An analytical study of the distribution of fatal ocean drowning by tidal phase and state in the Western Cape

By

Charlotte Roos

Division of Emergency Medicine

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Supervisor: Dr Daniel Jacobus van Hoving

Co-Supervisor: Dr Colleen Saunders

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DECLARATION

By submitting this dissertation electronically, I, Charlotte Roos, declare that the entirety of the work contained herein is my own, original work, that I am the sole author thereof (save to the extent explicitly otherwise stated), that reproduction and publication thereof by Stellenbosch University will not infringe any third-party rights and that I have not previously in its entirety or in part submitted it for obtaining any qualification

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GLOSSARY

Bathometry:	The study of water depth in relation to sea level or water surface.
Drowning:	The process of experiencing respiratory impairment from submersion/immersion in liquid and may be categorized as fatal, non-fatal with morbidity or non-fatal without morbidity.
Ebbing tide:	The period 1.5 hours after high tide until 1.5 hours before low tide.
First quarter moon:	The moon is one-half illuminated by the sun.
Flood tide:	The period between 1.5 hours after low tide up to 1.5 hours before high tide.
Full moon:	The phase of the moon in which its whole disc is illuminated.
High Tide Slack:	It is the 1.5 hours on either side of High Tide
High tide:	The state of the tide when at its highest level.
Last quarter moon:	The moon is one-half illuminated by the sun. Occurs when the moon's illumination is decreasing.
Low Tide Slack:	It is the 1.5 hours on either side of Low tide.
Low tide:	The state of the tide when at its lowest level.
Neap tide:	A tide just after the first or third quarters of the moon when there is least difference between high and low water.
New moon:	The phase of the moon when it first appears as a slender crescent, shortly after its conjunction with the sun.
Normal tide:	The state of the tides in between spring and neap tide.
Spring tide:	A tide just after a new or full moon, when there is the greatest difference between high and low water.
Tidal phase:	Neap, spring or normal tides.
Tidal range:	The vertical distance between mean sea level and the peak high or low sea height in a 12-hour cycle.
Tidal state:	Classified as high or low tide slack, ebbing tide or flood tide.
Tide:	The alternate rising and falling of the sea, usually twice in each lunar day at a particular place, due to the attraction of the moon and sun.

ABBREVIATIONS

EMS	Emergency Medical Services
HREC	Health Research Ethics Committee
ICD	International Statistical Classification of Diseases and Related Health Problems
ILCOR	International Liaison Committee on Resuscitation
ILS	International Lifesaving Federation
IQR	Interquartile Range
NSRI	National Sea Rescue Institute of South Africa
SA	South Africa
SD	Standard Deviation
STROBE	Strengthening the Reporting of Observational Studies in Epidemiology
WHO	World Health Organization

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PART A: LITERATURE REVIEW ON FATAL, UNINTENTIONAL DROWNING

Introduction

The World Health Organization (WHO) has identified drowning as a neglected, yet preventable, public health threat that claims the lives of more than 320 000 people per year globally.[1] . Drowning is the process of experiencing respiratory impairment from submersion/immersion in liquid and drowning outcomes should be categorized as fatal, non-fatal with morbidity or non-fatal without morbidity.[2] The drowning process can be interrupted by rescue at any time and can therefore be associated with full recover (no morbidity) or a range of neurological and cardiac sequelae due to hypoxemia.[3] Furthermore, van Beeck et al. (2005) recommend that the following terms should be avoided: 'near drowning', 'dry or wet drowning', 'secondary drowning', 'active and passive drowning', and 'delayed onset of respiratory distress', as they are confusing and lead to under-representation of the burden of drowning.[2] The simplified definition above has therefore been implemented to reduce confusion and improve reporting efficacy. By definition, drowning victims all have some respiratory impairment due to the airway's exposure to a liquid. This literature review will provide a brief overview of the physiology of drowning and the drowning chain of survival, before discussing the global and local epidemiology of drowning. This is followed by a brief introduction to ocean tides and currents, and how they relate to fatal drowning in the ocean.

The physiology of drowning

The drowning process begins with immersion (upper airway is above water) or submersion (upper airway is below water level) in a liquid medium, either voluntarily or involuntarily.[4] The initial responses may include panic and sympathetic activation due to a fear of drowning, breath-holding, a cold shock response and diving response.[4] These responses are commonly accompanied by the struggle to stay above water and the loss of normal breathing patterns. [4] [5]

Breath holding is an early response to either immersion or submersion. It is characterised by an "easy going" phase that lasts approximately 60-90 seconds.[4] This is followed by the "struggle phase" characterised by involuntary inspiratory muscle contractions, and the end of the breath hold response when the breaking point is reached and respiratory drive over rides the breath hold response.[4]

Most drowning incidents occur in water that is colder than 35°C and therefore trigger the cold shock response upon immersion or submersion.[4] The cold shock response is a sympathetic response initiated by cold receptors in the skin and peaks in water around 10-15°C. [4] It is characterised by increased respiratory drive that results in gasping and hyperventilation, as well as increased cardiac output, peripheral vasoconstriction, and hypertension.(4) This results in increased metabolic activity and a reduction in breath hold time. (4) The diving response is a powerful autonomic response triggered by apnoea and facial immersion. It is characterised by both sympathetic and parasympathetic activity and results in peripheral vasoconstriction, hypertension, and bradycardia.(4) Upon submersion in cold water, autonomic conflict may arise due to simultaneous parasympathetic stimulation of the diving response in conflict with sympathetic activation due to the cold shock response and this increases the risk of arrhythmias.(4)

The primary physiological consequence of drowning is hypoxemia and hypoxia. Hypoxemia leading to cerebral anoxia, loss of consciousness and eventual cardiac arrest, is the primary cause of drowning mortality and morbidity during non-fatal drowning.(4) Submersion duration is shown to be the strongest predictor of outcome.(4, 6) (7, 8) Favourable outcomes are associated with submersion of less than five minutes, shorter emergency medical service (EMS) response times, and salt water rather than fresh water submersion.(8) Interestingly no outcome difference has been noted with water temperature nor victim age,(8) despite the fact that cerebral metabolic rate decreases by 5% for every degree Celsius below 37°C.(9)

The drowning chain of survival

Drowning is a progressive process following immersion or submersion in a liquid. After assessing the best available evidence and evaluating prior models, Szpilman et al (2014) developed the "drowning chain of survival".(3) It has been put forward as a guide for both lay and professional rescuers (Figure 1),(3) and provides a step wise approach from preventing drowning to providing high quality medical care.

Figure 1: The drowning chain of survival as proposed by Szpilman et al. (2014)

The drowning victim can be rescued at any stage of the drowning process and therefore present with an array of physiological sequelae. Survival rates for drowning incidents vary significantly by setting but are noted to be as high as 75-84%.[6, 8] Non-fatal drowning with morbidity is associated with a range of short and long term sequelae, most important of which are the irreversible neurological sequelae, ranging from minor neurological deficits to severe hypoxic encephalopathy.[6] Residual neurological deficit is present in approximately 4–6% of non-fatal drowning victims.[6, 8] It is also likely associated with a significant socio-economic burden.[10]

An overview of drowning epidemiology

Drowning is estimated to account for 7% of total injury related mortality globally, and is the third leading cause for unintentional injury fatalities.[1] More than 90% of these deaths occur in low- and middle-income countries.[1] According to the WHO the African region has up to a 20 times higher risk for drowning deaths compared to many high-income countries,[11] with a drowning mortality rate of 13.1 per 100 000 population.[12]

The global drowning burden is likely to be considerably underestimated.[13] Intentional drowning (suicide and homicide), as well as deaths from flood disasters and water transport incidents are often excluded from global drowning statistics.[1] Under-estimation of unintentional fatal drowning is also a concern, even in well-resourced developed countries. Franklin et al. (2017) found that only 61% of actual drowning fatalities were captured by the traditional ICD-10 codes (W65-74) used to capture drowning data.[14] Formal drowning surveillance has been noted as unreliable or absent in the developing world, particularly in Africa.[15] It is estimated that only 1 in 4 drowning cases are reported in the African region.[16] In South Africa, failure to report drownings and expedited burial of drowning victims for cultural purposes are just some of the factors that may contribute to inaccurate reporting.[11] In addition, many estimates of the global drowning burden do not include non-fatal drowning incidents. The ratio of fatal to non-fatal drowning has been estimated between 1:4[17] and 1:10[17], with the ratio of admission and non-admission to hospital being approximately 1.7:1.[17] The paucity of good quality data describing non-fatal drowning incidents remains a significant concern[6] and further results in an under-representation of the world's drowning problem.

