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A study on chemical insertion and physical property changes of sunken timber; *Terminalia arjuna* along with river water in Sri Lanka

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Abstract:
Background*: With the massive development of the construction sector, the demand for timber, as a construction material is projected to increase over the next half century. It has predicted that with the increment of the global population, industrial roundwood consumption, including timber, will be increased by 28% to 61% from 2010 to 2060.The word timber specifies any stage between its harvesting and fitness for utilize as a construction material. Using of immense quantity of artificial timber preservatives, direct and indirect energy usages for timber processing make a contrast with the sustainability of timber as a construction material.The objectives of this research were (a) to analyze the chemical elements and their composition inserted towards Terminalia arjuna through river water bodies in Sri Lanka and (b) to calculate the compression strength and identify the color changes, grain pattern and texture of sunken Terminalia arjuna.*
Materials and Methods*:Purposively seven rivers in Sri Lanka were selected and 35 sunken and raw Terminalia arjuna samples were used. Genius 3000 portable XRF, Amsler Universal wood testing machine and Meiji metallurgical optical microscope were used to determine the chemical elemental characterization, compressive strength, color variation and grain pattern & texture respectively.*
Results*: Sunken Terminalia arjuna contained minerals in higher percentages; Mg (15-100%), S (17-100%), P (17-100%), Cl (10-100%), Fe (0.01-100%), Al (13-74%), Si (20-100%), Mo (19-25%),Ca (45-100%) comparatively to the raw timber samples of Terminaliaarjunaand specially, Ti, Mo, Sr and Sb which present in the sunken timber samples, strengthen, harden in a range of 380-2500 kgf with a clear difference of color, grain pattern and texture other than the raw samples.*
Conclusion:*Results showed that sunken Terminalia arjuna has enhanced chemical and physical properties compared to raw Terminalia arjuna.*
Key Word*: Construction materials;Sunken timber; Terminalia arjuna; Underwater logging.*

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I. Introduction

The history of the construction industry is as old as humankind. Timber is one of the oldest building materials used by man. Construction and its associated materials have been an extremely important to human evolution and our standards of living[1]. Although there are many construction materials have introduced including concrete and steel, still there is an irreducible demand for timber[2]. With the massive development of the construction sector, the demand for timber, as a construction material is projected to increase over the next half century and it becomes the major damaging cause to tropical forests. It has predicted that with the increment of the global population, industrial roundwood consumption, including timber, will be increased by 28% to 61% from 2010 to 2060[3]. The word timber specifies any stage between its harvesting and fitness to utilize as a construction material. Consummated timber is supplied for the construction industry, as hardwood and softwood for variety of applications, from housing to commercial buildings. Throughout thousands of years fiber dwells as a sustainable construction industry. There were several myths which were ratify the above statement. Although it is a natural product, from harvesting wood, processing to final distributing of timber it requires large amount of energy, directly as well as indirectly. Specially for the kiln drying, vacuum extraction and production of timber preservatives. The dynamic expansion of the world population and the inexpiable expectations of the construction industry root for the over exploitation of forest. So being renewable is not meant that it is sustainable[4]. Even though large woody buildings sequester carbon, it is released back to the atmosphere with the demolition and subsequent decay of the building [2]. Immense quantity of artificial timber preservatives which are used for the treating of timber, cause huge adverse impacts to the human health and the environment [5]. In the sense of sustainability, comparatively steel is more sustainable than timber as it has 90% recycling rate while timber is typically a single-use material. Usually at the end of the life of the building the

wood frame is landfilled or incinerated. For anything to become sustainable, it should be economically viable, environmentally friendly and socially accepted[4]. When comparing the life cycle cost and impacts for the environment as well as for the human health, question arises: Is timber a truly sustainable construction material? Since this, people are searching for a sustainable applicability of timber.

With the massive global demand for the timber, whole world is looking for a sustainable solution. As a result, companies such as Timeless Timber of Ashland, Wisconsin have started to re discover logs that sank during log drives on rivers as much as a century ago. In those days there was a limited market for sunken timber who appreciate the wood′s historic and environmental value[6]. But now it has become a promising solution for world′s taste for timber as a construction material. Though the underwater logging and the sunken timber concepts are new phenomena to Sri Lanka, most of countries such as; Canada, the United States, Panama, Brazil, Australia, Ghana and Malaysia have started to harvest them[7]. There were no any researches conducted regarding underwater logging or sunken timber and its benefits in Sri Lanka. Sri Lanka is a tropical island lying close to the southeast tip of India. It has a radial network of rivers begins from the central highlands. There are about 103 distinct river basins covering 90% of the island [8]. Chemical compositions of the river water can be altered due to the microbial pathogens, physical agents, chemical compounds or radiologic agents [9]. *Terminalia arjuna* is special class upper timber species conferring to State timber corporation, Sri Lanka. It can be easily found in underwater of rivers as it delights to grow peri of river banks [10]. If the chemicals from river water which contribute to the preservation or to enhance any other quality, are inserted to this highly dense *Terminalia arjuna*, it will happen better in low dense timber. It will be a great achievement for using timber as a sustainable construction material.This research has recognized the potential of re-discovering sunken logs from the rivers in Sri Lanka and their beneficial properties as a sustainable construction material.

II. Material And Methods

Experiments of the study were conducted in main four steps (Figure no 1).

