FEASIBILITY OF IMPROVING WATER QUALITY USING *Terminalia arjuna* MEDICINAL PLANT AND ITS' ECONOMIC BENEFITS

Gnei Nazeema Haniff Buhar

(128254 M)

Degree of Master of Business Administration in Project Management

Department of Civil Engineering

University of Moratuwa
Sri Lanka

November 2016

FEASIBILITY OF IMPROVING WATER QUALITY USING *Terminalia arjuna* MEDICINAL PLANT AND ITS' ECONOMIC BENEFITS

Gnei Nazeema Haniff Buhar

(128254 M)

Thesis/Dissertation submitted in partial fulfilment of requirement for the degree of Master of Business Administration in Project Management

Department of Civil Engineering

University of Moratuwa
Sri Lanka

November 2016

Declaration of the candidate and supervisor

“I declare that this is my own work and this thesisdoes not incorporate without acknowledgement any material previously submitted for a Degree or Diploma in any other University or institute of higher learning and to the best of my knowledge and belief it does not contain any material previously published or written by another person except where the acknowledgement is made in the text.

Also, I hereby grant to University of Moratuwa the non-exclusive right to reproduce and distribute my thesis, in whole or in part in print, electronic or other medium. I retain the right to use this content in whole or part in future works (such as articles or books)".

Signature:
G. Nazeema H. Buhar
553B Kurunduwatta 1st Lane,
Averiwatta Road, Wattala, Sri Lanka *Date:*

The above candidate has carried out research for the Thesis of the Master of Business Administration in Project Management under my supervision.

Signature of the supervisor:
Prof.ChinthaJayasinghe,
Department of Civil Engineering,
University of Moratuwa, Sri Lanka *Date:*

Dedication

This work is dedicated to both parents of mine, who laid foundation stones to all the achievements in my life.

Acknowledgements

Professor ChinthaJayasinghe, my supervisor for directing and encouraging in a positive way to conduct this research.

Dr. Lesley Ekanayake and the Staff of Construction Engineering and Management Division, Department of Civil Engineering of Moratuwa University, for providing all the assistance and necessary letters to meet Government officials.

Professor Asoka Perera and all the MBA lecturers, who provided valuable knowledge and support during the MBA course study period.

Dr. Lakna Paranavithana for introducing Professor Piyasiri Yapa.Professor Piyasiri J. Yapa, Eng. Gamini D. Nanayakkara and Dr.ShameenJinadasa for providing valuable literature and advice.

Indigenous Ayurvedic Medical Doctors Dr. Sharma, Dr. A. A. D. Chandraratne, Dr.W. M. Ruwan Bandaraand very special thanks to Ayurvedic Dr. T. Kumarasinghe, Galkulama, Anuradhapura for joining the field visit to recognize the trees and plant species and giving valuable details of Ayurvedic medicinal plants.

Mr. Sudath Rathnayake, ChiefEngineer, and his officials of NWSDB including Mr. Chandana,Anuradha-pura, Eng. P.U.K. Thilakarathne, Divisional Irrigation Engineer and his officials in Anuradhapura.

D. Susil A.P. Jayasinghe, Anuradhapura,and Ms. Kusumalatha and his son Ajith of Basawakkulama, Anuradhapura.

D. D. Swarna, Wattala

Mr. K.M. Tilakaratne and Eng. K.M.Palitha S. Bandara for approving leave, encouraging and providing valuable advice.

Manela Karunadasa and Talisha Jamaldeen for helping me in editorial work.

At last but not least, My Family Members.

Abstract

Feasibility of Improving Water Quality using *Terminalia arjuna*Medicinal Plant and its' Economic Benefits

One of the main issues faced by the isolated rural poor communities is the unavailability of safe drinking water[1], resulting in the worsening of health conditions (eg. chronic kidney disease) and related social issues. With the pollution of natural water bodies, the government has to spend enormous amount of revenue for water treatment to produce safe drinking water to the nation. Approximate cost of chemical consumption for a conventional water treatment plant is US$4to5 per $1m^3$ per year[2]and presently, NWSDB produces 590million m^3 of water annually[3] in Sri Lanka.