Similar to many low- and middle-income countries, robust drowning surveillance data is lacking in South Africa.[18] From the beginning of the century the national drowning mortality rate for South

Africa has decreased from 5.09 per 100 000 to an estimated 3.95 per 100 000 population in 2016.[19] Drowning accounted for 2083 deaths in 2016 with a calculated 122 479 disability-adjusted life years lost due to drowning.[19] Evidence suggests that there is variation in both the burden and epidemiology of fatal drowning between the nine provinces of South Africa, particularly between coastal and inland provinces.[20]

The coastal province of the Western Cape is the third largest and fourth most populated province in South Africa. According to the 2018 mid-year population estimates from Statistics South Africa it has a population of 6.6 million inhabitants[21]. Due to the paucity of published data on the epidemiology of drowning within South Africa, the Western Cape Government: Directorate for Disaster Management commissioned the development of a strategic framework for drowning prevention and water safety in the Western Cape.[20] This report indicated 1473 fatal drowning incidents in the Western Cape in the 7.5 years between 2010 and mid-2017, equating to approximately 200 fatal drowning incidents annually.[18] The crude drowning mortality rate for the Western Cape was observed to be 3.25 per 100 000 population, which correlates with national drowning statistics.[10]

Drowning risk factors

The risk factors for drowning are multifactorial and include alcohol consumption, underlying medical conditions, unsafe access to bodies of water, ineffective adult supervision, the absence of appropriate policy, legislation and regulation, and most particularly age and sex. [18]

Globally, the highest rates of drowning occur among children under the age of five.[1, 22] In Bangladesh drowning accounts for 43% of deaths among children younger than five years old.[1] In the Western Cape province of South Africa, the highest age-specific mortality rate was observed in children under five years old (4.8 per 100 000 population) with a rate of 3.8 per 100 000 population for all children (0-19 years).[18] In individuals over the age of 65 the risk of drowning is also noted to be elevated, likely due to the increased incidence of systemic disease.[23]

Fatal drownings are consistently found to be more common in males. The WHO global report on drowning indicates that males are involved in double the amount of fatal drownings when compared to females globally.[1] The male to female ratio in the Western Cape was 4:1 between 2010 and mid-2017.[18] Adolescents (15-19 years) and young adult males (20-34 years) were observed to have particularly high drowning mortality rates (5.7-6.6 per 100 000 population), with male to female ratios between 5.8:1 and 12.6:1, likely due to elevated risk behaviour in males in this age group.[15, 18, 23]

Existing medical conditions have been identified as risk factors for drowning, particularly in the elderly.[23] In the over 64 year old population the majority (84%) of drowning fatalities had pre-existing medical or psychiatric conditions.[23] Other medical conditions frequently observed in drowning fatalities in the elderly are epilepsy or seizure disorders.[23] Autism and other developmental disorders have also been noted to increase risk of drowning in children.[24, 25]

The consumption of alcohol has been strongly associated with drowning, especially in men and adolescents.[1, 26] Measured blood alcohol levels were elevated in 30% to 70% of swimming and boating fatal drowning victims in Australia, and alcohol consumption directly attributed to between 10% and 30% of these deaths.[27] Blood alcohol levels above 0.05g/100ml are associated with progressive cognitive impairment.[28] There is limited South African data reporting on the association of alcohol consumption with drowning. In one study of fatal drowning between 2001 and 2005, 40% of drowning deaths where blood alcohol was measured were found to be alcohol related with 85% of these cases having a blood alcohol level at or above 0.05g/100ml.[29] Males were 11 times more likely than females to have a blood alcohol level above 0.05g/100ml at the time of their death.[29]

Lack of adequate supervision in children and the medically incapacitated has also been highlighted as a preventable risk factor for unintentional drowning.[1, 15] In South Africa, only 18.7% of drownings in children younger than five are witnessed.[6] Poverty, unemployment and structural inequalities have been highlighted as some of issues compromising adequate supervision in South Africa.[20] In addition, adolescents are less likely to be supervised at all and have a tendency for high risk behaviour, placing them at an elevated risk.[15]

Temporal risk factors for drowning are likely associated with increased exposure to recreational water activities. In South Africa, fatal drowning is more prevalent during the warmer seasons with almost two thirds occurring during Spring (24.7%) and Summer (42.0%).[10] The majority of drowning incidents occur over weekends, and public holidays have been associated with an increased risk of fatal drowning.[10] Drowning incidents are also more prevalent in the afternoon and early evening, with 59% occurring between 12h00 to 19h59.[10]

The distribution of drowning by body of water differs with age, with an increasing proportion of drowning in natural bodies of water with increasing age.[18, 20, 22] In the Western Cape, 72.2% of fatal drowning in children under five years of age occurs in and around the home.[20]. However, in adults 77.8% of fatal drowning between 2010 and 2016 occurred in large, natural bodies of water with 28.6% (n=398) occurring in the ocean and lagoons. [20] Research conducted in Australia, looking specifically at international travellers, found that unintentional drownings in this group were most prevalent in the ocean.[26] A recent study assessing the operations of the National Sea Rescue Institute (NSRI) of South Africa over a 5 year period, found that the majority (45.2%) of rescue operations conducted nationally were in the south western coastal region, corresponding largely to the Western Cape province, of South Africa.[30] This data indicates that there is a substantial burden of ocean drowning in the Western Cape province.

An overview of ocean tides and currents

An introduction to tides

Tides are the alternate rise and fall of the surface of the sea, caused by the gravitational forces of the moon and sun. [9,10] Tidal action is mostly due to the gravitational force that the moon exerts on the ocean, causing it to bulge towards the side of the moon. The opposite side of the earth also experiences a high tide (bulging away from the earth's surface) due to centrifugal forces. Tides move in six-hour cycles with both high and low tide occurring twice in every 24-hour period (Figure 2). The specific types of currents associated with tides are the offshore ebb, which pulls away from the shore during the change from high to low tide, and the onshore flood current, which pushes towards the shore during the change from low to high tide.[31] The vertical distance between high and low tide is called the tidal range (Figure 3). The maximal tidal range on the Southern Africa coast line is approximately 1.8m, with the exception of the amplified Mozambique Channel tides that can reach 6.4m.[31]

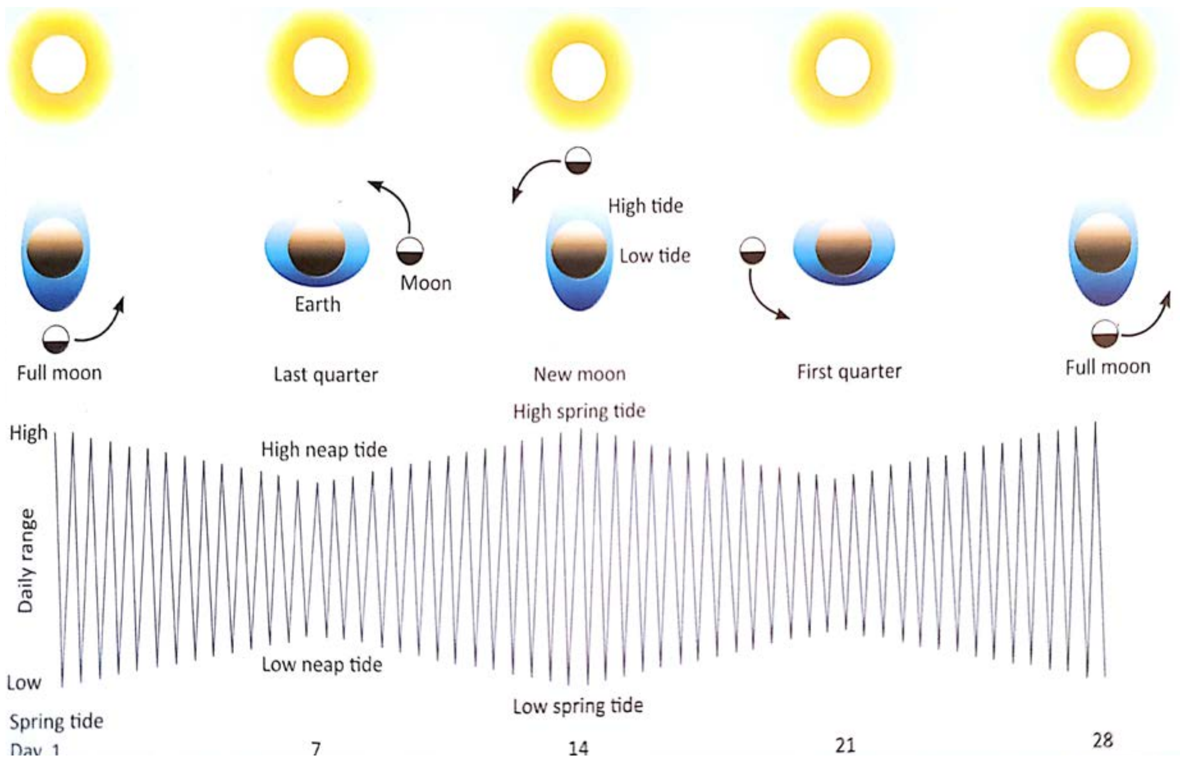

Figure 2: Tidal range with gravitational forces of the Moon and the Sun. (32)