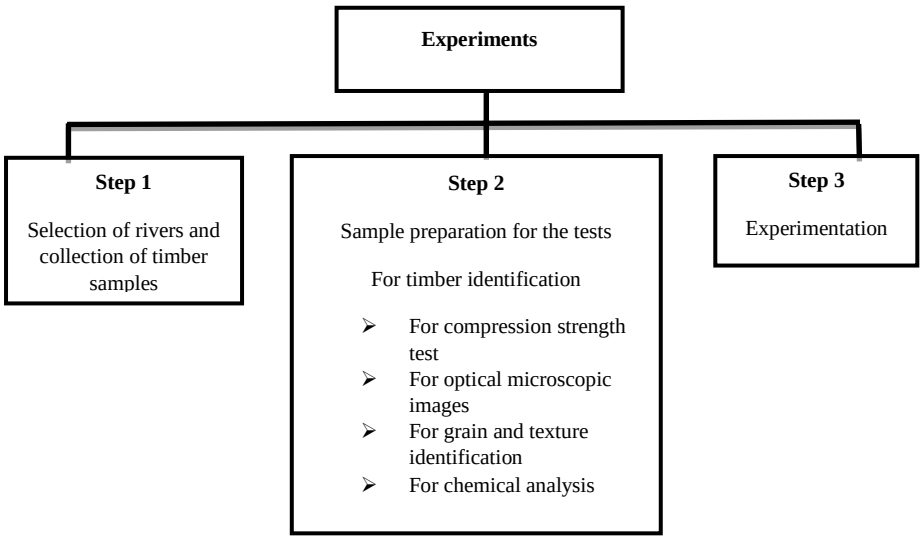

Figure no 1: Main steps of the experiments.

Selection of Rivers and Sample Collection

Purposively seven rivers were selected (Table no 1). The samples were collected from an intermediate place between the source and the drainage.

Table no 1: Selected Rivers.

Name	Length	Source	Drainage
River Gin	113 km (70 mi)	Sinharaja	Galle
River Kalu	129 km (80 mi)	Adam's Peak	Kalutara
River Kelani	145 km (90 mi)	Horton Plains	Colombo
Mahaoya	134 km (83 mi)	Hakurugammana	Negombo
River Mahaweli	335 km (208 mi)	Kotmale	Trincomalee
River Menik	114 km (71 mi)	Namunukula	Yala
River Walawe	138 km (86 mi)	Adam's Peak	Ambalantota

Terminalia arjuna samples from River Gin were collected from Thawalama area (6^0 20′35.7432″N $80^0$19′57.6012″E and 6^0 21′ 3.9168″N 80^0 20′3.2388″E); River Kalu-Thoradalla road ($6^0$37′22.0656″N $79^0$59′20.13″E); River Kelani-Pugoda area ($6^0$58′16.266″N 80^0 7′22.6092″E); Mahaoya-Rambukkana (70 18′54.3528″N 80^0 21′4.5612″E and 7^0 17′52.1484″N 80^0 36′20.538″E) and Alawwa area(7^0 17′35.5448″N 80^0 14′23.424″E); River Mahaweli-Peradeniya area (7^0 16′39.9108″N $80^0$36′20.538″E and 7^0 16′54.2604″N 80^0 36′24.8436″E); River Menik -Katharagama ($6^0$25′24.1428″N $81^0$19′32.124″E) and SellaKatharagama ($6^0$26′15.9216″N $81^0$18′1.5552″E); River Walawe-Liyangasthota ($6^0$14′8.8044″N $80^0$56′46.0932″E) and ($6^0$20′44.2248″N $80^0$56′46.0932″E).

Sunken timber samples were collected from sand mining areas of rivers. Five timber samples were collected from each seven rivers. Main focus was given in collecting sunken timber samples which appeared to be old, washed away over time with only a pith remaining. The above activity upgrades the accuracy of the chemical analysis of the sunken timber samples.

Raw, non-treated *Terminalia arjuna* timber samples were taken from timber mills which are located surrounding areas where the sunken timber samples were collected (Purpose: To maintain same environmental conditions which affect for the plant physiological and chemical mechanism). Purpose of the collecting raw timber samples was to compare both physical and chemical properties of terrestrial and sunken timber samples.

Preparation of Timber Samples

Sample preparation for the identification of timber species: Timber identification was done with the collaboration of state timber corporation Sri Lanka. A slide of timber sample was required for the test. It was essential to identify whether the selected timber samples are exactly authenticated *Terminalia arjuna*. For that, sunken timber samples (which were sufficient to make slides of timber samples) were submitted to the state timber corporation.

Sample preparation for compression strength test: Sample preparation for the compression strength test was assisted by the wood workshop of Department of Mechanical Engineering of Faculty of Engineering, University of Moratuwa. According to the standard NF B 51-007, timber samples with a length of 60 mm and a section of 20×20 mm^2 were used.

Study of grain pattern and texture of timber: Grain pattern and texture of raw and underwater timber were studied as physical property of timber. For a clearer study of grain pattern and texture, 4×4×1/2 $inch^3$ timber samples were used.

Sample preparation for optical microscopic images: Optical microscopic images were taken to observe the color variation from edge to the center of a cross section of sunken timber sample. Timber samples with a thickness of 3 mm were used to take optical microscopic images. The thickness that was used (3 mm) is not a standard size to cut timber samples to microscopic images. Hence, it is a hard material, for the test above pre-decided size was used as it is a difficult task to cut timber into thin slices (Figure no 2).

Figure no 2: Sample preparation for the taking of optical microscopic images (a, b; Preparation of sunken timber samples using power saw, c; Prepared sunken timber sample for microscopic images).

Sample preparation for the chemical analysis: Specifically, Chromium free blades were used to prepare timber samples. Blades were cleaned with 90% of Ethanol before cutting the timber slices from each of the timber samples which were collected from the rivers. From taking of timber samples out of rivers and until finishing the chemical analysis special concern was directed on external factors as there is a high possibility of contamination.

Experimentation for Prepared Timber Samples

Prepared timber samples were subjected to several tests; for the identification of the timber species and examining of physical and chemical properties.

