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Abstract

Access to water is an important aspect of development. Finding simple technology that can ease in water access helps communities build capacity in other ways by eliminating much of the time and labor intensive activity typically spent in water collection. This is particularly true for women and girls. Tanzania is a country where water security is low and most rural communities lack access to water within a 15km distance. Because of this, it is particularly important in this region to develop low cost, sustainable water transport solutions. The Hippo Water Roller is a design for such a transport system. Over 26,000 rollers have been distributed throughout the developing world and they have helped communities collect water with ease. However, because of the bi-modal rainy season in Tanzania and the intensity of rainfall, the roller is not successful for a large portion of the year. Mud and water prevent the roller from working how it was designed to. With guidance from the World Food Program we were able to see a need for a modified design for water transport in the region. Our design combines the benefits seen from the Hippo Water Roller with modifications made to optimize the performance in the rainy season. The addition of an inflatable bladder, treading and a mud scraper, eliminates many of the problems associated with the Hippo Water Roller. This simple, concise and relatively cost effective design has great potential at increasing the effectiveness and use of water rollers within rural Tanzania as well as globally.

Overview

The goal of this project was to find a means to improve a system that is already very much ideal outside of a specific environment. Because of this adding functionality to the design became challenging. . Many times throughout development is felt as though we were trying to 'redesign the wheel' and working with many factors outside of our control. We could not change the environments we were working in or change the speed at which the roller could be pushed. We also could not add much complexity because part of the beauty of the Hippo Water Roller, and the reason for its success, is precisely in its simplicity. The final design is concise but effective. It takes the underlying design principles that have made the Hippo Water Roller a success and has improved upon them in order to make the solution viable in a specific set of circumstances. Through this report we will explore how the modified roller system has been made effective in these circumstances and the steps we took in understanding how this could be made possible.

Problem Statement

Introduction

In order to understand how to improve the system it was important to understand why such a system was important. The primary reason is that issues associated with water collection limit development. Traditionally water collection is extremely strenuous and consumes time and energy that could be dedicated to other activities. This is evident in the lives of women and girls who do the majority of domestic tasks. The time that these tasks demand of them ultimately limits their access to education and empowering roles in the community. Distributed by the World Food Program, an alternate water transport method known as the Hippo Water Roller has been coveted as the solution. However, it is unable to function in the rainy season, which plagues the country for more than half of the year (Fig. 2). With this in mind, a new system is required to not only to cope with the traditional issues associated with rural water collection but also to manage such issues in varying conditions.

Global Water Issues

An important catalyst for development, water is key to the success of rural communities. While water availability is linked closely to health and welfare, it also impacts the distribution of household labor due to the time and energy spent collecting water (Madula, 2003). In many countries in the world, collecting water is an activity that consumes much of the day. For a family of five, it is estimated that 80L of water is required for minimal daily tasks (Van Coppen, 2004). This would mean four round trips to the nearest water source, which can be a considerable distance. The devotion of so much time to water collection is particularly detrimental in impoverished regions and agricultural subsistent economies, of which rural Tanzania is both. Having easily accessible sources of water can determine the ability of a society to develop proper infrastructure, education and health services.

Another obstacle to community development is the protection of water from contamination during collection and storage. The World Health Organization recognizes that contamination during transport and household storage can present a significant health risk (WHO, 2011). Therefore, effective technology in the storage and safe transport of water has a direct role in reducing infectious diseases. This creates further room for productivity and other benefits associated with improved health. (WHO, 2011)

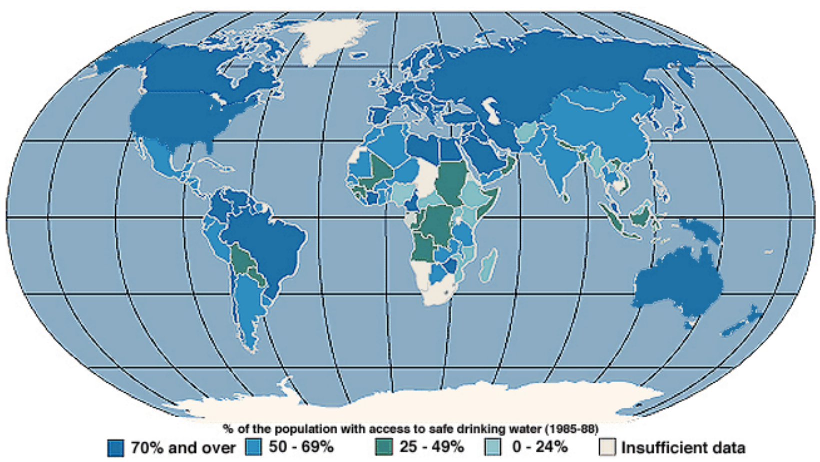


Fig. 1 Global Water Availability . Source: earth.rice.edu

Tanzania

Tanzania is located in Eastern Africa just south of Kenya and to the north of Mozambique. (Fig.1) The country is a developing nation where much of the population still struggles with extreme poverty. This is particularly true in rural regions where 74% of the population lives today (CIA Factbook, 2011). While the country is culturally diverse and split between a Muslim and Christian population, it is marked by relative political and cultural stability (USAID, 2011). Tanzania is rich in resources such as diamond, gold and iron. However, because the country relies heavily on agriculture, water insecurity in rural communities continues to plague and limit citizen's ability to prosper.

Fig. 2 Geographical Location of Tanzania
Source: pbs.org

Water in Tanzania

As seen in Tanzania, water collection disproportionally affects the lives of women and young girls because they are responsible for most domestic activities within rural impoverished communities (Kyessi, 2005). This includes meal preparation, cleaning, washing and water collection. The additional amount of time required to complete these tasks when water sources are distant from family dwellings has an adverse effect on the women and girls and subsequently the community as whole. The girls are unable to become educated and the women are unable to develop any further roles within their community. This stops potential microeconomic and social development in its tracks (James, 2003).

Because its wide-reaching impact it has never been more important to find time saving technology for daily domestic tasks. Of these tasks, water collection is of particularly great importance in Tanzania. Approximately 60% of the population does not have access to piped water and most communities with water "within the village" are still travelling between 5 and 15km to the nearest water source (Kyessi, 2005). This issue is magnified in the dry season when the distance to water sources sharply increases (James, 2003).