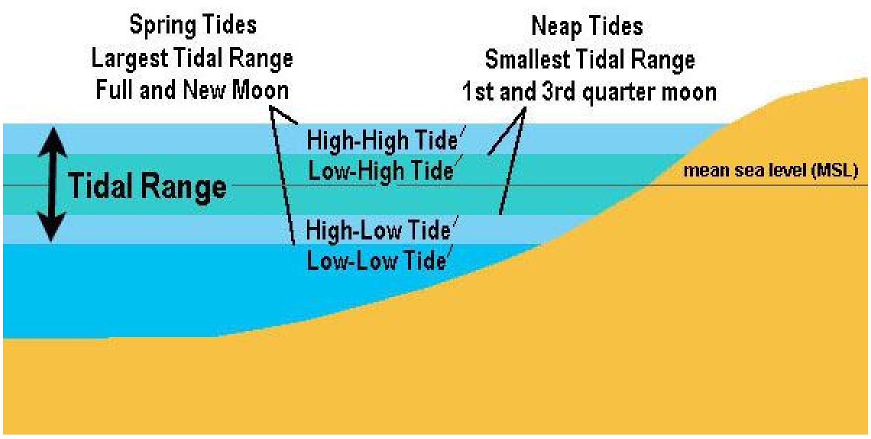

Figure 3: A graphical explanation of tidal range and phases (Source: Oceanography 101 online course, chapter 11)

The moon orbits around the earth approximately every 28 days.[(31)] The gravitational force of the sun is less than half that of the moon due to the sun being much further away from the earth. When the earth, sun and moon align during new and full moon, the gravitational pull reinforces each other. During this time the tides are extra high and called spring tides. When the three celestial bodies are at right angles toward each other, the tides are less marked and called neap tides.[31]

For the purposes of this research, the term "tidal state" will refer to high or low tide, whereas the term "tidal phase" will refer to neap, spring or normal tides. The terms "ebbing" and "flood" are used to address the change in tidal state from high tide to low tide and from low tide to high tide respectively.

Rip currents

Rip currents are currents with strong flows of water away from the beach back into the ocean, and are associated with the swift movement of tidal water during tidal changes.[33] [34] The changing tides also affect wave action. At low tide gentle, spilling waves occur, but these become dumping waves, which break with severe force and pose more danger to swimmers, as the tide rises and waves hit a steeper part of the beach.[35] Alteration in wave action by changing tides can contribute to the formation of rip currents, although tides do not directly cause rip currents.[34] The tide elevation at the coast may however affect the speed and strength of a rip current.[34] Rip current velocities mostly increase with the ebbing tide, making this period more dangerous for swimmers.[34] Increases in wave heights increase rip current velocities, especially with heights above 1m.[33]

Rip currents and the threat they pose to swimmers have been investigated by coastal scientists for more than 75 years. In Australia, an average of 21 confirmed human fatalities per year are due to rip currents.[36] Analysis of the existing data records indicates that rip currents account for more human fatalities in Australia each year than the combined deaths from bushfires, floods and cyclones.[36] According to the USA National Oceanic and Atmospheric Association, 70 of the 113 (62%) fatal drownings on the coast of America in 2017 were related to rip currents.[37] A case study from the Southwest of England found that rip currents represented the most significant environmental threat to water users.[38] Large tidal ranges were noted to be hazardous due to increased water speed horizontal to the shoreline, tidal cut off through high water levels as well as increased rip current velocities during the ebbing tide.[38] The NSRI of South Africa have suggested that rip currents are the greatest cause of ocean drowning incidents and noted an increased risk of drowning during spring tide periods.[39]

Local current conditions are influenced by complex interaction of a plethora of factors. The velocity and direction of a current does not always follow a linear relationship with tidal phase and state. Some of the factors that influence the velocity and direction of currents are briefly discussed below. Inshore bathometry is the study of water depth, and the underwater sea floor or shape of a specific area influences the tidal direction and velocity.[40] A simple example of its influence can be seen at an area of narrowing where the velocity of the water accelerates.[40] Local wave conditions can also influence current velocity and direction. Wave-current interaction is complex and depends on a multitude of factors.[40] One of the interesting aspects of wave-current interaction is the decreased tidal phase amplitude during periods of high waves.[41] In addition, patterns of wind influence tidal conditions to a varying degree. Offshore winds can exaggerate the receding flow during ebbing tide as it moves water away from the shore. Onshore winds can exaggerate flooding tide velocity by piling water onto the shoreline.[42]

Tidal currents

Standing wave current the wave profile remains in a constant position (oscillate about a fixed point), in contrast progressive wave current moves across the ocean's surface.[43] Individual locations may predominantly have either a standing wave – or a progressive wave type current. It is important to note that, at locations with a *standing wave* type current, the lowest current velocity occurs over the high and low tide periods (Figure 4).[44] During standing wave current conditions, the maximum current velocity usually occurs mid-tide.[44] The average delay, or so-called phase lag, is noted to be approximately three hours after tidal phase change. At locations with a *progressive wave* type current, the maximum current velocity coincides with high tide or low tide (Figure 4). In the Western Cape both standing wave and progressive wave currents are found, but the majority of locations are out of phase and are therefore standing wave type currents.

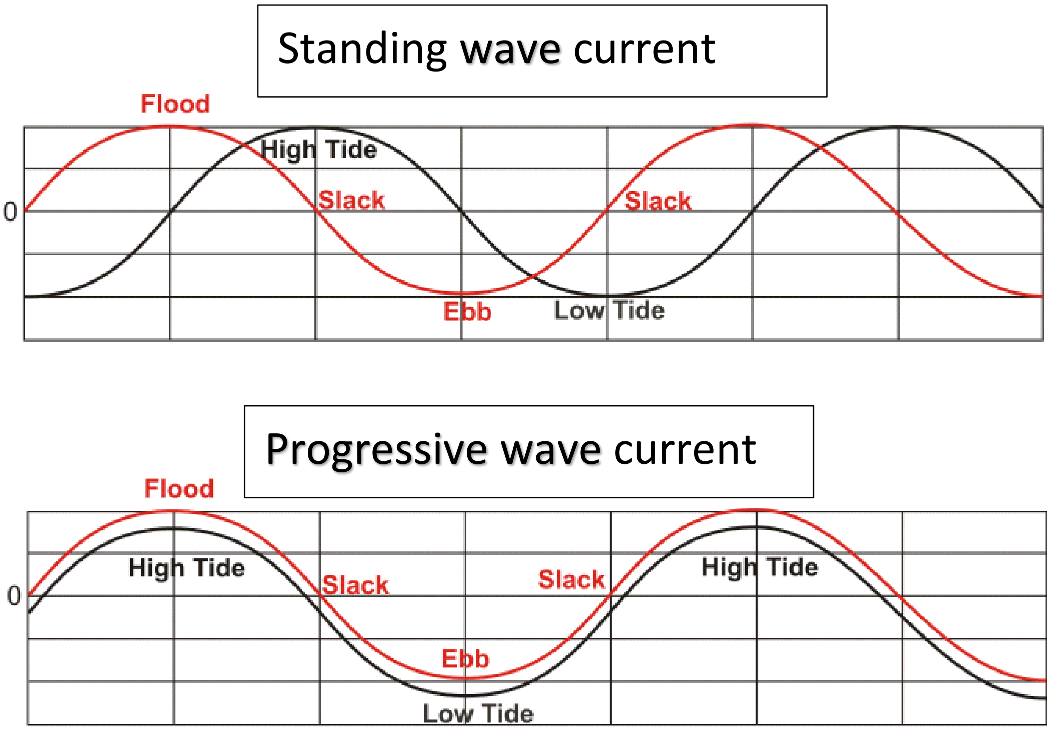

Figure 4: Modified graphical representation of maximum velocity (ebbing or flooding) in relation to tidal state[(44)].

Summary

Drowning is a serious and neglected, yet preventable, public health threat.[(1)] It is a leading cause of unintentional injury, with the highest mortality rates among children under the age of five. In the Western Cape province of South Africa, high rates of drowning mortality have also been observed in young, adult males with a high proportion of fatal drowning occurring in the ocean. There are approximately 200 fatal drowning incidents in the Western Cape annually, 29% of which occur in the ocean or lagoons.[(18)] A better understanding of the contributing factors in these drowning incidents will allow for improved implementation of prevention strategies.