Identification of timber: The identification of timber was done collaborating with the State Timber Corporation, Sri Lanka. As it was essential to carry out the other tests, the sunken timber samples were checked and made confirmed that the collected samples were authenticated as *Terminalia arjuna*. Raw timber samples were not involved in the above process of checking as they were taken from the timber mills with the prior

knowledge that they were authentic *Terminalia arjuna*.The testing procedure was done according to the methodology of examining external features, anatomical features by hand lens and comparing of external and anatomical features with authenticated samples available (APPENDIX A). The other tests were conducted after receiving the certificate of confirmation regarding the timber species (*Terminalia arjuna*) from the State Timber Corporation.

Compression strength test: Amsler 6000 kgf Universal Wood Testing Machinewas used to check the compression strength of timber. Maximum compression load of the machine is 6000 kgf. Basically, 20 raw and underwater timber samples were used to analyze the compression strength of the timber samples. Prepared timber samples were placed between two compression platensof 30 mm. The upper platen was fixed whilst the lower one rests on the bending beam. When the latter was raised, the specimen was crushed between the platens. Breaking load of the timber sample was taken as the compression strength of each timber sample (Figure no 3). The results of the compression strength test of both sunken and raw timber samples were included in a one bar graph in order to observe a clear difference between the obtained values.

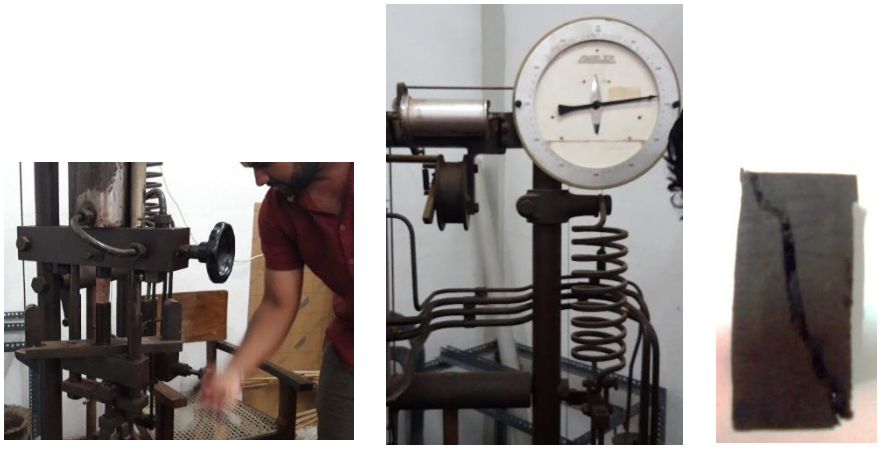

Figure no 3: Taking of compression strength value of timber samples (a; Gradually increasing the load, b; Reading the breaking load of the timber sample, c; The timber sample that is subjected to the compression strength test).

Taking of optical microscopic images: Figure no 4 shows theSoftware controlled MEIJI Metallurgical Optical Microscope which was used to take microscopic images. Microscopic images were taken with 50 times magnification of both raw and sunken timber samples from five consecutive points of their edge to the center. Seven ideal sunken timber samples were selected from seven rivers (one from each). The optical microscopic images were analyzed by observing the color variation from edge to the center of thin slices from sunken timber samples.

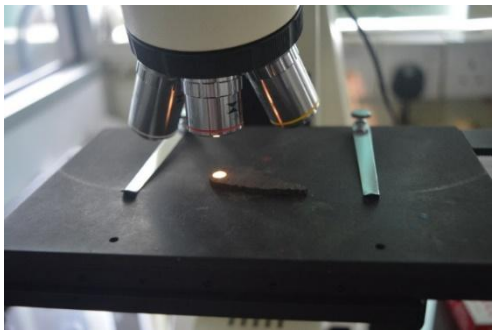

Figure no 4: Selecting of five points from edge to the center.

Chemical element analysis with X-ray Fluorescence (XRF): Genius 3000 handheld X-Ray Fluorescence Spectrometer features rapid non-destructive elemental identification and composition with precise detection of any element from Magnesium to Uranium (Figure no 5). Performance and the accuracy similar to Desktop XRF System. Genius 3000 XRF is harnessed with bluetooth, expandable SD Card for data storage and mini-USB for PC connection and built in high definition camera for real-time sample observation.

Figure no 5: Genius 3000 Portable XRF.

Five thin slices from each seven rivers were used for the chemical analysis. The same five consecutive points which were taken from edge to the center to take microscopic images were applied for the chemical analysis. Underwater and raw timber samples from the same context were subjected to chemical analysis with the use of Genius 3000 XRF. The chemicals that were detected by the XRF from the points of edge to the center of each samples were inserted into a spread sheet. The variation of the detected elemental chemical constituents was compared from the points of edge to the center of each timber samples.

III. Result

Physical Properties of Sunken *Terminalia arjuna*

Compression strength of the sunken *Terminalia arjuna:* Figure no 6 shows the compression strength of the sunken *Terminalia arjuna* vs raw *Terminalia arjuna* and the values varied in the range of 380-2500 kgf in sunken samples and 970-1620 kgf in raw samples, respectively.