An opinion survey was carried-out regarding water purifying natural plants in Sri Lanka among traditional medical practitioners, through a questionnaire. The survery results show that *Terminalia arjuna* (Kumbuk[S]), *Strychnos potatorum* (Ingini[S]), *Vetiveria zizanioides* (Sevendara[S]), *Nelumbo* (Nelum[S]), *Madhuca longifolia* (Mee[S]), *Aponogeton* (Kekatiya[S]) plants are among the commonly used plants for water purification in Sri Lanka. Literature reviewed and data collected from traditional doctors and villages revealed that many traditional methods are used for water purifications with freely available natural resources. However, most of these methods lack scientific evidence and are not combined with new technological findings to improve the effectiveness of application for water purification and value addition for economic benefits.

The following is a study attempting to scientifically reveal the possibility of water purification by Medicinal Plants/*Terminalia arjuna* plants. This study included a detailed investigation of the water purification ability of *Terminalia arjuna* plants. A sample reservoirs with a significant plant coverage in the North Central province of Sri Lanka, was selected. The selected reservoirs act as drinking water sources of the villagers in the area. Water samples collected from the reservoirs were tested for a chosen pollutant concentration (Cadmium[4])in the laboratory. Test results were analysed to develop a relationship between water quality and coverage of *Terminalia arjuna* plant. A trend of reducing cadmium concentration with the increase in *Terminalia arjuna* plant coverage in the surroundings, was observed.

[1] In Sri Lanka, 16% of Citizens do not have access to safe drinking water, as per National Water Supply & Drainage Board (NWSDB) Website, Safe Water Coverage data, updated as at 15 July 2016.

[2]Green Tech Consultants (Designed and Supervision Consultant) prepared for Rideemaliyadda PS, Detailed project report for Rideemaliyadda Water Supply Scheme under ADB Financed LGESP-AF, June 2016.

[3]P.H. Sarath Gamini, NWSDB, Challenges in the Water Sector and Wastewater Sector, March 2013.

[4] Renal tubular damage due to exposure to cadmium develops at lower levels of cadmium body burden than previously anticipated - Lars Järup,et al; Low Level Exposure to Cadmium and Early Kidney Damage: The OSCAR Study, Occupational and Environmental Medicine, Vol. 57, No. 10 (Oct., 2000), pp. 668-672.

The outcome of the research demonstrates a sustainable means of water purification with a greater contribution to the forest cover.

Keywords: Water purification, medicinal plants, Terminalia arjuna, Cadmium, ion adsorption/adsorption.

Table of content

List of Figures

List of Tables

List of Appendices

List of abbreviations

Abbreviation	Description
BOD	biochemical Oxygen demand
CKD	chronic kidney disease
COD	chemical Oxygen demand
DO	dissolved Oxygen
FC	fecal coliforms
FTW	Floating treatment wetlands
FWS	free water surface
GDP	Gross Domestic Product
HLR	hydraulic loading rate
HSSF	horizontal subsurface flow
MPCA	Medical Plant Conservation Area
NCD	Non Communicable Diseases
NTU	Nephelometric Turbidity Unit
S	Sinhala name
TC	total coliforms
TFP	total factor productivity
TSS	total suspended solids
WHO	World Health Organization
MIC	minimum inhibitory concentration

1. INTRODUCTION

1.1 Rationale and Challenges

Rapid urbanization, increased land usage for agricultural purposes, inappropriate usage of chemical fertilizers, weedicides and pesticides, has intensified water pollution in many parts of the world. Many diseases with unknown origin; for example chronic kidney disease, are widely spreading causing not only health issues, but also enormous environment and social issues. There are many conventional methods available to purify water to overcome this issue, which are very expensive and demand heavy investments and maintenance costs. For a government in middle income country, this situation poses a massive burden when maintaining a sustainable economic growth.

The Government has to spend excessive funds to provide safe drinking water to the nation. Especially it is very difficult to provide safe drinking water to the isolated rural villages where the natural water bodies are polluted and beyond safe human consumption.

Historical records suggest that biological/medicinal plants and materials from the natural environment have been used as methods of water purification[1]. Though almost all plants increase the Oxygen level in water, rural communities believe, that some biological plants and seeds improve the quality of water quantitatively and qualitatively.

It is important to conduct research to find out the credibility of the myth behind the traditional/indigenous knowledge or unproved facts of these biological/medicinal plants. Research will also help in applying the findings effectively and economically, combined with new technology, for the betterment of nature and

[1]K.W.G. Rekha Nianthi and M.A.S. Jayakumara; Progress of Research on Cascade Irrigation Systems in the Dry Zones of Sri Lanka – extracted from Water Communities, Community, Environment and Disaster Risk Management, Volume 2, 109-137, 2010.

humanity, before this knowledge is buried off with elderly citizens, and also to stop inappropriate and unethical usage. When considering water purification, it is important to conduct research on which plant absorb what kind of ions and minerals, in which quantities and according to what environment situations.