Multiple factors contribute to ocean conditions, which are likely to be associated with increased risk of oceanic drowning.[(10)] However, tidal action correlates strongly with ocean conditions, and the intensity of tidal phases influences both current strength and direction.[(35)] [(31)] Large tidal ranges increase the speed and strength of not only normal tidal currents but also rip currents.[(34, 36)] The association of fatal drowning and rip currents has been well established.[(36)] However no data currently exists investigating the relationship between tidal changes and fatal drownings in South Africa or internationally.

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PART B: MANUSCRIPT IN ARTICLE FORMAT

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Authors information:

Dr Charlotte Roos (MBChB)
Division of Emergency Medicine
Faculty of Medicine and Health Sciences
Stellenbosch University
South Africa

Dr. DJ van Hoving (MBChB, DipPEC, MMed, MScMedSci)
Division of Emergency Medicine
Faculty of Medicine and Health Sciences
Stellenbosch University
South Africa

Dr. Colleen J. Saunders (BSc(MED)Hons, PhD)
Division of Emergency Medicine
Faculty of Health Sciences
University of Cape Town
South Africa

Corresponding author:

Dr Colleen J. Saunders

c.saunders@uct.ac.za

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Abstract

Drowning is a serious public health concern that is often overlooked. Understanding risk factors is key to the development of preventative strategies. The aim of this study was therefore to describe the frequency of fatal drowning in the Western Cape during different tidal phases and states. This was a retrospective, analytical study describing all fatal drowning incidents in the ocean, tidal pools and harbours in the Western Cape province of South Africa between 2010 and mid-2017. The most important finding of this study is a 2.4-fold increased incident rate of fatal drownings during spring (29.8 per 100 days) and neap (29.1 per 100 days) tides when compared to Normal tide (12.2 per 100 days). In addition, the odds of drowning during the flooding tide were 2.2-fold higher in spring tides when compared to neap tides. The factors contributing to drowning in the ocean are multifactorial and complex, and these initial findings suggest that future research on the influence of in-shore bathometry and wave character on environmental factors such as current velocity and force would aid understanding our site-specific drowning risk.

Keywords

Drowning; Immersion; Submersion

Introduction

Drowning is defined as the process of experiencing respiratory impairment from submersion/immersion in liquid and may be categorized as fatal, non-fatal with morbidity or non-fatal without morbidity.[(5)] Drowning claims the lives of 372 000 people per year globally, and is a serious and neglected, yet preventable, public health threat.[(1)] Low- and middle-income countries account for more than 90% of these deaths.[(1)] In 2012 the drowning mortality rate for the World Health Organization (WHO) African region was estimated at 13.1 per 100 000 population and accounted for approximately 20% of global drowning.[(1, 2)] From the beginning of the century the national drowning mortality rate for South Africa has decreased from 5.09 per 100 000 to an estimated 3.95 per 100 000 in 2016, with 2083 deaths and 122 479 disability-adjusted life years lost due to drowning.[(19)]

The 2007 International Lifesaving Federation (ILS) World Drowning Report indicates the absence of reliable drowning surveillance in the developing world, particularly in Africa.[(6)] Similar to many low- and middle-income countries, consistent data collection regarding water safety and drowning prevention is lacking in South Africa.[(7)] This makes the development of evidence-based drowning prevention strategies very difficult. The Western Cape Government recently commissioned the development of a strategic framework for drowning prevention and water safety in the Western Cape, a province of South Africa. This report showed that there were 1473 fatal drowning incidents in the Western Cape in the 7.5 years between 2010 and mid-2017, with a crude drowning mortality rate of 3.25 per 100 000 population,[(18)] which correlates with national drowning statistics.[(4)]

A number of different risk factors for fatal drowning were identified in the report: underlying medical conditions, access to bodies of water, the lack of adult supervision, the lack of policy, legislation and regulation, and most particularly age and sex.[(18)] Fatal drownings were found to be more common in males than females, with a male to female ratio of 4:1. The average age of fatal drowning victims in the Western Cape was 27 years old (Standard deviation [SD] 25-29), with the highest age-specific mortality rate found in children under five years old. Most fatal drownings occurred over weekends and public holidays in the warmer seasons. The bodies of water accounting for the highest proportion of fatal drownings were found to be the ocean (27%), ponds, dams and lakes, (26%) and canals and rivers (23%).[(18)] There were 398 fatal drownings in the ocean (including harbours and tidal pools) between 2010 and mid-2017 in the Western Cape.[(18)]

Anecdotally, stakeholders such as lifeguards and sea rescue personnel have speculated on the correlation between ocean tidal changes and ranges, particularly during spring tide, and the risk of drowning.[39] Although there is some evidence to support this,[11] it has not previously been investigated. During spring tide the large tidal range causes not only an increase in the speed and strength of normal tidal currents but also increases the velocity and force of existing rip currents making it a higher risk period. The aim of this study was therefore to describe the frequency of fatal drowning in the Western Cape during different tidal phases and states. In order to achieve this aim, the current study describes the distribution of fatal drowning incidents in oceans, harbours and tidal pools in the Western Cape between 2010 and mid-2017 (inclusive) by (i) basic epidemiological variables, (ii) mean tidal range, (iii) tidal phase and (iv) tidal state. In addition, the relative frequency of fatal drowning during spring tide is compared with that during neap tide or normal tides, and the relative frequency of fatal drowning during the ebbing tide is compared with that during the flood tide or slack period.

Methodology

Study design, setting and population

This retrospective study describes all fatal drowning incidents recorded by the Western Cape Government Forensic Pathology Services in the ocean, tidal pools and harbours in the Western Cape between 2010 and mid-2017. The Western Cape is a province of South Africa situated on the south western coast of the country. It is the fourth largest of the nine provinces, and is the third most populated, with an estimated 6,5 million inhabitants in 2017.[21]

Data collection

This study was approved by the Health Research Ethics Committee of the University of Stellenbosch (HREC S19/01/008), and the Western Cape Government Department of Health. De-identified epidemiological data for all fatal drowning incidents in the ocean, tidal pools and harbours in the Western Cape between 2010 and mid-2017 were sourced from the Western Cape Government Forensic Pathology Services.

Accurate tide tables for the corresponding study period were requested from the South African Naval Hydrographic Office. Tides on Southern African coasts are regular, semi-diurnal, and their range seldom exceeds 2.2m.[16] Tidal range is defined as the vertical distance (metres) between mean sea level and the peak high or low sea height in each 12-hour cycle [16]. For the purposes of this study, each

12-hour cycle was divided into four tidal states (Figure 1). High Tide Slack was defined as 1,5 hours on either side of High Tide, and Low Tide Slack was defined as 1,5 hours on either side of Low tide. The ebbing tide was defined as the period 1,5 hours after the peak of high tide up until 1,5 hours before the peak of low tide. The flood tide was defined as the period between 1,5 hours after the peak of low tide up to 1,5 hours before the peak of high tide.

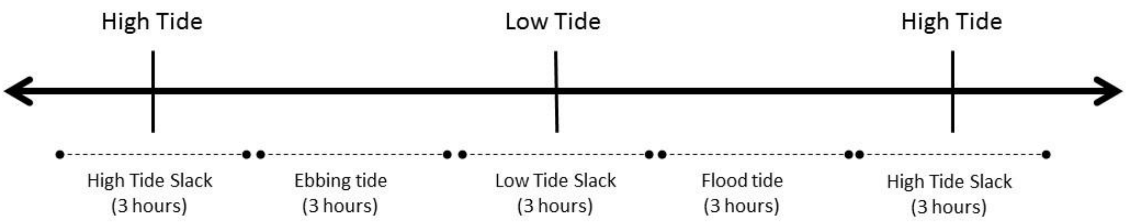

Figure 1: A graphical explanation of tidal state categories used in this study

In addition, the dates on which the New Moon, First Quarter Moon, Full Moon and Last Quarter Moon occurred were used to determine the spring and neap tide periods. The spring tide period was defined as the 72-hour period following the new and full moons. The Neap tide period was defined as the 72-hour period following the first and last quarter moons and occurs approximately seven days after a spring tide.(17) All fatal drowning incidents were annotated with the corresponding tidal range, tidal phase and tidal state.

Data analysis

Data was analysed using the Epi Info™ (CDC) statistical package with the level of significance set at 0.05. Data are reported using descriptive statistics as appropriate. The students t-test was used to detect any significant difference in mean age between males and females. Analysis of variance (ANOVA) was used to detect significant differences in tidal range between tidal phases. In order to compare the relative frequency of fatal drowning between tidal phases, an incident rate per 100 days was calculated as the quotient of the number of incidents per solar year (365 days) and the number of days per solar year corresponding to each tidal phase. The Chi-square test was used to detect differences in the distribution of incidents by tidal state in each of the tidal phases. The Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) checklist was used to structure this report(45).