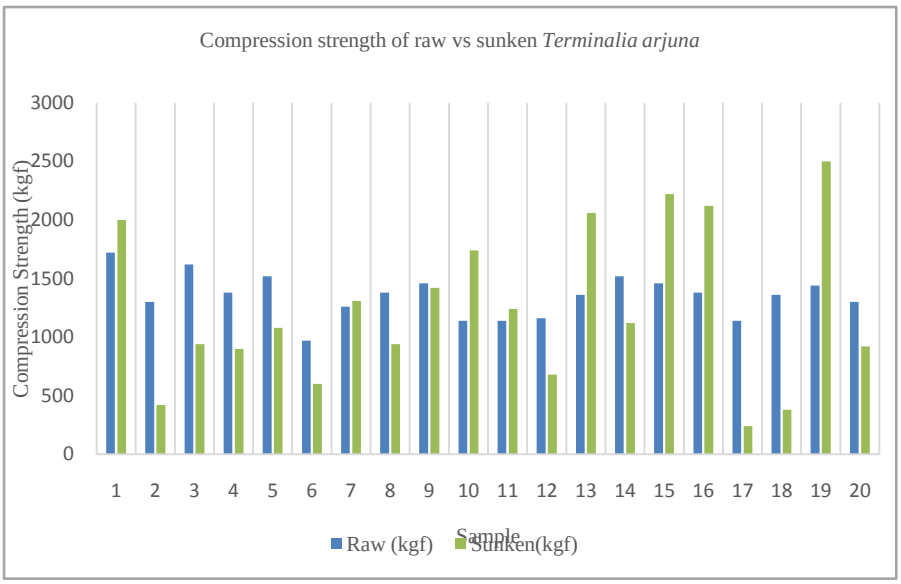

Figure no 6: Compression strength of raw *Terminalia arjuna*vs sunken *Terminalia arjuna.*

Color variation of the sunken *Terminalia arjuna:* Figure no 7 shows the natural color of raw *Terminalia arjuna*.Sapwood is pinkish-white and the heartwood is brown to dark-brown[10]. The color variation of the selected sunken *Terminalia arjuna* samples from each river are shown in following Table no 2.

Figure no 7: Natural color of raw *Terminalia arjuna*.

Table no 2: Color variation of selected sunken *Terminalia arjuna* samples from the rivers.

	Point 1	Point 2	Point 3	Point 4	Point 5
Sample from River Gin					
Sample from River Kalu					
Sample from River Kelani					
Sample from River MahaOya					
Sample from River Mahaweli					
Sample from River Menik					
Sample from River Walawe					

Grain pattern and texture: There was a clear difference observed in the grain pattern and the texture of sunken *Terminalia arjuna*other than raw *Terminalia arjuna*. Plain sawn and live sawn of the sunken *Terminalia arjuna* timber samples are shown in Figure no 8. It showed a straight to somewhat interlocked grain pattern and a medium texture [11].

Figure no 8: Sunken *Terminalia arjuna* timber sample (a; Plain sawn, b; Live sawn).

Raw *Terminalia arjuna* samples from North Western area, darker in color and the raw *Terminalia arjuna* samples from rest areas of the island comparatively lighter in color. Figures no 9 and 10 show plain and live sawn raw *Terminalia arjuna* timber samples from North Western and South Western areas. Raw *Terminalia arjuna* has an interlocked grain pattern and a coarse texture. Wood is diffuse-porous and Rays are fine to very fine, distinct only under hand lens[12].

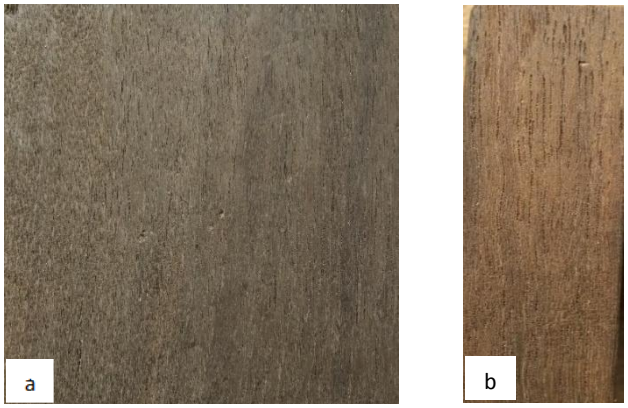

Figure no 9: Raw *Terminalia arjuna* timber samples from North Western area (a; Plain sawn, b; Live sawn).

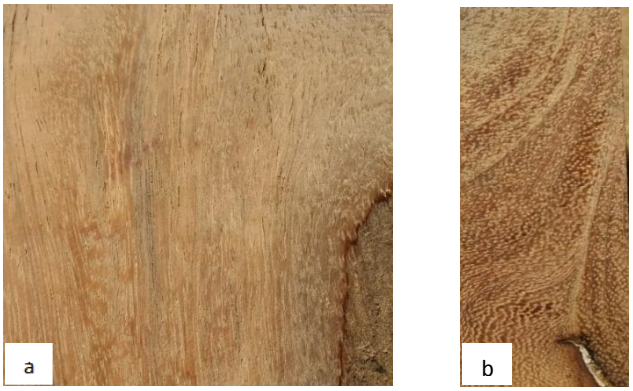

Figure no 10: Raw *Terminalia arjuna* timber samples from South Western area (a; Plain sawn, b; Live sawn).

Chemical constituents of the sunken and raw *Terminalia arjuna* timber: According to the chemical analysis, raw *Terminalia arjuna* samples contained, Mg:18-39%, S:16-37%, P:19-45%, Cl:9-34%, Fe:0-0.01%, Al:14-37%, Si:20-48%.

Conferring to the chemical analysis, sunken timber samples of *Terminalia arjuna* contained higher atomic percentage within 1×1 mm^2 area compared to raw timber samples of *Terminalia arjuna.* Table no 3-9 show that the almost all the samples contained Mg:15-100%, S:17-100%, P:17-100%, Cl:10-100%, Fe:0.01-100%, Al:13-74%, Si:20-100%, Mo:19-25%, Ca:45-100%. Corporately, a gradual decrement of the concentrations of Mg, Cl, P, Si, Al and S were visualized from outermost to the innermost point of the samples. It was appeared an observable darker to lighter color changes from edge to the center (APPENDIX B).Moreover, Ti, Sr and Sb were detected from sunken timber samples of *Terminalia arjuna* which were not sensed by raw timber samples of *Terminalia arjuna*.

Table no 3: Chemical constituents of sunken *Terminalia arjuna* -River Gin.