Policy makers within the country and abroad have put protocols in place to try and mitigate the issue. The water policy developed in the mid nineties clearly aimed to ensure that 90% of Tanzanians would have access to water within a five minute distance. This goal was still far from realized in the beginning of 2002 when the act was amended. The amendment placed considerable emphasis on the decentralization of decision-making. It stressed the importance of water users in driving local programs and projects as a means of achieving sustainability. (Cleaver. F, 2006). However, despite continued integrated water management policy, the needs of the most vulnerable rural populations are yet to be addressed. Despite an awareness and willingness to find solutions, the problems associated with and compounded by water collection persist to this day. For this reason, transitional, appropriate technologies are necessary to mitigate the current state of water insecurity in the region. By ensuring water can be accessed efficiently and safely throughout the year, technology can play an important role in easing the burdens caused by excessive distances and strain related to water collection.

Existing Solutions

The solutions that exist so far are limited. Traditional water carrying is still practiced in much of the country. It involves carrying up to 20L on the head the entire distance from the water source (Cleaver, 2006). This method is problematic due to the physical problems stemming from the strenuous nature of the load. Studies have shown that excessive pressure from carrying full loads of water on the head can cause serious complications with childbirth (Bogdan 2009). Additionally, the capacity of such conventional water collection is limited. These containers are often open to the air which can lead to contamination and the greater prevalence of disease (WHO,2011). Another option, which is less strenuous, is to simply take recycled containers and carry them by hand. This has similar issues in limited capacity and further, depending on the prior use of the containers, there is potential for contamination.

The most successful solution to date has been the invention of the Hippo Water Roller. Distributed in Tanzania by the World Food Program, the hippo water roller escapes many of the downfalls of traditional water collection. By having a capacity of up to 90L, the system is less strenuous by using the bin as a roller (Fig 3). This allows for less strenuous transport of much greater volumes of water. While the system has a true weight of over 200 kg, the weight of the system once distributed by the roller is a mere 22kg (source:

Figure 3 The Hippo Water Roller
Source:http://en.howtopedia.org/wiki/How_to_Transport_Water

http://www.hipporoller.org/product). Over 26,000 have been distributed privately and through various aid agencies throughout the world.

While the Hippo Water Roller seems like the perfect solution in many parts of the world, in Tanzania it is falling short. This is due to an inability of the system to function in environments that are not ideal. In the rainy season this is particularly difficult, where added water and mud make the system unusable. Due to the nature of the rainy season in the region, this can make the solution viable for as little as 6 months of the year (Reichel,2011) .

Environmental Factors: Temperature and Rainfall

The rainy season in Tanzania is bi-modal and dependent upon the regions. On average however, the rainy season lasts between November and April with an average of 140mm a month (Fig. 4). Between May and October, there is an average of 9mm per month (Tanzania Climate, 2011) . This causes a substantial issue because any solution has to be adaptable to both the dry season and the wet season. (Reichel, 2011). With the Hippo Water Roller already being functional in the wet season, any design working on the fundamental principles would be assumed to function as well given those conditions. Therefore, our design focuses on the particular circumstances brought on by increased rain.

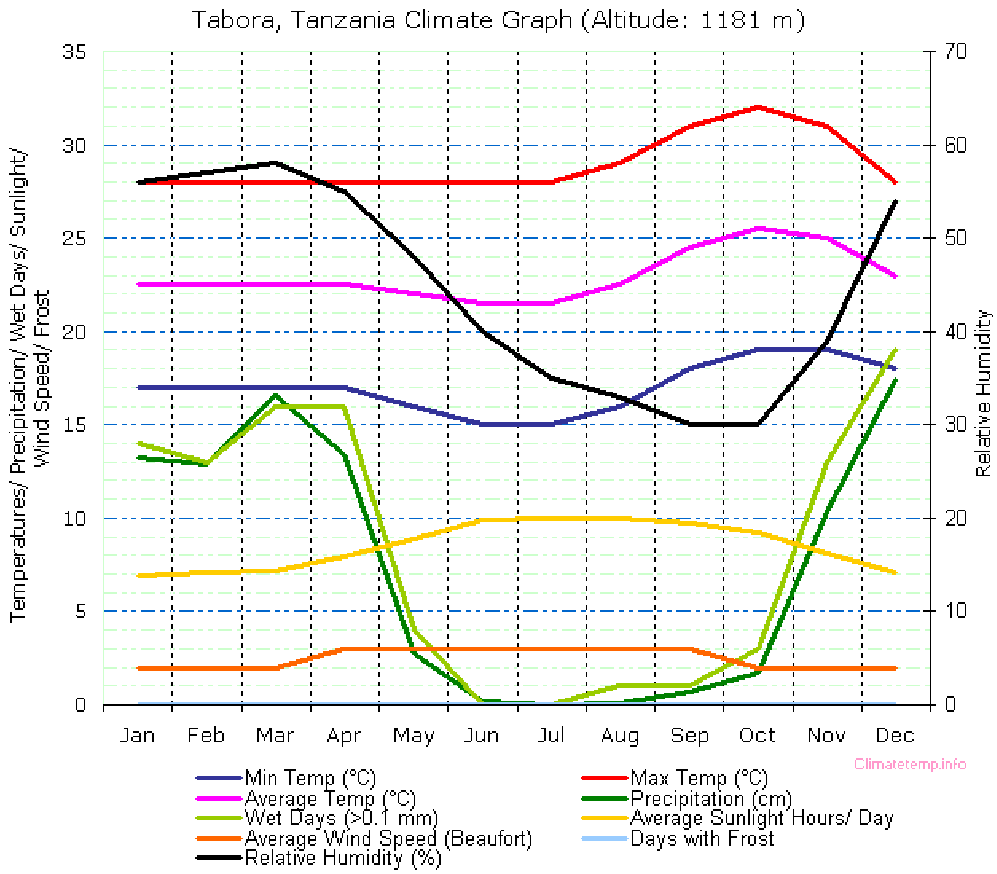


Fig.4 Tanzania Climate Graph. Precipitation indicated by dark green. Source:http://www.climatetemp.info/graph/tabora_files/image001.gif

Two Different Scenarios

Part of any analysis of terrestrial systems should include an analysis of the soil and terrain type. This is particularly important in order to understand how increased rainfall will effect the terrestrial environment on which the roller functions. In Tanzania, the soil texture has a huge variation form location to location and the moisture content complicates the issue even more. The results of this study suggest that Tanzania has a high percentage of loam-textured soils with a high percentage of sand, which are probably better than clay soils for burrowing and nesting, particularly in the rainy season. The lower preference for clay soils is probably related to the poor aeration in these soils and the water logging that occurs during the wet season (Massawe, 2008).