According to the responses of questionnaire survey, in many South Asian countries, including Sri Lanka, many people believe coolness and quality of water could be improved by growing *Terminalia arjuna* [Kumbuk(S)] trees near wells and rivers.

Terminalia arjuna is a large deciduous tree, where it takes about 6 to 7 years to bear fruits. The real effects of these trees may be different according to the plant age, surrounding environment and climate conditions, distance to the water body/sample area. In addition to carrying out experiments using plant parts, it is recommended to carry out experiments/research in natural environment. The lively seedlings also could be used for laboratory experiments. Experiments have been carried out to see the absorption of Chromium ions by chemically activated carbons prepared by *Terminalia arjuna*[2].

To address this issue, it is important to be aware of traditional/indigenous knowledge of natural environment and to analyse the possibility of applying this knowledge on controlling the effects of natural and manmade disasters through an environment friendly manner.

1.2 Research Objectives

The objectives of the study were formulated based on following questions:

- What are the suitable species of plants that could be used to purify the natural water sources?

[2]Kaustubha Mohanty, Mousam Jha, B.C. Meikap, M.N. Biswas; Removal of chromium (VI) from dilute aqueous solutions by activated carbon developed from Terminalia arjuna nuts activated with zinc chloride, Elsevier, Chemical Engineering Science,Volume 60, Issue 11, June 2005, Pages 3049–3059.

- What is the opinion based on available indigenous knowledge on the water purification by plants?
- Whether a desirable species of plant can be selected to purify the water in the reservoirs with possible quantification of the effect?

This research was carried out with the above objectives as the focus based on a sustainable and an economical solution for water purification for the vulnerable communities who do not have access to safe drinking water. An attempt was made to combine traditional indigenous knowledge with technological findings.

1.3 Research Methodology

In order to achieve the above objectives following methodology was conducted subsequent to a detailed literature review:

- An opinion survey was conducted on water purification plants in Sri Lanka. A sample of traditional medical practitioners was selected for the opinion survey.

- A field study was conducted in the north central province of Sri Lanka, in order to assess the feasibility of the selected species of plant (s) for water purification. North Central province was selected for the field study and also for the collection of water samples, since this area is considered to be the most affected for the CKDU, in Sri Lanka for which poor quality water is believed to be the main cause.

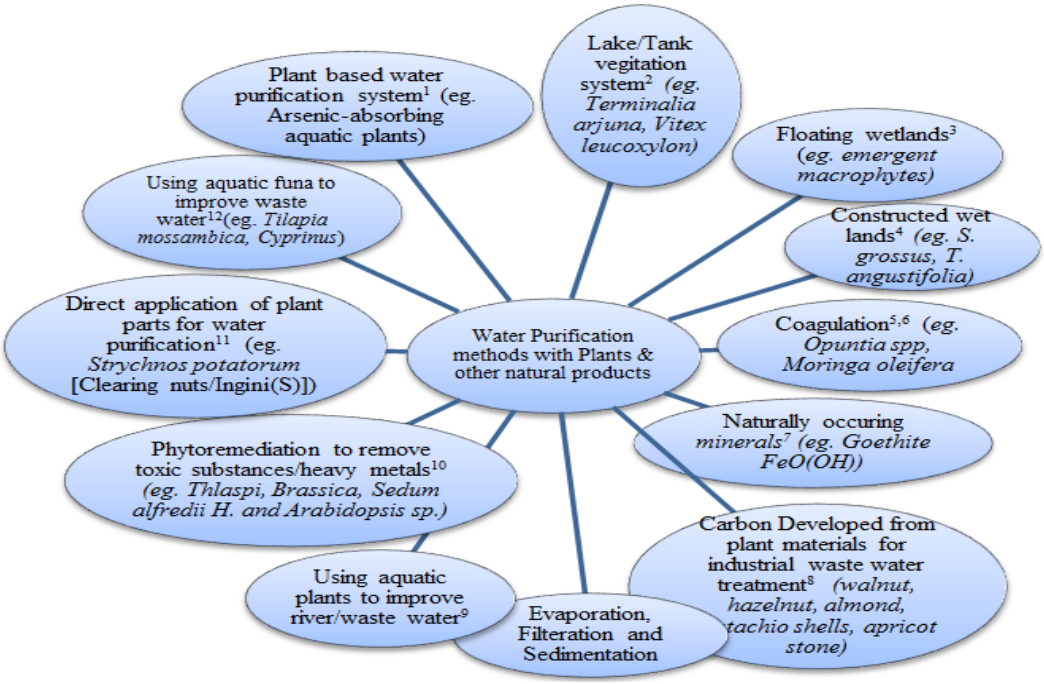
- The pollutant concentration of the water samples was tested in the laboratory and an attempt was made to develop a correlation with the coverage of the selected species of plant.