Sample	Elements	Point1(%)	Point2(%)	Point3(%)	Point4(%)	Point5(%)
1	Al	54.57	45.32	38.86	30.22	26.62
	Mg	23.44	25.62	48.56	18.16	18.23
	Cl	47.85	38.95	32.56	21.99	20.45
	P	100		35.46		25.64
	Si	100	34.78		20.35	
	S		30.63			
	Fe		54.3	32.56		
	Mo	25.7	20.45			
2	Mg	100	100	100	76.39	69.01
	Cl	59.03	50.99	46.52	38.19	38.15
	Al	22.69	60.43	32.87	47.35	28.64
	Si	77.31	67.13	49.01	53.48	40.97
	Sr	22.71				
	S			32.14	23.86	
3	Al	100	25.68	70.27	1.85	25.98
	Mg	34.35	57.56	60	18.9	37.12
	Si	62.88	59.55	42.36	48.32	34.27
	Cl	42.44	40.91	40	29.81	23.29
	Fe	36.58				0.01
	S	100	37.24		29.25	
	P			42.52		
	Sr	32.01				4.11
4	Mg	67.38	45.84	36.72		26.63
	Al	73.37	67.28		23.37	
	Cl	46.18	61.26	59.97	25.67	50.73
	Si	64.53	38.74	40.03	50.96	33.37
	S	42.57				31.24
	Fe				0.01	
	P					18.03
	Sr	2.73				
5	Al	67.15	56.11	51.51	31.17	25.74
	Mg	53.98	41.01	26.48	22.83	18.12
	S	23.58	21.81			18.98
	P	22.43	46.02	18.98	29.93	
	Cl	45.44	43.89	18.18	29.06	24.29
	Si	35.07		33.87	56.79	27.41
	Fe	0.01				

Table no 4: Chemical constituents of sunken *Terminalia arjuna* -River Kalu.

Sample	Elements	Point1(%)	Point2(%)	Point3(%)	Point4(%)	Point5(%)
1	Mg	59.59	40.88	34.85	32.35	20.77
	Cl	72.04	50.38	41.36	23.32	10.77
	Al	31.12	26.9	26.88	26.76	
	Sr	27.96	3.57	3.45		
	Ti	20.45				
	Si	73.24	65.15	49.73	46.8	35.45
	Fe	0.01				
	Mo	19.55				
2	Mg	72.98	64.32	39.35	29.9	22.29
	Al	70.1	53.86	49.03	34.17	13.01
	Cl	48.99	43.98	35.67	27.02	23.85
	Si	73.52	67.07	44.91	37.99	
3	Mg	32.04	21.63	18.57	20.62	16.87

	Si	70.42	42.34	38.15	39.67	22.84
	Cl	40.43		28.97	20.14	15.13
	Al	29.84	36.03	53.69	31.94	29.58
4	Mg	32.04	23.66	18.57	20.62	16.15
	Si	38.99		22.88	39.67	26.87
	Cl	49.04	46.8	28.97	27.48	20.14
	P	99.99		39.64	35.76	
	Fe	0.01				
	Sb	9.41				
	Al	53.2	50.96	22.79	20.69	
	S					17.24
5	Mg	26.83	26.5	26.49	19.06	18.9
	Al	73.5	34.32	33.29	31.82	22.78
	Si	77.22	66.71	49.13	35.36	32.31
	S	21				
	Cl	20.84		17.77		14.47
	Fe		0.01			

Table no 5: Chemical constituents of sunken Terminaliaarjuna -River Kelani.

Sample	Elements	Point1(%)	Point2(%)	Point3(%)	Point4(%)	Point5(%)
1	Al	74.2	62.58	60.64	53.99	28.9
	Mg	35.8	35.47	43.95	25.8	20.78
	Si	64.53	56.05	56.31	37.96	
	S	100	46.01			25.16
	Cl	59.99	39.36	37.42	26.24	27.31
	Ti	22.23				
	P	36.93				
	Sr	12.1				
2	Al	65.44	57.18	55.32		19.17
	Mg	34.56		25.09		
	Cl	44.68	42.82	35.76		22.53
3	Mg	36.07	100	60.12	37.49	27
	Si	63.93	60.24	34.25	42.67	70.79
	Al	100	60.37	50.94	29.21	24.82
	S	26.76	25.59			16.74
	Cl	74.41	73.24	57.33		13.36
	Sr	1.52				
	Fe		0.01		0.01	
4	Mg	65.09	39.38	33.99	33.98	15.38
	Si	41.49	40.33	36.06		25.31
	Cl	44.77	34.91	25.69	24.54	15.66
	Al	100	72.2	56.22		32..90
	S			29.92		22.49
	P					23.32
5	Si	64.97	64.37	46.02	41.62	25.99
	Cl	53.98	26.04	24.18		47.34
	P	40.33	35.87			
	Al	71.15	52.66	48.42	35.03	30.24
	Mg		35.63		28.25	25.54
	S		43.01			27.97

Table no 6: Chemical constituents of sunken Terminaliaarjuna -MahaOya.

Sample	Elements	Point1(%)	Point2(%)	Point3(%)	Point4(%)	Point5(%)
1	Al	74.2	62.58	60.64	53.99	28.9
	Mg	35.8	35.47	43.95	25.8	20.78
	Si	64.53	56.05	56.31	37.96	
	S	100	46.01			25.16
	Cl	59.99	39.36	37.42	26.24	27.31
	Ti	20.23				
	P	36.93				
	Sr	12.1				
2	Al	65.44	57.18	55.32		19.17
	Mg	34.56		25.09		
	Cl	44.68	42.82	35.76		22.53
3	Mg	36.07	100	60.12	37.49	27
	Si	63.93	60.24	34.25	42.67	70.79

	Al	100	60.37	50.94	29.21	24.82
	S	26.76	25.59			16.74
	Cl	74.41	73.24	57.33		13.36
	Sr	1.52				
	Fe		0.01		0.01	
4	Mg	65.09	39.38	33.99	33.98	15.38
	Si	41.49	40.33	36.06		25.31
	Cl	44.77	34.91	25.69	24.54	15.66
	Al	100	72.2	56.22		32..90
	S			29.92		22.49
	P					23.32
5	Si	64.97	64.37	46.02	41.62	25.99
	Cl	53.98	26.04	24.18		47.34
	P	40.33	35.87			
	Al	71.15	52.66	48.42	35.03	30.24
	Mg		35.63		28.25	25.54
	S		43.01			27.97

Table no 7: Chemical constituents of sunken Terminalia arjuna -River Mahaweli.