Two different scenarios were considered; those of “sliction” (situations with pooling water) and stiction (situations with mud). Stiction is experienced in situations with a rough wet substrate (mud). It is dependent upon the speed, the area of contact, the pressure per unit area, the surface tension of the film moisture, and the surface itself. Sliction is experienced in situations of surface water accumulation (ponding). It is dependent upon the pressure per unit area, the speed, the moisture content, the viscosity, the smoothness of the surface and amount of material of which the surface is composed. (NRC, Cargo Report No. 3). However, our design objective is improving the feasibility of the roller for the worst scenario- which we have already established as stiction (situation with sticky saturated clay mud). . For the purposes of analysis we have assumed that the soil is clay. This assumption was made due to the fact that clay soil would cause the most stiction in wet conditions. In case of sliction, the benefit of buoyancy can help the success our design by decreasing the normal load on the ground. Because of this it is considered the “worst case” scenario and all design parameters from this point were considered from this vantage point.

Initial Design

Initial Design Considerations

The proposal for our design is therefore to design a water transport system that encompasses all of the benefits of the Hippo Water Roller while having the added benefit of usability in the rainy season. The parameters of the design are to be able to transport at least 90L, to have a low functional weight, to be able to minimize contamination, to be functional in all seasons and terrain.

While encompassing all of this there is a greater parameter that must be met as well. Due to the nature of the communities the solution is for, the solution must also be appropriate for the communities it is entering. Appropriate technology is defined as technology that keeps in mind the social, economic, cultural and environmental expectations and requirements of the population being designed for.

(Kaplinsky, R. 2011) This must be considered through every step of the design process. For this project it means that cost has to stay low, parts have to be minimal, and the design must be functional within existing infrastructure and cultural norms of the communities (Kyesssi, A. 2003)

In Winter 2011 we analyzed various design options in order to maximize the performance in the rainy season. We considered the two situations listed above, those of stiction (muddy terrain) and those of sliction (terrain with pooling water). While both would require different design parameters it was our goal to find a solution that would perform optimally in either. The final solution from Design II was a rubber inflatable outer shell is added outside of the existing roller (Fig. 5). Assuming the weight of the rubber is negligible compared to the weight of water in the inner bin, the added radius would increase buoyancy and decrease rolling friction.

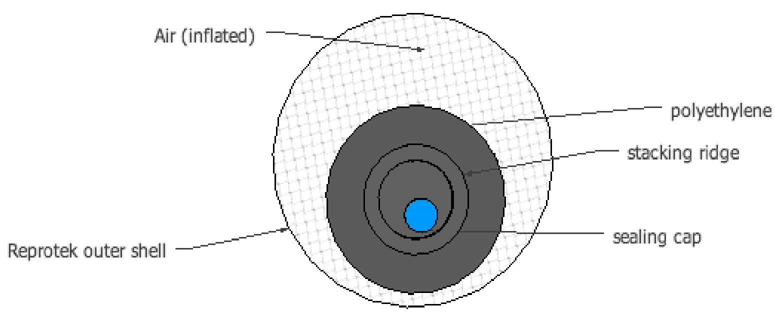


Fig 5. Simple Schematic "Water Roller initial Design"

Design Obstacles

While the initial design was beneficial in environments with pooling water and little adhesion it still struggled significantly with problems from adhesion and respectively cohesion when in environments that were very muddy. Through continued analysis it became clear that two major obstacles hindered the overall success of the design. These can be summarized as follows.

- Primary: increased surface adhesion from presenting of water and mud
- Secondary: accumulation weight of mud on the roller

The two obstacles are interconnected. The adhesion on the surface from mud (stiction environments) prevents mobility and the continual addition of mud adds to the weight of the system considerably, which makes any benefits from the added radius marginal.

Amended Objectives:

In order to achieve and solve the primary issues we refined our objectives for the performance of the roller. We determined that the main objectives for the design in order to be successful in all environments are:

- Primary: Decreasing rolling friction overall
- Secondary: Reduce adhesion of mud
- Tertiary: Increase Buoyancy
- Quaternary: Optimize the contact surface area for minimum combination of hysteresis and pressure acting on the ground

Final design:

Design Summary

i. Outer Shell
   a. Inflatable
ii. Inner Bin
   a. Sealing lid
   b. Stackable
iii. Handle
iv. Scrubber

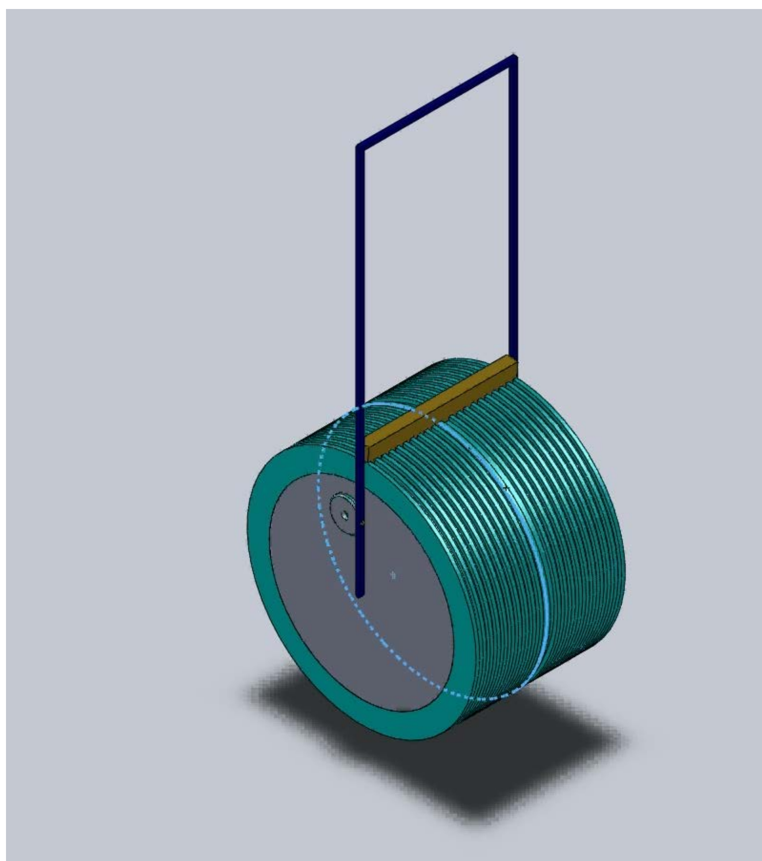


Fig. 6 Final Design

Our goal in Design III class is to optimize the design using mathematical analysis to prove the feasibility and surpass the benefits of the Hippo Water Roller in each type of environment. The analysis leads us to the conclusion that the design with the greatest impact and variability would continue to be the bin with an outer rubber shell. When the shell is pumped with air is causes greater surface area and greater buoyancy of the system. The immediate advantage comes from increasing the radius while not significantly increasing the weight. In order to improve the system, radial-ply treads and silica were added to the inflatable rubber shell. A scraper was also added to eliminate adhesion.