2. LITERATURE REVIEW ON PLANT SPECIES FOR WATER PURIFICATION

Literature review suggests that many plant species could be used for soil and water purification.

Research has been carried out by many scientists to prove the application of several methods of using plant based materials for water purification and there are proven positive results on effectiveness of application of these methods. Following diagram is a summary of these methods.

Figure 1 : Summary of Water Purification Methods with Plants & Other Natural Products[1,2,3,4,5,6,7,8,9,10,11,12]



[1]Stephen Goodwin Honan; Plant based water-purifying system named "Idea that will change the world", Dezeen Book of Interviews, 17 September 2013.
[2]Rekha Nianthi & Dharmasena; Indigenous knowledge of farming practices and water management in dry zone of Sri Lanka, 2009.
[3]Tanner & Headley; Components of floating emergent macrophyte treatment wetlands influencing removal of stormwater pollutants, Elsevier, Volume 37, Issue 3, March 2011, Pages 474–486 2011.
[4]K.B.S.N. Jinadasa, N. Tanaka, S.Sasikala, D.R.I.B. Werellagama, M.I.M. Mowjood and W.J. Ng; Impact of harvesting on constructed wetlands performance – a comparison between Scirpus grossus and Typha agustifolia, Journal of Environmental Science and Health Part A (2008), 43, 664-671.
[5]Sarah M. Miller, Ezekiel J. Fugate, Vinka Oyanede Craver, James A. Smith and Julie B. Zimmerman; Toward Understanding the Efficacy and Mechanism of Opuntia spp. as a Natural Coagulant for Potential Application in Water Treatment, Environ. Sci. Technol., 2008, 42 (12), pp 4274–4279.
[6]M A A W Moramudali, P Fernando and P A J Yapa; Use of seed of Moringa oleifera to clarify trurbid water and waste water, Vidyodaya J. of Sci. (2001) Vol.10 pp 167-182.
[7]N. Salami and F A Adekla; A study of sorption of Cadmium by Goethite in aqueous solution Bull.Chem. Soc. Ethiop. 2002, (16)1, 1-7.
[8]Maryam Kazemipour, Mehdi Ansari, Shabnam Tajrobehkar, Majdeh Majdzadeh, Hamed Reihani Kermani; Removal of lead, cadmium, zinc, and copper from industrial wastewater by carbon developed from walnut, hazelnut, almond, pistachio shell, and apricot stone, Elsevier, Journal of Hazardous Mat., Volume 150, Issue 2, 31 January 2008, Pages 322–327.
[9]Y. Zimmels, F. Kirzhner, S. Roitmen; Use of naturally growing aquatic plants for waste water purification, Water Environment Research, Volume 76, 222 (2004).
[10]Mohammad Iqbal Lone, Zhen-li He, Peter J. Stoffella, and Xiao-e Yang; Phytoremediation of heavy metal polluted soils and water: Progresses and perspectives, J Zhejiang Univ Sci B. 2008 Mar; 9(3): 210–220.
[11]G. Vijayaraghavan, T. Sivakumar, A. Vimal kumar; application of plant based coagulants for waste water treatment, ijaers/vol. I/ issue i/october-december, 2011/88-92.
[12]Ludwig C.A. Naegel; Combined production of fish and plants in recirculating water, Aquaculture, Volume 10, Issue 1, January 1977, Pages 17-24.

A water-filtration system that uses plants to extract arsenic from water supplies and allows the user to sell the poisonous substance at a profit has been voted the "Idea that will change the world" at the Global Design Forum in London. Clean Water, developed by *Oxford University* MSc student *Stephen Goodwin Honan*, was voted the best of five world-changing ideas presented at the forum. Clean Water uses special, arsenic-absorbing plants, which are grown in a container. Water is pumped through the container and arsenic is trapped in a filter, and then absorbed by the plants where it poses no danger.