Sample	Elements	Point1(%)	Point2(%)	Point3(%)	Point4(%)	Point5(%)
1	Sb	10.56				
	Al	100	74.55		34.92	21.81
	Si	100		46.95	45.37	41.33
	Cl	100	41.69	37.96	31.24	22.61
	S	100	100		62.71	
	Mg	62.04	58.31	25.45		19.71
	Sr	23.25				
2	Cl	99.98	70.23	65.86	52.45	48.52
	Mg	70.04	65.03	65.46	62.74	62.03
	Si	64.96	43.95	43.35	39.94	35.75
	S	64.75				
	Fe	0.02	0.01			
	Al	100	68.09	67.5	60.05	53.74
3	Mg	21.01	72.81	36.03	31.01	26.17
	Al	73.83	49.61	46.25	45.16	33.4
	Si	45.59	100	57.23	42.27	52.11
	P	99.99	58.57			
	Fe	0.02	0.02			0.01
	Cl	99.98	50.39	37.25	23.83	17.73
	S	100				
4	Al	66.55	57.39	54.71	37.5	31.98
	Mg	52.07	31.85		24.24	21.15
	Cl	48.25	45.29	43.11	42.61	21.66
	P	62.5	47.93			25.21
5	Mg	62.67	37.6	35.24	23.86	15.84
	Al	53.74				22.5
	S	99.98	37.33			
	Si	64.76	62.4	54.44	22.4	29.41
	P	32.25				

Table no 8: Chemical constituents of sunken Terminaliaarjuna -River Menik.

Sample	Elements	Point1(%)	Point2(%)	Point3(%)	Point4(%)	Point5(%)
1	Fe	0.02				
	Cl	100	65.68			
	Sr	34.32	8.02			
	Si	74.35	70.97	58.27	47.53	39.33
	Ca	100	77.53	75.41	49.53	45.29
	Al		29.03			
	Mg	52.47	42.94	39.5	24.73	
	S		48.6			
2	Mg		100	52.47		25.73
	S	21.82	26.93	26.93		27.25
	Cl	73.07		46.74		
	Mg	28	46.4	46.4	20.92	
	Fe	100	100	100		
	Si	100	70.65		46.5	
	Ca	100	77.53	75.35	68.48	45.29
	P	26.75				

3	Al	100	100	100	32.58	
	Cl	100	64.27	50.6	47.14	37.18
	Mg	100				
	Si	100	52.86	49.4	24.64	22.92
	P	39.09	27.25			
	Sr		26.73			
4	S	72.75				
	Mg	100	68.05	64.8	29.73	27.17
	Cl	58.28	48.71	44.76	35.2	10.42
	Al	100	72.83	32.9	30.15	23.91
	Si	51.29	41.72	38.87		24.64
	P	82.93				
	Sr	18.65				
	Ca	90.13	89.58	74.17	52.69	
	S				30.6	
5	Mg	63.64	47.03	42.38	35.45	22.67
	Cl	57.1	36.36	27.41	18.89	12.05
	Al	100	47.74	36.87	31.26	28.09
	Si	100	64.55	42.9	37.5	29.66
	P	28.4	25.56	27.9		
	Sr	1.34				

Table no 9: Chemical constituents of sunken Terminalia arjuna -River Walawe.

Sample	Elements	Point1(%)	Point2(%)	Point3(%)	Point4(%)	Point5(%)
1	Mg	100		63.98		28.9
	Cl	36.02				
	Si		34.67			
	S		65.33			
	P				100	
	Al					71.1
2	Si	57.36				
	Cl	100	100		42.64	
	Al				100	100
3	Cl	100	63.54			32.76
	S		36.46			
	Al			100		
	Mg				67.24	44.95
	Si				55.05	
4	Si	100	52.01			39.71
	Cl		100	47.99	37.07	24.54
	Al		23.22			
	Mg				75.46	
5	Si	100				
	Cl		100	51.43		
	S			30.78		
	P			17.79		

IV. Discussion

Physical Properties of Sunken *Terminalia arjuna*

Compression strength of the sunken *Terminalia arjuna:* According to the above Figure no 6, the highest and the lowest compression strength values were visualized by sunken *Terminalia arjuna*. Higher fluctuation was observed in compression strength values of sunken timber, compared to the raw timber samples. The lowest compression strength value (380 kgf) was obtained by a sunken timber sample. That was due to exceeding of the "Fiber Saturation Point" (FSP) of the timber. It denotes the point in the drying process at which only water bound in the cell walls remains all other water, called free water, having been removed from the cell cavities [13]. If the moisture content of the wood exceeds 30%, it results in reduce the strength of the wood fibers. Further drying of the wood results in strengthening of the wood fibers and is usually accompanied by shrinkage. The sample which had the lowest compression strength value, apparently very old. At the end of the compression strength test, it became fragile [14].