Design aspect I:

i.The Outer Shell

Dimensions: r=24.7cm, h=93.5cm, t=1mm
Material: Rubber made of recycled tires (with silica)
Other Features: Treaded

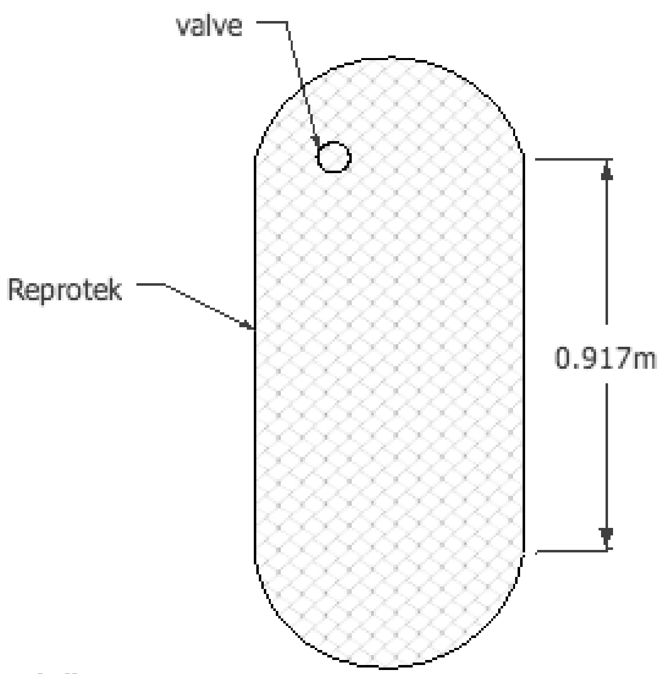


Fig. 7 Inflatable Outer Shell

The outer shell must be composed of a material that is inflatable, has a high tensile strength and it must not break down easily. Our initial analysis lead us to a material called Hypalon or chlorosulfonated polyethylene (CSPE) synthetic rubber (CSM) .

This material is used in inflatable boats and other waterproof applications that require great strength and variability. The properties of the material that make it ideal are its resistance to chemicals, temperature extremes, and ultraviolet light and its strength.

However, this material was discontinued in 2001 due to large environmental concerns. The material was also incredibly expensive which does not fit into our economic constraints. A suitable replacement for Hypalon has been stated to be Reprotek. Reprotek, like Hypalon, is resistant to chemical, temperature extremes and UV light and has a high impact resistance. This material is also made from recycled tires which is beneficial as the region already has tire recycling. The Hypalon would have mild treading as opposed to being smooth. This allows for greater reduction of rolling resistance. Further, the addition of silica in the manufacturing process would allow for more rigid contact.

This amended material not only meets the physical constraints but also fits well within the social, economic and environmental constraints set out earlier in the proposal. By using recycled tires and being manufactured locally, this solution becomes incredibly accessible to rural communities and encourages local economies.

Design Aspect II:

ii. The Bin.

Dimensions: r=17.5cm, h=90cm, t=2mm

Material: Polyethylene

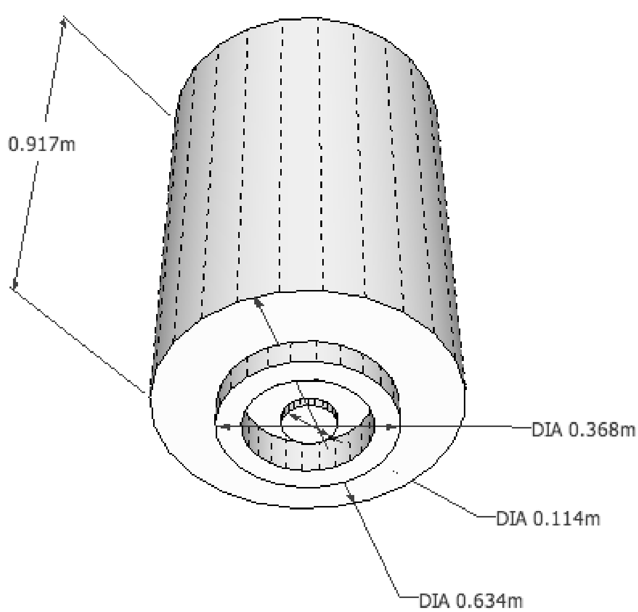


Fig. 8 Inner Bin

The bin's design works on the fundamental design principles laid out by the Hippo Water Roller. However, it has been optimized for greater storage and distribution capabilities. The bin is made of UV-resistant polyethylene. It has an equivalent capacity of 90L and stands just under 1 meter tall. The lid is embedded in the surface of the bin and along with a ridge, allows for stack ability to ensure easy transport. The lid itself is fully sealing and the diameter is large enough that collecting water and cleaning the bin can be done with ease. The bin itself although made to roll is also able to stand upright to provide sanitary storage.

Design Aspect III:

iii. The handle

Dimensions: r=4mm, h=110cm (from center of bin)

Material: steel alloy

The handle, made of a generic steel alloy. It attaches to either side of the bin to allow for the bin to be moved with ease. The handle is removable for transport where the bins must be stacked. Additionally, the fit is adjustable to meet the needs of adults as well as children.

Design Aspect IV:

iv. Mud Scraper

Material: Aluminum Alloy

The mud scraper is added at the base of the handle to eliminate the problem of adhesion. The scraper is set at a 45° angle with teeth that align with the treads on the inflatable outer shell. The scraper allows for the design to benefit from the added radius without succumbing to the affects of greater adhesion. Once the mud is scraped off, gravity causes the mud to fall to the ground. Any mud stuck can be easily removed manually.

Design Modifications

Treads vs Smooth Outer Shell

The tread pattern of the tire also influences the rolling resistance. Radial-ply tires' rolling resistance is significantly lower than the bias-ply one (Fig 9). Other contributing friction factors include wheel radius, and forward speed. The rolling friction is directly proportional to the applied load and inversely proportional to the radius of the cylinder.