Results

Between 2010 and mid-2017, there were 431 fatal drowning incidents in the ocean, tidal pools and harbours in the Western Cape, resulting in a mean of 57.5 fatal drowning incidents per year. The majority (89.1%) of fatal drowning victims were male, and the mean age was 33 years (SD = 17; Interquartile Range [IQR] = 22–45) with no significant difference in mean age between males and females. The majority (77.7%) of fatal drownings were among those who were 20 years of age or older (Table 1).

Table 1: The distribution of fatal drowning incidents by age and sex in the ocean, tidal pools and harbors in the Western Cape between 2010 and mid-2017

Age category	Proportion of total; n (%)	Proportion male; n (%)
Under 5 years	3 (0.7)	3 (100.0)
5-19 years	82 (19.0)	73 (89.0)
≥ 20 years	335 (77.7)	298 (89.0)
Unknown	11 (2.6)	10 (91.0)
Total	**431 (100.0)**	**384 (89.1)**

Almost half (46.4%) of the fatal drownings occurred in the summer season compared to 22.7% in spring, 20.9% in autumn and 10.0% in winter. Saturdays (20.4%) and Sundays (22.0%) were the most frequent days when fatal drownings occurred (Figure 2). Nearly half (49.2%) of all fatal drownings in the ocean occurred on weekends and public holidays.

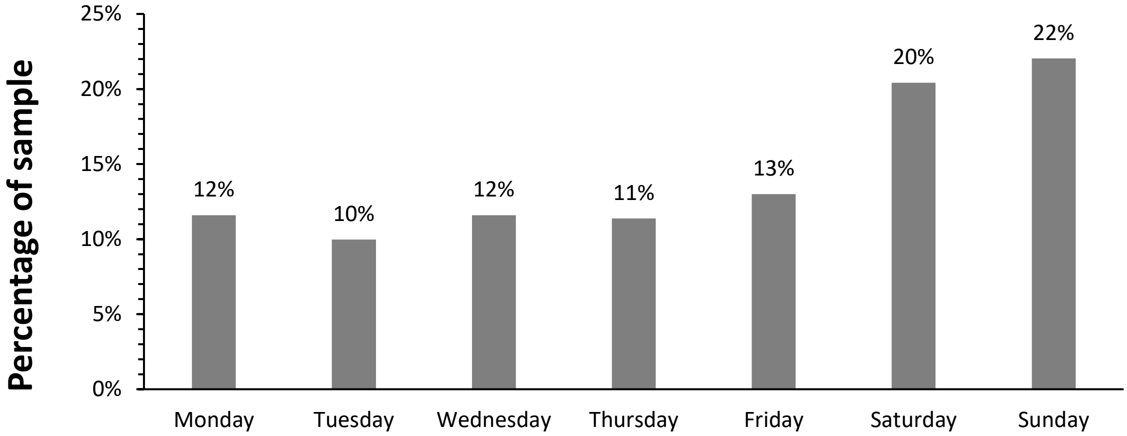

Figure 2: Fatal drownings in the ocean, tidal pools and harbors of the Western Cape (2010 – mid-2017) according to day of the week

The mean tidal range at the time of fatal drowning incidents was 1.13m (SD = 0.42; Range: 0.29-2.26). There was a significant difference in tidal range between different tidal phases ($p < 0.001$). The mean tidal range for incidents occurring during the neap tide was 0.72m (SD = 0.22; Range: 0.29-1.35), while for normal and spring tide it was 1.12m (SD = 0.37; Range: 0.43-2.26) and 1.55m (SD =0.25; Range: 1.07-2.23) respectively.

The majority (62.0%) of fatal drownings occurred during normal tide. Drowning incidents during neap and spring tidal phase both occurred less than 20% of the time (Table 2). However, the fatal drowning incident rate per 100 days was 2.4-fold higher (95% CI: 1.2-4.7) during spring and neap tides compared to normal tide.

Table 2: Relative frequency of fatal drowning incidents in the ocean, tidal pools and harbors in the Western Cape between 2010 and mid-2017 during three tidal phases

Tidal Phase	Frequency of fatal drownings (% of total)	Frequency per solar year	Number of days (per solar year)	Incident Rate (per 100 days)
Spring tide	83 (19.3)	11.1	37.1	29.8
Neap tide	81 (18.8)	10.8	37.1	29.1
Normal tide	267 (62.0)	35.6	290.8	12.2
Overall	431	57.5	365	15.7

Study period included 7.5 solar years. Mean lunar month = 29.5 days of which 3 days were classified as Spring tide, 3 days classified as neap tide and 23.5 days as normal tide.

The highest proportion of fatal drownings occurred during the flood state (n=125, 29.0%) followed by the low tide slack period (n=115, 26.7%), the ebbing tide (n=101, 23.4%) and the high tide slack period (n=90, 20.9%). Figure 3 shows the distribution of fatal drownings by individual tidal state during each of the three tidal phases. There was no significant difference in this distribution between the tidal phases (χ^2=9.85; p=0.131). However, the distribution of fatal incidents in the combined flood and associated low tide slack period compared to the combined ebbing and associated high tide slack period, was significantly different between tidal phases (χ^2=6.244; p=0.044). In particular, fatal drowning incidents during spring tides occurred more frequently during the flood tide and low tide slack period (65.1%) compared to the similar state during neap tides (45.7%; Odds Ratio = 2.2 (95% CI: 1.2-4.2); p=0.018).

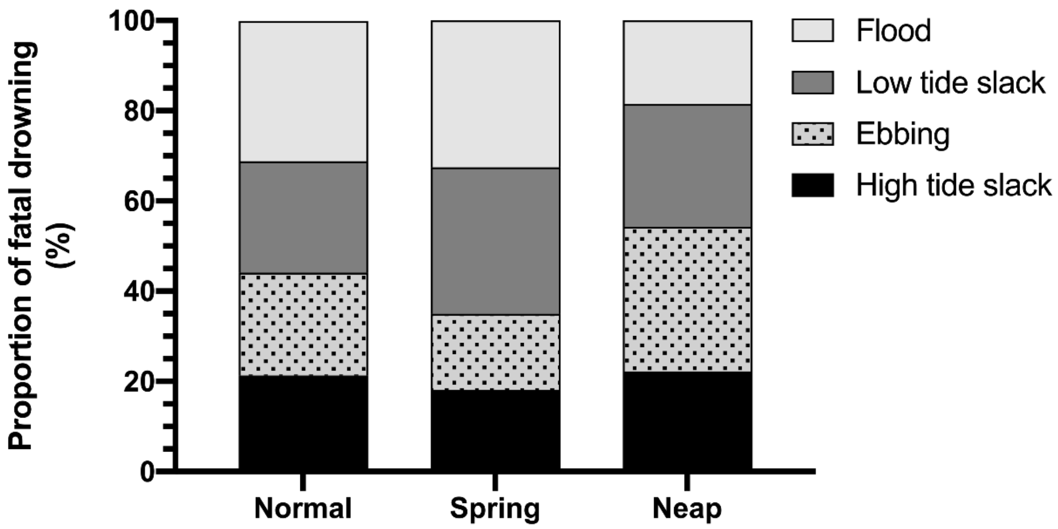

Figure 3: Distribution of fatal drowning incidents in the ocean, tidal pools and harbors in the Western Cape between 2010 and mid-2017 by tidal phase and state (N=431)

Discussion

The many risk factors contributing to drowning risk can be classified as personal factors, behavioural factors and environmental factors. The current study aimed to investigate an environmental risk factor by comparing the relative frequency of fatal drowning in the Western Cape between different tidal phases and states. The most important finding of this study is the 2.4-fold increased incident rate of fatal drownings during spring (29.8 per 100 days) and neap (29.1 per 100 days) tides when compared to normal tides (12.2 per 100 days). We postulated that there would be an increased incident rate of fatal drowning during spring tide, however the concurrent increased rate during neap tide was unexpected. This increase in risk is complex and multi-factorial in nature. Large tidal ranges during spring tide are highlighted as one contributing factor, with higher tidal ranges associated with an increase in the speed and strength of normal tidal currents and contributing to the formation of more forceful rip currents[34]. In Australia, rip currents account for an average of 21 confirmed human fatalities per year.[36] Based on analysis of the longest existing data records, rip currents account for more human fatalities in Australia each year than bushfires, floods and cyclones combined.[36] This does not however explain the increased drowning risk observed with neap tides in the current study. One possible explanation for this is the perception of decreased risk during neap tides leading to a higher amount of people entering the water, although this is yet to be studied. Inshore bathometry, such as sand-bar behaviour, long shore current speed, and wave speed unique to a specific area or beach could possibly explain varying risk with different tidal states.[46] This is an area for future research to improve risk stratification and drowning interventions in high risk areas.