The highest compression strength value was acquired by sunken timber samples. Conferring to the theory behind the Fiber Saturation Point, the results may incorrect. But according to the chemical analysis of the sunken timber, majority of the sunken timber containing 45-100% of Si, while raw timber containing 35-50%.Sodium silicate polymerization methodis a promising technique to enhancing the strength of timber. This method was used toincorporate sodium silicateinto an insoluble matrix. A water-soluble sodium silicate/borate mixture was forced into the interior of various cellulosic materials by using of vacuum/pressure technique. Then heat is polymerized into an insoluble fire-retardant matrix. According to the chemical analysis, sunken timber

originally contains higher amount of Si [15]. The 19th sunken timber sample which has recorded the highest compression strength value, is from River Kalu (APPENDIX C). It contains 80.65% of Ti. Ti is a chemical element with low density and high strength [16]. The 15th and 19th samples contained Mo according to the chemical analysis. Mo is an element which contributes to the hardenability and toughness of the materials [17].

The bending, compressive or tensile stress apply through a timber beam or column section may not be the same [18]. The sunken timber can be used effectively if timber layers of different strength properties are used to form a composite section such as ply web beams, box columns, spaced beams, lattice columns, timber portals etc.Enhanced compression strength of sunken timber will have a great future in construction industry in order to face global sustainable development challenges. Sunken timber can be introduced as an innovative building material with lesser usage of energy and chemical treatments for increase the mechanical properties of timber [6].

Color variation of the sunken *Terminalia arjuna:* All samples showed darker to lighter color from edge to the center of the cross section of the sample. There was a clear color variation can be observed in the sunken *Terminalia arjuna* timber samples compared to the pinkish-white and the brown to dark brown color of the raw *Terminalia arjuna*. Sunken Terminalia arjuna owns a wide range of colors including blackish -brown, blackish-maroon, blackish-yellow, pinkish-grey.

Sunken logs are barelyaffected by their decades of submersion. Concurrently river water is often too cold and too deficient in oxygen for decay organisms to survive. Although sugars have leached from the sunken logs because of the above effects, this effectively seasons the wood, and making it highly desirable for use in musical instruments due to its appearance and durability [6].

These slight color changes over the natural color of timber, adding ornamental value to the timber structures and furniture[19]. It adds different architectural qualities for the same space of timber structures without paying extra cost for the artificial timber colors.

Grain pattern and texture: The grain appears differently depending on how the board is sawed. The way the log is cut is what creates differences between grains. There are four cuts commonly used for flooring: plain sawn, rift sawn, quarter sawn and live sawn. The texture of the wood is determined by the relative size of the longitudinal cells. Wood species with large cells are said to have a coarse texture, while those with similar cells have a fine texture [20].

Specially in underwater logging, the low temperatures and oxygen content of rivers preserved the logs, some nearly 700 years old, embalming them like mummies from a lost civilization. Because these mummified logs in underwater in low light and limited nutrient conditions, they matured slowly. The result is a superfine grain, with 25 to 70 growth rings an inch (the highest count yet is 77 rings an inch) [21].

Architects like to work with timber, as it has unique characteristics including natural grain patterns.When compared to other construction materials such as reinforced concrete or structural steel; solid timber gives an architectural value to columns, beams, floor boards with its grain pattern [18]. Sunken timber has a slight variation from the raw timber and it gives a different view of natural finish that raw timber gives.Various shapes can be formed with altered grain patterns and textures of sunken timber while it is being used effectively. When compared to steel plate girders which could be used with variable sections to get optimum use and the beauty of the buildings, with varied grain pattern and texture can also be formed to various shapes while providing suitable moment resisting connections.

Chemical constituents of the sunken and raw *Terminalia arjuna* timber: Chemically timber is composed of, complex carbohydrates (cellulose and hemicellulose), lignin, extractives and mineral matter[22]. Terrestrial trees uptake nutrients in two forms. Nutrients are either taken up by the roots, which dominant in nutrition, or by the leaves, which is only additional in nutrition. The nutrient uptake from the roots is happened by root interception, mass flow or diffusion movement [23]. According to the chemical analysis, the chemical elemental distribution of raw timber samples of *Terminalia arjuna* having somewhat homogenous throughout the cross section of the timber sample, except having large fluctuation or regular pattern from edge to the center. Mg, S, P, Cl, Ca, Fe and Mo play a major role as essential nutrients for plants and they are supplied either by soil minerals or soil organic matter [24].

Tin is the third abundant material in earth crust after Al and Fe [25]. Usually Tin is in the environment as the form of Tin oxide. It is insoluble, so the amount of Tin in soil and natural water is very low [16]. Researchers have found that, it can present in portable water and forest vegetation [25]. The results discovered that, long time exposure to the water results for the insertion of Ti from river water to timber.

Sr is insoluble in water, but it can be soluble in water with chemical reaction. General concentration of Sr in soil varies between 0.001-39 mg/L [26]. Hence, Sr was inserted to the sunken timber, with the long-term experience in the river water.

Sb is a limited element in soil and natural water due to its partial solubility. Usually, in natural water Sb mainly exists in the inorganic of Sb^{3+} and Sb^{5+} [27]. Sb was inserted to the sunken timber with the natural pressure of river water.

Generally terrestrial *Terminalia arjuna* transport the essential nutrients across the plasma membrane, and on the primary uptake from soil into roots [28]. Therefore, the elements were distributed homogenously throughout the parts of trees. But in sunken timber of *Terminalia arjuna*, recorded regular decrement of respective concentrations of chemical elements from outermost layers to innermost layers. Furthermore, it contained Ti, Sr and Sb which were not sensed in raw timber samples of *Terminalia arjuna*. That was due to the insertion of chemicals to the sunken timber samples with the long-time exposure to the river water.

According to the obtained values from the compression strength test, Ti and Mo have contributed to increase the hardenability, toughness and the strength of the sunken *Terminalia arjuna* timber samples [16,17]. Although there were not any prior studies regarding the chemical and physical properties of sunken timber, this research has found that sunken timber has enhanced physical and chemical properties other than the raw timber. Further studies should be conducted to find out, how will these inserted chemicals affect for the preservation of sunken timber and how will the sunken timber become hazardless preservative technique for public with micronized or nanotechnology.

