is to reduce the range of stability safety (meaning the vessel capsizes sooner at a smaller angle of roll).

b) *Loaded below load line*

When a ship loads below the required load line; the result of the relationship between the ship and stability is as indicated in the table 4 below.

Table 4: Correlations between ship's stability and load for loading below load line

Correlations

		loadssize	**stability**
Loadssize	Pearson Correlation	1	.134
	Sig. (2-tailed)		.124
	N	132	132
Stability	Pearson Correlation	.134	1
	Sig. (2-tailed)	.124	
	N	132	132

Source: Authors' computation (2020)

The table 4 above shows the correlation that there is no correlation between load size and stability of ship with the p>0.05. The correlation value at two-tailed test was 0.124 which is showing 0.134 level of relationship. Since it was not significant, there is no need to go further in the analysis. However, a careful observation reveals that, this is a bit better than when there was no load onboard the vessel.

c) *Load as required by load Line*

This part examines the stability when the load is at the required load line of the vessel.

Table 5 presents the result of the relationship between the load size and stability as indicated below. In this case, the correlation was significant with p<0.05. The p-value of 0.002 is less than 0.05. Therefore, there is positive relationship between load size and vessel's stability.

Table 5: load size and vessel's stability using load line

Correlations

		loadssize	**stability**
Loadssize	Pearson Correlation	1	.265**
	Sig. (2-tailed)		.002
	N	132	132
Stability	Pearson Correlation	.265**	1
	Sig. (2-tailed)	.002	
	N	132	132

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

Source: Author's computation (2020)

This shows that vessel must load according to load line if stability is to be maintained.

Table 6 shows the relationship between stability and when the load is slightly above the load line. The implication and result of such loading on stability can be seen in this regard.

Table 6: Above load line loading and stability

Correlations

		loadssize	**stability**
Loadssize	Pearson Correlation	1	.218*
	Sig. (2-tailed)		.012
	N	132	132
Stability	Pearson Correlation	.218*	1
	Sig. (2-tailed)	.012	
	N	132	132

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

Source: authors' computation (2020)

The correlation value in the above Table 6 is 0.012 which is above the acceptable 0.05 level of significance therefore; the null hypothesis here will be rejected.

The third objective is to identify the various factors responsible for ship instability. This is examined with the aid of analysis of variance-one way. The following factors have been identified base on the responses from the respondents:

a) Improper loading
b) Sea waves
c) Hogging and Sagging H&S (means the inward bending and outwarding bending of ship due to moment rotation)
d) Ingress (a situation whereby water has access into the vessel)

Looking at the factors, the ANOVA is able to analyse the responses as seen in the Table 7.

Table 7: ANOVA for identified factors

ANOVA						
		Sum of Squares	**df**	**Mean Square**	**F**	**Sig.**
Hogging & Sagging	Between Groups	13947.679	30	464.923	17.838	.000
	Within Groups	2632.382	101	26.063		
	Total	16580.061	131			
Sea Waves	Between Groups	8059.145	30	268.638	.941	.560
	Within Groups	28832.492	101	285.470		
	Total	36891.636	131			
Ingress	Between Groups	12190.190	30	406.340	5.344	.000
	Within Groups	7679.530	101	76.035		
	Total	19869.720	131			

Source: Output of Analysis (2020)

The careful observation of Table 7 above revealed that *Hogging and Sagging* is the most crucial factor among the factors identified for ships instability. It has the highest value of F-ratio of 17.837 with significance $p<0.05$. Conversely, sea wave is not significant to causing ships' instability, with p value greater than 0.05. The indication here is that the sea waves may not necessarily be a factor within the inland water ways specified by the respondents to cause instability of ships in Nigeria waters. Ingress is the next factor that is actually the second factor to be responsible for instability of vessels. It has F-ratio of 5.334 which is significant at *p*-value less than 0.05.

The trends of accidents for ships and boat were monitored and the concerned states were given their respective scores of accident rate. It was observed that riverine areas or states are prone to accidents from the occurrences of accidents across the selected states. Ship without cargo causes instability on water as indicated by the correlational analysis using the Pearson Moment Correlation Coefficient. Moreover, examining the laden the vessel with cargo below load line, there was no correlation between load size and stability of ship with the $p>0.05$. However, using the load line to gauge the loading satisfied the buoyancy and stability of the vessel. Therefore, there is positive relationship between load size and vessel's stability. Any loading that is above the load line is not good for loading on board as indicted with negative effects in the analysis. Using the analysis of various to determine factors that are responsible for instability of vessels, it was realised that hogging and sagging has the highest percentage with the F-ratio of 17.838 and ingress the second with F-ratio of 5.344.

5. Conclusion and recommendations

The resultant accidents from the instability of vessels are caused majorly by hogging and sagging of vessels, and notably, the occurrence is much in riverine areas in Nigeria. Loading the vessel has a relationship with the vessel's stability, as depicted from the analysis in this research. The load line is crucial to the loading of vessels and all the boats plying the various Nigerian inland waterways to ensure that they follow the rules strictly so as not to record incessant mishaps of boat accidents in the country.

a) There should be regulations for all the boat operators to make use of load line for both goods and passengers to curb the number of accidents on our waterways

b). Life jacket must always be worn by both operators and passengers of vessels

c) The boat and ship building or repair must be appropriately regulated to cushion the effects of ingress in our waterways

d) Ships cannot perform better when the loading is more than the capacity of the engine, therefore the engine should be commeasurable to load the ship is meant to carry

e) All the riverine areas in Nigeria like Niger, Rivers, Bayelsa, Lagos, Cross River States are to put up measures to curtailing ship or boat accidents arising from the instability of vessels

f) Taraba, Kogi and Kwara states in the Northern part are to work on enabling laws to curtail activities of boat or ship instability in riverine areas or canals in there states.

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