In addition to differences in drowning risk associated with different tidal phases, there is evidence to suggest that drowning risk may also differ by tidal state. The ebbing tide especially has been identified to be hazardous, leading to higher horizontal speed shoreline movements as well as causing increased rip current velocities.[38] We therefore expected that there would be an increased risk for drowning during the ebbing tidal state that occurs after high tide. In the current study, there were increased odds of drowning during this time during neap tides compared to spring tides, when fatal incidents occurred more frequently as the tide turned to flood. However, during normal tides, there was a tendency for more incidents (31%) to occur during the flood state compared to other states. This may be explained by the predominance of a standing wave current on the Western Cape coastline[47], where the highest inshore current velocities are observed approximately three hours prior to high tide during the flood tide state, with inshore current velocities increasing again during the low tide slack period[47]. Whilst this is an interesting observation, these findings need to be repeated in a more robust study that measures exact inshore current conditions at the time of drowning incidents.

Many personal and behavioural risk factors for drowning have previously been identified and are well established. These include, amongst others, age[1, 18], male sex[1, 18], alcohol consumption[1, 29], inadequate supervision[1, 48], and increased exposure to aquatic environments during recreational periods such as weekends and public holidays[18, 26, 29]. The epidemiological data presented in the current study is consistent with previous findings in that there was a disproportionate number of males (89.5%) involved in fatal drownings in the ocean. Similarly, the finding that more than three quarters of the fatal drowning incidents in the ocean involved adults 20 years and older is consistent with previous observations reporting an increasing proportion of natural water drownings with increasing age group[1, 10].

Nearly half (49.2%) of fatal drownings in this study occurred over weekends. This finding is likely due to the increased number of beachgoers during this period. This is also the likely explanation for the summer months accounting for nearly half (46.4%) of fatal drownings and winter months only 10.0%. This is in keeping with recent findings from both Australia[(49)] and previous findings from South Africa[(29)]. Public holidays and weekends are especially associated with increased risk behaviour, increased alcohol consumption, travel to unfamiliar areas and increased recreational aquatic activities.[(20)]

The current study has several limitations. Firstly, the recorded time of drowning incidents may not be accurate to the exact minute, but the tidal state categories used in this study cover a three-hour window, and therefore a reasonable degree of error in the incident time will not significantly affect the allocation of the corresponding tidal state category. In addition, this study only includes fatal drowning incidents where bodies were recovered. Incidents where bodies are not recovered are more common in large bodies of water such as oceans, dams and rivers.[(4)] It is therefore possible that the data set included in this study does not include all fatal drowning incidents in the ocean and may underestimate the burden of these drowning incidents. Surveillance data on non-fatal drownings are not routinely collected and are therefore not included in this study. As non-fatal drowning incidents out number fatal drowning incidents, these represent a significant source of missing data. It is, however, likely that the distribution of fatal and non-fatal incidents by tidal phase and state may, in fact, be different. Data describing swell height and the presence or absence of a rip current at the time of the drowning incident was not available. However, this retrospective study did not aim to identify all the causal factors contributing to a fatal drowning incident but rather to explore the relationship between tidal phase and state and fatal drowning.

Notwithstanding the limitations described above, data describing the relationship between fatal drowning and tides has not been previously reported, and the data presented here provide an initial indication that tidal state and phase may affect drowning risk, while offering directions for future research to advance our understanding of the environmental risk factors for drowning in the ocean. Future work should include identifying the beaches posing the highest risk and investigating the unique constellation of contributing factors leading to drowning incidents in these areas.

Conclusion

The factors contributing to drowning in the ocean are multifactorial and complex. These include an individual's unique profile in terms of personal and behavioural factors as well as the site-specific environmental factors related to the body of water which combine to create a unique setting for every incident. The findings of the current study provide initial evidence to suggest that the risk of fatal drowning is higher during spring and neap tide phases, and that the distribution of drowning risk by tidal state differs during these tidal phases. In particular, fatal drowning risk is increased when the tide turns to flood during spring tides compared to the similar period during neap tides. These initial findings suggest that future research on the influence of in-shore bathometry and wave character on environmental factors such as current velocity and force would be valuable in understanding site-specific drowning risk in oceans and harbors.

Acknowledgements

The Western Cape fatal drowning data was sourced, with permission, from the Western Cape Government: Health, Forensic Pathology Services.

Accurate tide charts for the Western Cape were sourced, with appreciation, from the South African Naval Hydrographic Office.

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Part C: Appendices

Appendix 1: Approved study proposal

An analytical study of the distribution of fatal ocean drowning by tidal phase and state in the Western Cape

Proposal for a study in partial fulfilment of the MMed degree

Principal Investigator (MMed candidate):

Dr Charlotte Roos,

Division of Emergency Medicine,

University of Stellenbosch.

Supervisors:

Dr Colleen Saunders,

Division of Emergency Medicine,

University of Cape Town

Dr Daniël van Hoving,

Division of Emergency Medicine,

University of Stellenbosch

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Table of Contents

Glossary

Drowning:	Drowning is defined as the process of experiencing respiratory impairment from submersion/immersion in liquid and may be categorized as fatal, non-fatal with morbidity or non-fatal without morbidity.
Ebbing tide:	**The period 1,5 hours after high tide until 1,5 hours before low tide.**
First quarter moon:	The moon is one-half illuminated by the sun.
Flood tide:	**The period between 1,5 hours after low tide up to 1,5 hours before high tide.**
Full moon:	The phase of the moon in which its whole disc is illuminated.
High Tide Slack:	It is the 1,5 hours on either side of High Tide
High tide:	The state of the tide when at its highest level.
Last quarter moon:	The moon is one-half illuminated by the sun. Occurs when the moon's illumination is decreasing.
Low Tide Slack:	**It is the 1,5 hours on either side of Low tide.**
Low tide:	The state of the tide when at its lowest level.
Neap tide:	A tide just after the first or third quarters of the moon when there is least difference between high and low water.
New moon:	The phase of the moon when it first appears as a slender crescent, shortly after its conjunction with the sun.
Normal tide:	The state of the tides in between spring and neap tide.
Spring tide:	A tide just after a new or full moon, when there is the greatest difference between high and low water.
Tidal phase:	Neap, spring or normal tides.
Tidal range:	The vertical distance between mean sea level and the peak high or low sea height in a 12-hour cycle.
Tidal state:	Classified as High or Low tide slack, ebbing tide or flood tide.
Tide:	The alternate rising and falling of the sea, usually twice in each lunar day at a particular place, due to the attraction of the moon and sun.

1. INTRODUCTION

1.1. Background

Drowning is a serious and neglected, yet preventable, public health threat, claiming the lives of 372 000 people per year globally.[1] More than 90% of these deaths occur in low- and middle-income countries.[1] The drowning mortality rate for the World Health Organization (WHO) African region was estimated at 13,1 per 100 000 population and in 2012, was found to account for approximately 20% of global drowning.[1, 2] The WHO global burden of disease study estimates that 125 500 years of life were lost due to drowning in South Africa in 2012, taking both morbidity and mortality into account.[3] The national drowning mortality rate for South Africa is estimated at 3,0 per 100 000 population.[4] Drowning is defined as the process of experiencing respiratory impairment from submersion/immersion in liquid and may be categorized as fatal, non-fatal with morbidity or non-fatal without morbidity.[5] When referring to drowning incidents, van Beeck et al. (2005) recommended that the following terms should be avoided; 'near drowning', 'dry or wet drowning', 'secondary drowning', 'active and passive drowning', and 'delayed onset of respiratory distress', as these confusing terms lead to underrepresentation of the issue of drowning.[5]

The 2007 International Lifesaving Federation (ILS) World Drowning Report indicates the absence of reliable drowning surveillance in the developing world, particularly in Africa.[6] Similar to many low-and middle-income countries, data collection regarding water safety and drowning prevention is lacking in South Africa.[7] This makes the development of evidence-based drowning prevention strategies very difficult. The Western Cape Government has recently commissioned the development of a strategic framework for drowning prevention and water safety in the Western Cape province of South Africa. This report showed that there were 1473 fatal drowning incidents in the Western Cape in the 7,5 years between 2010 and mid-2017, equating to approximately 200 fatal drowning incidents annually[8] The crude drowning mortality rate for the Western Cape was observed to be 3,25 per 100 000 population, which correlates with national drowning statistics.[4]

A number of different risk factors for fatal drowning were identified in the report, including alcohol consumption, underlying medical conditions, access to bodies of water, the lack of adult supervision, the lack of policy, legislation and regulation, and most particularly age and sex.[8] Fatal drownings were found to be more common in males than females, with a male to female ratio of 4:1. The average age of fatal drowning victims in the Western Cape was 27 years old, with the highest age-specific mortality rate found in children under five years old. Most fatal drownings occurred over weekends and public holidays in the warmer seasons. The body of water accounting for the highest proportion of fatal drownings were found to be the ocean (27%), ponds, dams and lakes, (26%) and canals and rivers

(23%)[8]. There were approximately 400 fatal drownings in the ocean (including harbours and tidal pools) between 2010 and mid-2017 in the Western Cape.[8] Anecdotally, stakeholders such as lifeguards and sea rescue personnel have speculated on the correlation between ocean tidal changes and ranges, particularly during spring tide, and the risk of drowning (Personal communication: Dr Colleen Saunders, Lifesaving South Africa). Although there is some evidence to support this hypothesis,[11] it has not been empirically tested.