Treaded Surface

Analysis was done to see if added treads would aid the design. When looking at other systems designed for the mud, tractors and military vehicles, it is easy to see that treads can greatly benefit a rolling system. This is partly because the road adhesion coefficient between wet rough surface and a patterned tire is lower than that of a smooth tire; The main advantage is due to the fact that water can be directed between the treads on a patterned tire.

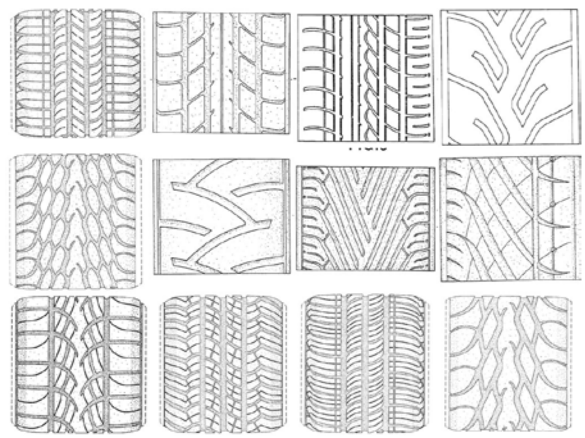


Figure 9 Various Tread Patterns

Smooth Surface

The other option is to have a smooth surface. A Smooth could offer the potential benefit of hydroplaning. The rolling motion creates hydrodynamics pressure in the water over a flooded surface. At a particular speed the hydrodynamic is strong enough to life the tire, and all contact with the ground is lost. The resistance decreases dramatically (Wong, 2010).For smooth or close-patterned tires that do not allow escape paths for water and for patterned tires on flooded surface with a fluid depth exceeding the groove depth in the tread the speed at which hydroplaning occurs may be determined by the formula presented by Horn and Joyner (Appendix A)

Treads vs Smooth : Conclusions

In order to see whether we could benefit from hydroplaning we did some basic calculations. Assuming that the average human walking speed is approximately 5km/h (Knoblauch, 1991) and that the design weight is approximately 0.95kN we calculated the minimum area necessary to benefit from hydroplaning would be 1.53m$^{2.}$ This is much larger than the current surface area of ***. Therefore, since we cannot use the benefit of hydroplaning, we chose tread tire over smooth tire to decrease adhesion by directing mud and water away from the system. Due to adhesion the benefit of the tread will be less in situations with mud and more beneficial with pooling water. However, further amendments have been made to ensure optimal performance in either condition.

Proof of Concept

Our design essentially works on the principles of a pneumatic tire. The inflation pressure causes tension to develop and along with the inner bin, provides the primary structure (Koutny, 2011). As seen in the previous study of rolling mechanics, the rolling force is inverse proportional to the radius (Garbari, 1964). Since the rubber outer shell has the largest radius the rolling resistance will be the smallest. The inflatable outer shell also acts as a deformable carcass, which causes greater contact surface area, which, as discussed in the analysis of deformable systems on deformable surfaces, decreases the total rolling resistance (Wong, 2008).

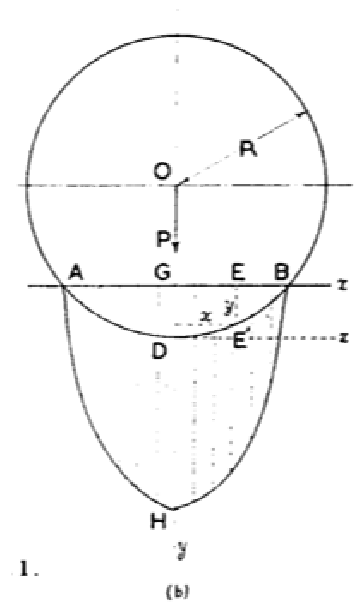


Figure 10 Elastic System Acting on a Deformable Surface (Garbari, 1964).

The work plastic deformation exerts due to the rolling material on the surface is rolling friction. As something rolls forward, it deforms the rubber ahead of it and in doing so does work on it (Neale, 2000). The rubber recovers elastically and does work on the rear portion of the cylinder pushing it forward. If the recovered energy in the rear portion were equal to that expanded on the front portion, the net work required to roll the cylinder would be zero. However, no material is ideally elastic. In the case of deforming and relaxing rubber, some energy is lost by elastic hysteresis (Neale, 2000). If the rubber shell is very bouncy, the hysteresis losses are very small. On the other hand, if the shell is very soft, the deformation energy may be really high.

Since we did not add any large amount of load on the original roller while raising the radius expressively, we reduce the rolling resistance quite a lot with the inflatable bladder alone (Wong, 2010). Since human walking speed is the limitation of our design, it is not possible to reduce the rolling resistance by raising forward speed. Plus, the rolling velocity does not reduce the rolling resistance considerably comparing the extra work we have to put it on.

Impact of Analysis on Design Priorities

Increase buoyancy

Inflatable Shell Increases Radius

Increase the total volume by increasing radius without significantly loads rising, we will decrease the total density of the superior roller by an important amount. As the water table on the surface increase, the water underneath the roller will flood up partial of the roller weight leading to normal pressure acting on the ground and reduce the rolling resistance almost proportionally. Comparing to original hippo water roller, increased radius will displace more water cause higher buoyancy (Wong, 2010).

There is increased benefit by having an inflatable outer shell because this provides not only the increased radius and deformable material but, as opposed to simply increasing the radius, also does so while minimal affecting the weight of the system due to the weight of the shell being negligible compared to the weight of the bin.

Decreasing Adhesion

Scraper and Treading Direct Water and Decrease Adhesion

While the concepts above acted as a basis for our preliminary design, it did not prevent the system from being overcome by adhesive and cohesive forces (mud sticking) and therefore rolling resistance, with the added surface area, was greater than the Hippo Water Roller alone. Therefore, further analysis and modeling was done to ensure the system had the lowest adhesion possible.

Adhesion contributes much more significantly to rolling resistance on wet surfaces. The stiction phase mentioned earlier occurs when there is enough moisture present to cause the soil to adhere to a sliding surface, but not enough to naturally be removed from the surface. The coefficient of sliding friction varies constantly depending on the soil properties. . For the ease of analysis in design II class, the surface of the system was assumed to be sufficient avoiding excessive adhesion. In Design III it was obvious that this would not be possible. By adding a scrapper attached to the handle on top of the roller will continuously brush down the mud while rolling forward. The weight of the roller will stay constant and treads can sustain their reducing adhesion job.