V. Conclusion

Sunken *Terminalia arjuna* samples were subjected to identify the color variation, grain pattern, texture, difference of compression strength, chemical constituents rather than the raw *Terminalia arjuna* samples. Clear observable color variation was detected from outer to inner layers of sunken timber samples of *Terminalia arjuna*. Compression strength of the sunken and raw timber samples of *Terminalia arjuna* varied in the range of 380-2500 kgf and 970-1620 kgf respectively. Both the highest and the lowest values were acquired by sunken timber samples. Sunken timber samples showed an interlocked and a medium texture while raw timber sample showed an interlocked grain pattern and a coarse texture.

Sunken *Terminalia arjuna* contained: Mg:15-100%, S:17-100%, P:17-100%, Cl:10-100%, Fe:0.01-100%, Al:13-74%, Si:20-100%, Mo:19-25%, Ca:45-100% in higher concentrations relatively to the raw *Terminalia arjuna*. Moreover, Ti, Mo, Sr and Sb were sensed in sunken timber samples and they have contributed to increase the hardenability, toughness and the strength of the sunken *Terminalia arjuna*.

The inserted minerals and low light, oxygen, temperature conditions of underwater add novel attributes into timber sediment and cause for deviate its natural color, grain pattern, texture and strength comparatively to the raw *Terminalia arjuna.*

Further studies should be conducted to find out, how will these inserted chemicals affect for the preservation of sunken timber and how will the sunken timber become hazardless preservative technique for public with micronized or nanotechnology.

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Appendices

Appendix no 1: Timber authentication report from State Timber Corporation, Sri Lanka

රාජ්‍ය දැව සංස්ථාව
அரசாங்க மரக் கூட்டுத்தாபனம்
STATE TIMBER CORPORATION
ස්වර්ණ ජයන්තිය 1968 - 2018

82, රජමල්වත්ත පාර, බත්තරමුල්ල.
82, ராஜமல்வத்த வீதி, பத்தரமுல்லை
82, Rajamalwatta Road, Battaramulla, Sri Lanka.
Tel: 2866601/5 Fax: 2866623

මහවැලි සංවර්ධන හා පරිසර අමාත්‍යාංශය மகாவலி அபிவிருத்தி மற்றும் சுற்றாடல் அமைச்சு Ministry of Mahaweli Development & Environment

මගේ අංකය: எனது இல: My No: STC/4/Re/18
ඔබේ අංකය: உமது இல: Your No:
දිනය: திகதி: Date: 12.12.2018

TIMBER IDENTIFICATION REPORT
REPORT NO. 126/2018

Client : **D.M.N.A. Disaiyaka,**
Wilagala Road,
Pussella,
Kegalla.

Reference : Client's letter dated Dicember 05, 2018

Particulars of the samples :

Sample No.	Thickness	Width	Length
372	30mm	70mm	190mm

Service Required : Identification of samples

Method of Examination :
i. Examination of external features.
ii. Examination of anatomical features by using hand lens.
iii. Comparison of external and anatomical features with authenticated samples available here.

Results & Conclusion : Sample 372 is Kumbuk (*Terminalia arjuna*)

The specimen tested was submitted by the client. It was not sampled by the State Timber Corporation officers. The report is therefore, limited specifically to this specimen. The report is issued for the information of the client. It shall not be published in total or in part without the written authority of the Chairman, State Timber Corporation.

Checked By

Dr.Nimal Ruwanpathirana*(B.Sc,M.Sc,Ph.D)*
General Manager
STATE TIMBER CORPORATION

C.K. Muthumala*(B.Sc,M.Sc)*
Manager (Research, Development & Training)
STATE TIMBER CORPORATION

Warning: Any person or any party who alters or adds, delietes or interpolates any provisions or words or letters or figures shall be liable legal action.
N.B. Any such alteration unless authenticated by the State Timber Corporation will not be the responsibility of the State Timber Corporation.

සැමට පැලයක්

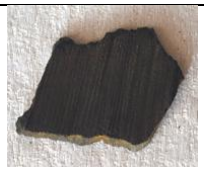
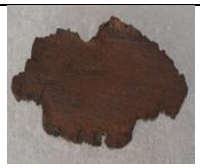
Appendix no 2: Results of the compression strength test

Sample No:	Raw (kgf)
1	1720
2	1300
3	1620
4	1380
5	1520
6	970
7	1260
8	1380
9	1460
10	1140
11	1140
12	1160
13	1360
14	1520
15	1460
16	1380
17	1140
18	1360
19	1440
20	1300

Sample No:	Sample	Sunken(kgf)
1	River Gin 4	2000
2	River Walawe 3	420
3	River Kelani 3	940
4	River Mahaweli 3	900
5	River Mahaweli 1	1080
6	MahaOya 5	600
7	River Menik 1	1310
8	River Gin 3	940
9	River Menik 4	1420
10	River Menik 3	1740
11	River Kelani 1	1240
12	River Mahaweli 2	680
13	River Gin 1	2060
14	MahaOya 2	1120
15	MahaOya 1	2220
16	River Kalu 4	2120
17	River Walawe 2	240
18	River Walawe 4	380
19	River Kalu 1	2500
20	River Kalu 5	920

Appendix no 3: Prepared samples for the chemical analysis

River	**Sample 1**	**Sample 2**	**Sample 3**	**Sample 4**	**Sample 5**
Gin					
Kalu					
Kelani					

MahaOya					
Mahaweli					
Menik					
Walawe					

Dissanayake DMNA1,et.al. "A study on chemical insertion and physical property changes of sunken timber; Terminalia arjuna along with river water in Sri Lanka." *IOSR Journal of Environmental Science, Toxicology and Food Technology (IOSR-JESTFT)*, 13(1), (2020): pp 54-69.