Tides are the alternate rise and fall of the surface of the sea, caused by the gravitational forces of the moon and sun.[9,10] Tides move in six-hour cycles with both high and low tide occurring twice in each 24-hour period. For this study, the term "tidal state" will be referring to High or Low tide, whereas the term "Tidal Phase" will be referring to Neap, spring or normal tides. The vertical distance between high and low tide is called the tidal range (Figure 1). The specific types of currents associated with tides are the offshore ebb, which pulls away from the shore during the change from high to low tide, and the onshore flood current, which pushes towards the shore during the change from low to high tide.

The changing tides also affect wave action. At some beaches spilling waves will occur at low tide but, as the tide rises, waves hit a steeper part of the beach and they become dumping waves that break with tremendous force. Alteration in the wave action by changing tides can contribute to the formation of other currents like rip currents.[9,10]

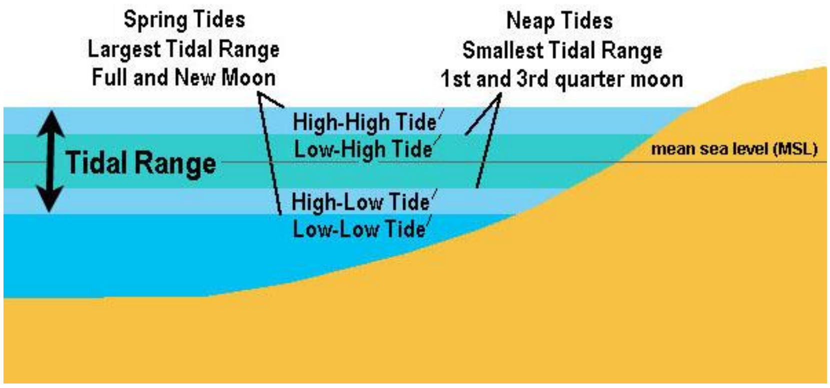

Figure 1: A graphical explanation of tidal range and phases

(Source: *Oceanography 101 online course, chapter 11, Figure 11.2*)

Rip currents are strong flows of water running from the beach back into the ocean. The mechanisms causing rip currents are complex and involve interactions between waves and water levels, waves and the shape of the shore bottom (bathometry) and wave-wave interaction. Although rip currents are not caused by tides, the tide elevation at the coast may affect the speed and strength of a rip current.

Generally, rip current velocities increase as water levels decrease with the ebbing tide, making this period more dangerous for swimmers.[11] Rip current velocities also typically increase as wave heights increase. Rip currents and the threat they pose to swimmers have been investigated by coastal scientists for more than 75 years. In Australia, rip currents account for an average of 21 confirmed human fatalities per year.[12] Based on analysis of the longest existing data records, rip currents account for more human fatalities in Australia each year than bushfires, floods and cyclones combined.[12] According to the USA National Oceanic and Atmospheric Association, 62 of the 93 (67%) fatal drownings on the coast of America in 2017 were related to rip currents.[13] A case study from the Southwest of England found rip currents to represent the greatest environmental threat to water users.[14] In addition, they identified large tidal ranges to be hazardous due to tidal cut off through high water levels and horizontal speed shoreline movements as well as causing increased rip current velocities during the ebbing tide.[14]

1.2. Motivation

Considering the evidence presented above, and anecdotal information from surf rescue personnel in the Western Cape, we hypothesize that there is an increased risk for fatal drowning during the ebbing tide. In addition, during spring tide the large tidal range causes not only an increase in the speed and strength of normal tidal currents but also increases the velocity of existing rip currents and contributes to the formation of more forceful rip currents making it a higher risk period. No data currently exists investigating the relationship between tidal changes and fatal drownings in South Africa. The findings of this study will provide insight into one of the risk factors possibly associated with fatal drowning in the ocean and will inform further research towards provincial drowning prevention strategies.

1.3. Aim and objectives

The aim of this study is to compare the relative frequency of fatal drowning in the Western Cape between different tidal phases and states.

To achieve this aim, the following objectives will be addressed:

i. To describe the distribution of fatal drowning incidents in oceans, harbours and tidal pools in the Western Cape between 2010 and mid-2017 (inclusive) by sex, age group, day of the week and season.
ii. To describe the mean tidal range during fatal drowning incidents in oceans, harbours and tidal pools in the Western Cape between 2010 and mid-2017.
iii. To describe the distribution of fatal drowning incidents in oceans, harbours and tidal pools by tidal phase in the Western Cape between 2010 and mid-2017 and compare the relative frequency of fatal drowning during spring tide with that during neap tide or normal tides.
iv. To describe the distribution of fatal drowning incidents in oceans, harbours and tidal pools by tidal state in the Western Cape between 2010 and mid-2017 and compare the relative frequency of fatal drowning during the ebbing tide with that during the flood tide or slack period.

2. METHODOLOGY

2.1. Study design, setting and population

This is a retrospective, cross-sectional, analytical study of all fatal drowning incidents in the ocean, tidal pools and harbours in the Western Cape between 2010 and mid-2017. The Western Cape is a province of South Africa situated on the south western coast of the country. It is the fourth largest of the nine provinces with an area of 129 449 square kilometres, and is the third most populated, with an estimated 6,5 million inhabitants in 2017. About two thirds of these inhabitants live in the metropolitan area of Cape Town.(15)

Approximately 200 fatal drowning incidents occur in the Western Cape annually. Epidemiological data for all drowning incidents that resulted in a fatality at any time point are available from the Western Cape Government Forensic Pathology Services. This de-identified data has successfully been sourced for other ongoing projects, including the development of the Western Cape Strategic Framework for Drowning Prevention and Water Safety.

2.2. Data collection

Deidentified epidemiological data for all fatal drowning incidents in the ocean, tidal pools and harbours in the Western Cape between 2010 and mid- 2017 will be sourced from the Western Cape Government Forensic Pathology Services.

For each fatal drowning incident, the following data will be requested:

- Age of the drowning victim
- Sex of the drowning victim
- Scene of the drowning incident (Body of water)
- Season
- Day of the week
- Time of day
- Apparent manner of death
- Location of drowning incident (Municipal district)
- Location of drowning incident (Suburb/town)

Accurate tide tables for the corresponding study period are available upon request from the South African Naval Hydrographic Office. Tides on Southern African coasts are regular, semi-diurnal, and their range seldom exceeds 2.2m.[16] Tide tables record the tidal range (meters), and the exact time of high and low tides in each 24-hour period. Tidal range is defined as the vertical distance (meters) between mean sea level and the peak high or low sea height in that 12-hour cycle[16]. For the purposes of this study, each 12-hour cycle has been divided into four tidal states (Figure 2). High Tide Slack is defined as 1,5 hours on either side of High Tide, Low Tide Slack is defined as 1,5 hours on either side of Low tide. The ebbing tide is defined as the period 1,5 hours after the peak of high tide up until 1,5 hours before the peak of low tide. The flood tide is defined as period between 1,5 hours after the peak of low tide up to 1,5 hours before the peak of high tide.

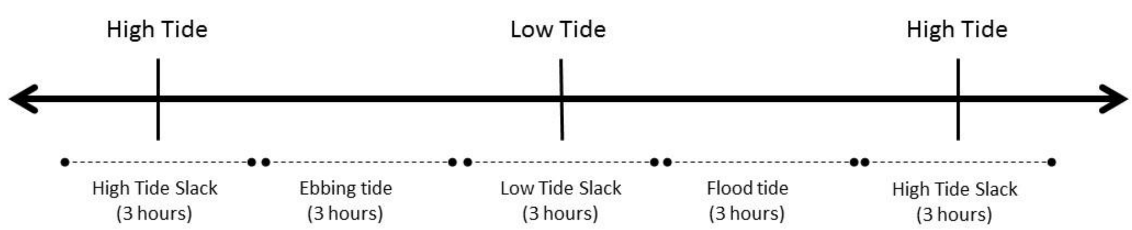

Figure 2: A graphical explanation of tidal state categories used in this study

In addition, the dates on which the New Moon, First Quarter Moon, Full Moon and Last Quarter Moon occur are also recorded on the South African Naval Hydrographic Office tide tables and will be used to determine the spring and neap tide periods. The spring tide period is the 72-hour period following the new and full moons. The neap tide period is the 72-hour period following the first and last quarter moons and occurs approximately seven days after a spring tide.[17]

The fatal drowning data from the Western Cape Forensic Pathology Services contains the recorded incident time of each fatal drowning incident. All fatal drowning incidents will be annotated with the corresponding tidal range, tidal phase (Figure 1) and tidal state (Figure 2).