Optimize Pressure

Addition of Silica Increases Rigidity without Increasing Pressure

On deformable surfaces, high infiltration pressure results in increased ground penetration work, and therefore higher rolling resistance (Neale, 2000). With lower pressure there is a decrease in ground penetration but increase resistance due to the deflection of the tire and hence hysteresis loss. We can find the optimum pressure to minimize the penetration work and hysteresis loss by doing detail analysis for various surface terra-mechanics. High pressure may cause high ground penetration work even soil failure when water is accumulated on the surface. During research, we found adding silica during inflatable tire production can increase rubber's rigidity by 10 times without compromising its elasticity or increasing pressure (source: http:// www.tyres-online.co.uk/technology/silica.asp).

Comparative Analysis

The basis for this design is that it is an improvement on a previous solution. Therefore, it is important to establish a comparative analysis of both the modified roller , from now referred to as the Superior Roller, and the Hippo Water Roller. Analysis was done based on the weights, costs, components, rolling resistance and pressure. The data for all of this can be seen in the table below (Table I).

System	Accumulated clay mass (kg)	Total mass (kg)	Maximum pressure (KPa)	Rolling resistance force (KN)
Hippo rollor on dry clay	0	95	250	126
Hippo rollor on wet clay no mud accumulati	0	95	352	107
Hippo roller with 1cm mud layer around	6.3	101.3	358	109
Hippo roller with 5cm mud layer around	32.8	127.8	387	180
Superior roller 100% effiecency on wet cla	0	102.2	80	25.4
Superior roller with 1cm layer mud around	7.7	109.9	81	25.7
Superior roller with 5cm layer mud around	39.8	142	91	27.5

Table1 Comparison of Hippo Roller with Superior Hippo Roller

Method:

Using the mathematical analysis shown in Appendix A, analysis of varying scenarios was calculated. As can be seen by the data and in the graph below, varying conditions in the wet season were analyzed. First was for situations with no mud and pooling water. This would be the environment expected in sandy soil with high rainfall. Following this environments with varying amounts of mud cover were analyzed. Because perfect cleaning of the roller will be difficult given situations with high adhesion. It was assumed that in the best case 1cm of mud would persist and in the worst case 5cm of mud would persist. After 5cm adhesion would be completely cohesion as the mud would have a cohesive force with the mud stuck on the roller. For each scenario the accumulated clay mass, the total mass of the system, the maximum pressure and the rolling resistance were calculated.

Rolling Resistance

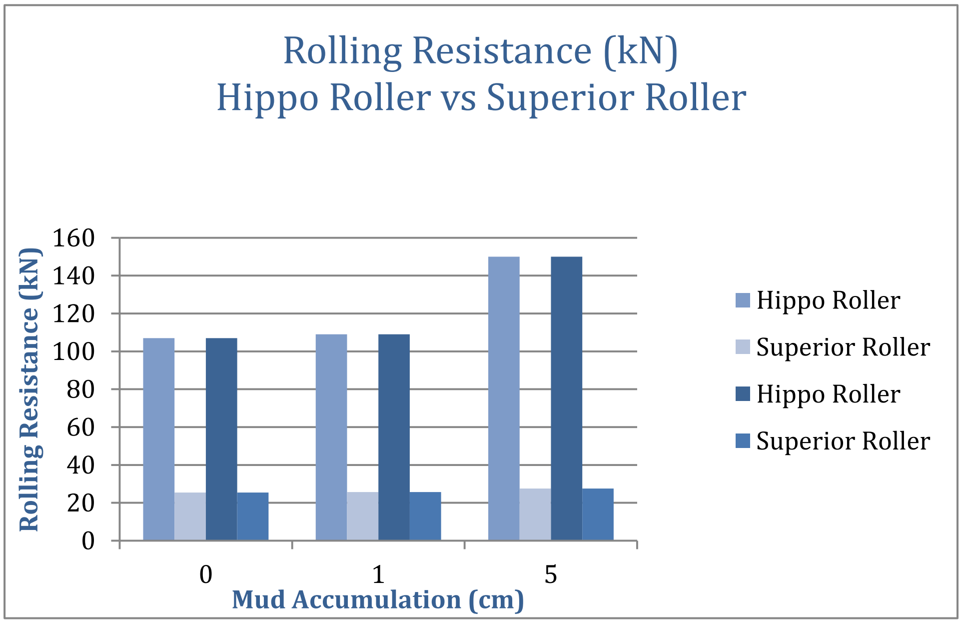


Fig 11 Comparing Rolling Resistance between Hippo Water Roller and Superior Roller

As can be seen above in Fig 11, the data proves that the modified roller, with mud scraper, performed better than the Hippo Water Roller even in situations where mud accumulation was comparable. Due to the lack of a mud removing mechanism, the Hippo Water Roller would accumulate more mud in identical environments. The modified roller still shows a considerable improvement in terms of rolling resistance alone. It would be assumed that given identical environments where adhesion was high, this improvement would only be heightened. This can be further seen when examining the percentage comparison below in Fig 12. Here, the modified roller is up to just 20% of the total rolling resistance seen by the superior roller.

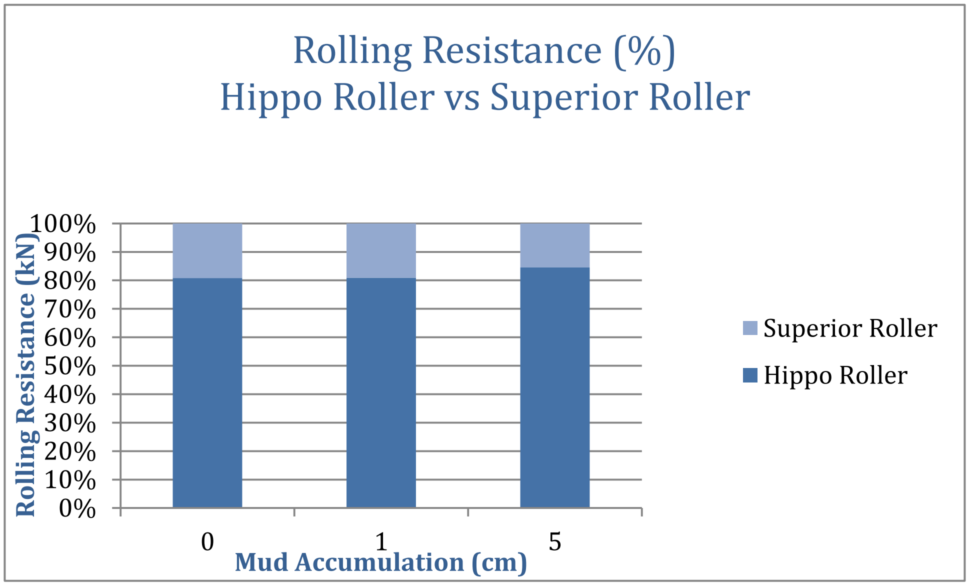


Fig. 12 Percentage Difference of Rolling Resistance between Superior Roller and Hippo Roller