Deidentified data will be stored in an Excel spreadsheet on a password protected computer during analysis. Data will be appropriately backed up by supplying copies of the data to both supervisors, who will store the data on their password protected computers.

2.3. Data analysis

Between 2010 and mid-2017, there were 399 fatal drowning incidents in the ocean, tidal pools and harbours in the Western Cape. Deidentified epidemiological data for all of these drowning incidents will be included in this study. Summary statistics will be used to describe all variables. Categorical data will be summarised using frequency counts or percentages, and distributions of variables will be presented as two-way tables or bar charts. Medians or means will be used as the measures of central tendency for ordinal and continuous responses and standard deviations or quartiles as indicators of spread.

The primary aim of the analysis will be to determine whether the frequency of fatal drowning differs by tidal phase and tidal state. For this purpose, proportions will be analysed and compared between the stated tidal categories using the $\chi 2$-test (if indicated, categories will be contracted) or Fishers exact test if the assumptions of the chi-squared test are not met, with 95% confidence levels indicated. Statistical significance will be set at an alpha level of 0,05. Statistical analysis will be run using Statistica v13.3 (TIBCO Software Inc, 2017). A consultant at the Division of Epidemiology and Biostatistics within the Centre for Evidence Based Health Care (CEHBC), Stellenbosch University, has assisted with the design of this study (and will assist with the analysis) through support from the Faculty of Medicine and Health Sciences.

The STROBE (Strengthening the Reporting of Observational Studies in Epidemiology) checklist will be used to structure the final report[18].

2.4. Time schedule

Ethical approval:	November 2018 - January 2019
Data collection and analysis:	February - March 2019
Write up:	April – May 2019

3. ETHICAL AND LEGAL CONSIDERATIONS:

The study will be conducted according to the guidelines for research involving human subject as reported by Helsinki 2013 and the South African Medical Research Council (MRC). Research ethics approval for the use of the deidentified fatal drowning data that will be used in the proposed study has previously been obtained from the Human Research Ethics Committee of the University of Cape Town (HREC 590/2017) and used with formal approval by the Western Cape Forensic Pathology Services. Research ethics approval for the additional analyses described in this sub-study has been obtained from the UCT HREC (Ref 555/2018).

Risks and benefits: As this study will not involve direct or indirect patient care, risk to patients is minimal. Only de-identified data will be obtained and analysed at the aggregate level. This study will provide insight into one of the risk factors possibly associated with fatal drowning in the ocean and will inform further research towards provincial drowning prevention strategies.

Informed consent process: Deidentified data was obtained from the Western Cape Forensic Pathology Services following ethical approval. Individual informed consent was not required for analysis of this secondary data. Individual consent will be impossible to obtain as the data pertains to patients who have already died. Getting consent from relatives is not feasible and this secondary data has been de-identified and will be analysed at the aggregate level. We therefore request a waiver of informed consent due to the nature of this secondary data.

Privacy and confidentiality: As described earlier, the study will make use of de-identified data to ensure anonymity of study subjects. Furthermore, only aggregated data will be reported.

We have obtained approval from the Human Research Ethics Committee of the University of Cape Town and the Western Cape Forensic Pathology Services for the additional analyses contained in this sub-study (HREC Ref 555/2018).

4. STRENGTHS AND LIMITATIONS

The recorded time of drowning incidents may not be accurate to the exact minute, but our tidal state categories cover a three-hour window, therefore a reasonable degree of error in the incident time will not drastically affect the allocation of the corresponding tidal state category.

The study only includes fatal drowning incidents where bodies were recovered and thus excludes the incidents where bodies were not found. Incidents where bodies are not recovered are more common in large bodies of water such as oceans, dams and rivers(4). It is therefore possible that the data set included in this study does not include all fatal drowning incidents in the ocean and may underestimate the burden of these drowning incidents.

Surveillance data on non-fatal drownings are not routinely collected and are therefore not included in this study. Limited data about the burden of non-fatal drowning has been recorded or investigated in South Africa and are therefore not available for inclusion in this study. This will be highlighted as an area for future research efforts.

Data describing swell height and the presence or absence of a rip tide at the time of the drowning incident is not available. This is a limitation of the study; however, this retrospective study does not aim to identify all the causal factors contributing to a fatal drowning incident but rather to determine the relationship between tidal phase and state and fatal drowning.

Notwithstanding the limitations described above, data describing the relationship between fatal drowning and tides has not been previously reported. This study will provide novel data upon which future explanatory research studies may be based.

5. REPORTING AND IMPLEMENTATION OF RESULTS

The findings of this study will provide insight into risk factors associated with fatal drowning in the ocean, which will inform future research and provincial drowning prevention strategies. Findings will be shared with the Western Cape Water Safety Task Team which consists of water safety and drowning prevention stakeholders in the Western Cape. Publication as an original article or short report in a peer reviewed journal is also anticipated.

6. RESOURCES

6.1. Resource utilisation

Fatal drowning data will be sourced from the Western Cape Forensic Pathology Services. Accurate tide charts are available upon request from the South African Naval Hydrographic Office.

6.2. Budget

This a low-cost study as there are no costs associated with obtaining the required data.

ITEM	COST
Principal Investigator (Personnel compensation)	nil
Consulting services	nil
Statistical services	nil *
Travel & Transport	nil
Telephone, computer & internet	R1000
Printing & copying	R250
TOTAL	**R1250**

* Statistical support will be provided by the Division of Epidemiology and Biostatistics, Stellenbosch University as subsidised by the Faculty of Medicine and Health Sciences' Dean's Fund.

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Appendix 2: Health Research Ethics Committee approval

UNIVERSITEIT
STELLENBOSCH
UNIVERSITY

Health Research Ethics Committee (HREC)

Approval

New Application

21/01/2019

Project ID :8246

HREC Reference # S19/01/008

Title: Distribution of fatal ocean drowning by tidal phase and state in the Western Cape

Dear Dr Charlotte Roos

The **New Application** received on 19/11/2018 10:04 was reviewed by members of **Health Research Ethics Committee via expedited** review procedures on 21/01/2019 and was approved.

Please note the following information about your approved research protocol:

Protocol Approval Period: 21 January 2019 - 20 January 2020

Please remember to use your project ID (8246)on any documents or correspondence with the HREC concerning your research protocol.

Please note that the HREC has the prerogative and authority to ask further questions, seek additional information, require further modifications, or monitor the conduct of your research and the consent process.

After Ethical Review

Translation of the informed consent document(s) to the language(s) applicable to your study participants should now be submitted to the HREC.

Please note you can submit your progress report through the online ethics application process, available at: Links Application Form Direct Link and the application should be submitted to the HREC before the year has expired. Please see *Forms and Instructions* on our HREC website (www.sun.ac.za/healthresearchethics) for guidance on how to submit a progress report.

The HREC will then consider the continuation of the project for a further year (if necessary). Annually a number of projects may be selected randomly for an external audit.

Provincial and City of Cape Town Approval

Please note that for research at a primary or secondary healthcare facility, permission must still be obtained from the relevant authorities (Western Cape Department of Health and/or City Health) to conduct the research as stated in the protocol. Please consult the Western Cape Government website for access to the online Health Research Approval Process, see: https://www.westerncape.gov.za/general-publication/health-research-approval-process. Research that will be conducted at any tertiary academic institution requires approval from the relevant hospital manager. Ethics approval is required BEFORE approval can be obtained from these health authorities.

We wish you the best as you conduct your research.

For standard HREC forms and instructions, please visit: Forms and Instructions on our HREC website https://applyethics.sun.ac.za/ProjectView/Index/8246

If you have any questions or need further assistance, please contact the HREC office at 021 938 9677.

Yours sincerely,

Mrs. Melody Shana ,

Coordinator,

HREC1

Appendix 3: Instructions to authors for chosen journal

This manuscript was formatted for submission to the *International Journal of Aquatic Research and Education*, an open-access, peer-reviewed DHET accredited publication.

The instructions for authors are available here: https://scholarworks.bgsu.edu/ijare/for_authors.html