Components Summary

The Superior Roller is adding to the fundamental design principles of the Hippo Water Roller. Because of this, it would be expected that the components of the Superior Roller would outnumber those in the Hippo Water Roller (Fig. 12). This is worth mentioning however because of the social environment being designed for. Because this design is essentially part of a development program, any added components mean added maintenance, shipping costs and comprehension. Because the design acts as a retrofit within the current infrastructure for the Hippo Water Roller, this was unfortunately unavoidable.

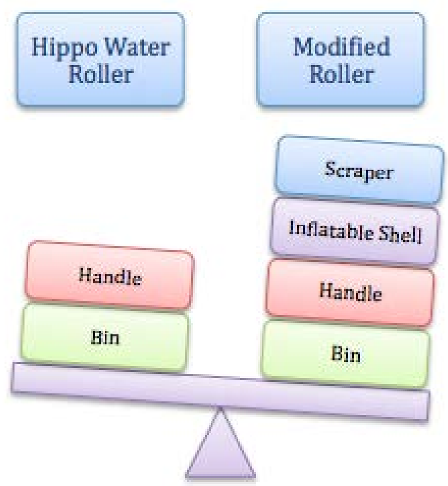


Figure 12 Component Comparison

Cost

Materials

It is important that the cost of the roller is comparable to the hippo roller. Regardless of the increase in functionality the design has to be affordable to fit within the existing funding mechanisms already in place. Making the assumption that the same South African manufacturer can be used, we estimate the price per bin and handle to be equivalent to the Hippo Water Roller, approximately $30 (handle included). It is estimated that the Retropek modification alone will cost an approximated $11 per roller. This is with Reprotek costing $21.56 per 100 yards and each roller being approximately 1.43m^{2}Included in this is the cost of the handle. The scraper, if made of an aluminum alloy can be estimated by Aluminum price being 0.95/kg today (source: http://www.metalprices.com). With the density of aluminum being 2.7*103kg/m3 and the volume of the scraper estimated to be 0.0042m3. The cost is approximately (Scraper cost= Volume *density *unit price) equal to $1.

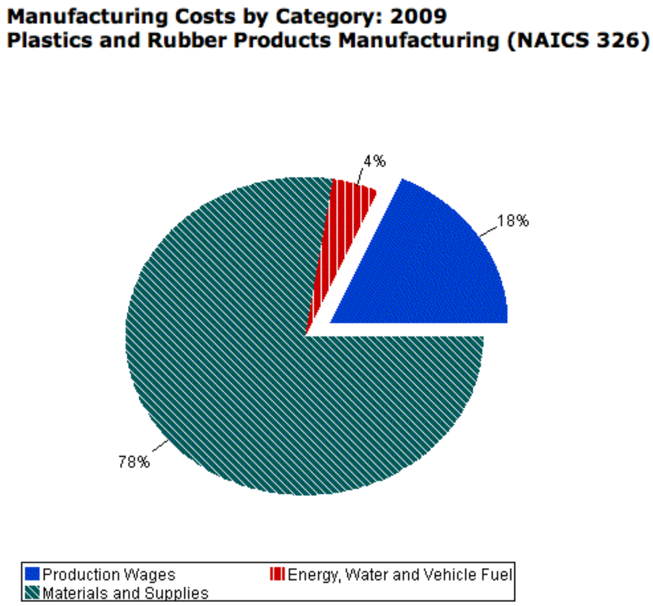
This cost estimate is outlined as follows:

Retroprek price (per yard): $21.50
Area required for outershell: 1.43m^2
Price per shell: $9.81
Valve: $0.10
Sweeper Cost= $1
Inner Bin and Handle Cost: $30

Total Materials: $40.91

Manufacturing

Rubber recycling manufacturing is available in Tanzania (source). When looking at the overall costs associated with manufacturing it can be assumed that the costs are not as significant as the material costs themselves. If using Canadian rubber and plastic manufacturing as an example, it can be seen that materials make up 78% of the total manufacturing costs. With manufacturing cost and distribution already included in the price of the Hippo Water Roller, an assumption was made that any further manufacturing costs (the scraper and inflatable bladder) are negligible.



Source: Stats Canada

Therefore the total cost associated with the design are: **$ 41.**

Cost Comparison

Compared to the Hippo Water Roller this is an increase of almost 30%. While some of the costs for the Hippo Water Roller estimate will be overhead costs it can be estimated that similar overhead costs will exist for the Hippo Roller. Greater volumes of manufacturing will mean a lowering of the price and it would be assumed that this would continue to improve.

Production & Distribution

Production facilities for the outer shell and inner bin were determined to be located in both Tanzania and South Africa. While cheaper production could likely be done abroad, for example in China, the importance of having the design have a positive affect of regional economics is an important aspect. Also, in order for the design to be sustainable, regional production is key.

Due to the nature of the market for the system, impoverished rural Tanzanians, the system would need to be attractive to organization such as the World Food Program, UNICEF and World Health Organization in order to be distributed. There is an assumption that distribution of our design would occur through similar channels as the original Hippo Water Roller. In order for the solution to be viable for rural developing communities, development and investment agencies would need to subsidize much of the cost associated with the design.

Large crates or even trucks very easily transport the system. The design has incorporated a stackable feature to ensure efficient easy storage during transportation (Appendix B, Fig. 4). This is an issue the Hippo Water Roller had which limited the capacity of agencies such as the World Food Program to distribute them (Reichel, 2011).

Advantages to the Design

Improves Performance in the Rainy Season

The immediate advantages of the design are that it allows for greater ease of water collection and greater capacity than conventional systems. It also improves upon existing innovations by being adaptable to multiple terrain and weather conditions based on the variability of the pressure while still being able to maintain rolling capacity.

Hygienic Storage

There is the added benefit of ensuring hygienic storage and transport with the potential for decontamination through pasteurization.

Relatively Simple and Cost Effective

The system is appropriate for rural developing countries. It is easy to use, relatively cost effective, and is accessible to communities by fitting in with existing water collection and storage infrastructure. It also has easy maintenance due to the strength of the inner bin and the easily accessible materials associated with the outer shell.

Ease of Distribution

With added ease of transport due to the stack ability, and local manufacturing, the distribution of the system can be done with ease.

Added Community Capacity

This ease and safety in terms of water collection is far reaching. It encourages community development, microeconomic development and the empowerment of women. Further, the system offers hygienic storage and transport of water in all seasons. With their potential use of thermal decontamination, this benefit can be even more effective.

Possibility of Retrofitting

Because the design builds on the fundamental design principles of the Hippo Water Roller it is possible that the advantages could be used as a retro-fit to the current technology. While there were improvements to the bin, this could act as a much more cost effective means of increasing access to water transport technology that is viable in the rainy season. If distributed as a retro-fit it can work with the existing infrastructure in place for the Hippo Water Roller and eventually be integrated into communities this way. This could also act as an important step in public education, maintenance, and integration of the new system.

Disadvantages of the Design

Inflation

It should be mentioned that an immediate problem exists if the inflation of the outer shell is too difficult. Due to there existing an optimal ratio of radius and pressure to ensure the lowest rolling resistance, the pressure within the outer shell is unknown until further analysis. Because of this, any calculations regarding the time required to pump would be incomplete. With a full analysis of the system, the viability of the use of a foot or electrical pump would need to be determined for rural Tanzania. If the pumping aspect of the design is too time consuming, it would defeat the purpose of designing a time saving mechanism entirely and a solution would need to be found. While electric pumps can be used, they would not be viable in all communities.

Damage to Outer Shell

There also are potential problems if the outer shell is left completely deflated. If the roller is used deflated, there is potential for destruction of the outer shell. This can be mitigated by educating how to patch the outer shell which is relatively simple with rubber systems. If the outer shell is worn down to the point where it is unable to be used, it could be recycled further.

Added Cost and Complexity

This design is also more expensive and complex than the Hippo Water Roller. This raises questions about the value of adding components and complexity to a design coveted for it's simplicity. Additionally, the added price point, while only approximated at $10, also poses a barrier. When being marketed for development work, a 30% increase in retail cost is substantial.

Community Acceptance

Community acceptance could also prove to be a barrier. Would the communities want the added component? Would they use the inflatable outer shell or simply opt to continue to use the barrel?

Conclusion

Through analysis of various environments, systems and solutions we have designed an alternative water transport system for rural Tanzania that outperforms the existing solution in the rainy season. The design is a simple one. It works of the successful design fundamentals that have made the Hippo Water Roller a success. The modified design has some limitations. It has more components and a higher cost than the original design. However, the added functionality means that in a region with high volumes of water in the rainy season, the roller can still be utilized. Our design takes into account the social, environmental and economic constraints that are present in rural developing communities. This technology has the potential to increase the quality of life of rural communities in Tanzania. However, the applications are not limited to that location or region. While the Hippo Water Roller was a success in using simple technology to solve one aspect of the problem, it's failure to be viable in more diverse terrain makes our solution not only more suitable, but viable globally. With further research we will be able to ensure the design is accepted by communities, is designed optimally and continue to assess means to make it as cost affective as possible.

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Appendix A: Mathematical analysis

Drum speciation: 52cm in diameter, 42cm in width and 0.5cm in thickness

Handle bar length is 1.1m form the center of the drum to human hand

$\rho_{polyethylene}$: 0.97g /cm^3; $\rho_{silicon\ rubber}$=1.2g/cm^3

Weight of the drum: $w = \left(\pi dw + \frac{\pi d^2}{2}\right) t\rho = 5kg$

Total weight of drum plus water=95kg

Inflated outer-shell speciation: 42cm in width, 0.3cm in thickness and 52cm in inner diameter (d_{in})

$$t\rho_{rubber}\left[\pi(d_{in} + d_{out})w + \frac{\pi({d_{out}}^2 - {d_{in}}^2)}{2}\right] + 95000 = 0.75\left(\frac{\pi {d_{out}}^2 w}{4}\right)\rho_{water}$$

d_{outer}=63.5cm

Weight of the rubber without the treads: 4.6kg

We decide to choose 0.5cm as tread depth as measured some mountain bike tires in supermarket. Each row is 1cm apart from each other ending up 22 rows with 2 sidewalls for a total of 42cm.

Weight of treads $22 * \pi * \rho * d_{out} * w_{tread} * t_{tread} = 2.6kg$

Total weight of superior roller 95kg+4.6kg+2.6kg=102.2kg

To recheck the total density of the superior roller is $\frac{102200*4}{\pi {d_{out}}^2 w} = 0.768g/cm^3$

The distribution of pressure P in the contact zone owing to an applied load N is equal to assuming the maximum pressure at the center of the contact zone

$$P = \frac{2N}{\pi a l}$$

Where l denotes the width of the cylinder, N is the applied load

$$a = \sqrt{\left[\frac{4Nr}{\pi l}\left(\frac{1-v_1{}^2}{E_1} + \frac{1-v_2{}^2}{E_2}\right)\right]}$$

Where v is Poisson's ratio, E is Young's modulus, r is the radius of the cylinder, and suffixes 1 and 2 denote the cylinder and plane respectively.

V_{poly}=0.46; V_{rubber}=0.5; $V_{saturated\ clay}$=0.5; V_{dry} clay=0.45; Esaturated $_{clay}$= 40 MPa; E_{poly}=236Mpa; E_{rubber}=1Mpa; $E_{dry\ soft\ clay}$=20MPa

All above value of silicon rubber is for smooth surface. We assume they do not change tremendously with adding treads. However in presence of treads, L, width of cylinder is almost decreased by two .With 100% working efficiency of scraper, $a_{superior}$= 0.027. On the other hand, original hippo water without mud accumulation, a_{hippo}=0.004. Maximum pressure comparison is $P_{superior}$=56kPa and P_{hippo}=352kPa. Using density of saturated clay 1826 kg/m3 and dry clay of 1089kg/m^3, All different pressure is summarized in table1 .

$$F = \frac{0.54P^{\frac{4}{3}}}{C^{\frac{1}{3}}L^{\frac{1}{3}}R^{\frac{2}{3}}}$$

Where,

F= rolling resistance in KN

P=reacting pressure of the ground in kN/m^2

L= width of the road contact in m

C= the terrain constant in kN/m^3

R = radius in m