The filtered water is then safe to drink while the plant can be harvested each year and the arsenic could be chemically extracted. The plants are a naturally occurring species selected for their ability to remove arsenic from the soil they grow in.

The system costs just $10 (£6) to set up but can produce arsenic - which is widely used in industries including the semi-conductor and mobile phone industries - worth $85 (£53) per year. All parts of the system, apart from the filter and the plants, can be sourced locally from everyday materials such as plastic tubs and bamboo.

There are no running costs and no specialist expertise required to maintain the system. "Eighty percent of people in Bangladesh [where the system has been trialled] are subsistence farmers," said Honan. "They understand how to look after plants." (*Source: Dezeen Book of Interviews, 17 September 2013, Plant based water-purifying system named "Idea that will change the world").*

Experiment on use of seeds of *Moringaoleifera,* to clarify turbid waters and wastewaters, has been carried out by *M A A W Moramudali, P Fernando and P A J Yapa*. According to these experiments mature seed extracts of *Moringa* were comparatively more effective than immature seed extracts. Manure seed powder at 50mg/20 ml reduced the turbidity (NTU) by 95% within 2 h. It was the aqueous extract of *Moringa* seeds that was really effective in clarifying turbid waters, not the insoluble fraction. A positive relationship between the protein content and purifying ability of seeds extract was observed. It was also found that extracts of

mature*Moringa* seeds have an ability to clarify textile dye solutions. Four solutions of textile dyes were clarified by *Moringa* seed extracts. pH is slightly reduced and conductivity is rapidly increased depending on treatment time and temperature. Clarifying ability against paper factory effluent, no significant effect was observed. Mature seed extracts of *Moringa* significantly reduced the bacterial growth of polluted waters. The effectiveness was directly proportional to the amount of seeds used. An antimicrobial activity was found in crude aqueous extracts of *Moringa* seeds *(Source: Vidyodaya J. of Sci. (2001) Vol.10 pp 167-182, M A A W Moramudali, P Fernando and P A J Yapa, University of Sri Jayawardenepura, May 2001).*

Floating treatment wetlands (FTWs) are a novel treatment concept that employ rooted, emergent macrophytes growing in the floating mat on the surface of the water rather than rooted in the sediments *(Tanner and Headley 2011: Fonder and Headley 2010).* The plant roots beneath the floating mat provide an extensive surface area for the attached biofilm growth and entrapment of suspended particulate matter. Since the plants are not rooted in the soils like subsurface flow constructed wetlands, they are forced to acquire their nutrition directly from the water column, which may enhance rates of nutrient and element uptake into biomass. Their buoyancy enables them to tolerate wide fluctuations in water depth and provides potential to enhance treatment performance by increasing the water depth retained during flow events to extend the detention time of storm water in the wetland *(Tanner and Headley 2011).*

The experimental results have demonstrated the effectiveness of floating wetland systems in removing both BOD_5 and inorganic nitrogen from polluted water. Floating wetlands may be a viable option for lake restoration in tropical conditions. On the basis of water quality improvement, there were no major differences in treatment performance between the two plants *(T. angustifolia and C. iridiflora).* Floating wetlands with *T. angustifolia* and *C. iridiflora* may be attractive options as they improve the aesthetic appearance of the treatment site. In comparison with the

performance of traditional subsurface flow constructed wetlands with the same plant species in the same environmental conditions, the removal efficiencies of the floating wetland systems showed even greater values for BOD_5 and NH_4^+-N, but lower values for NO_3^--N, Harvesting could be a sustainable plant management option for floating wetlands. Further studies are required to determine optimum harvesting cycles and develop guidelines on the surface area requirements for better treatment performance *(Source: S.K. Weragoda, K.B.S.N. Jinadasa, Dong Qing Zhang, Richard M. Gersburg, Soon Keat Tan, Norio Tanaka, Ng Wun Jeron – Tropical Application of Floating Treatment Wetlands).*

Constructed wetlands can be a sustainable water quality management option for tropical developing countries. No significant differences were observed in water quality improvement between *S. grossus* and *T. angustifolia* systems. But different trends were observed for above-ground biomass and below-ground biomass production in terms of repeated harvestings. *S. grossus* showed sustainable biomass production whereas *T. angustifolia* showed less tolerance to repeated harvesting. S. grossus was found to be a suitable plant species for water quality improvement and sustainable biomass production with repeated harvesting. The results also implied that under the free water surface (FWS) condition, the macrophyte has a limited role in water quality improvement since the water column may play a greater role in removing dissolved and particulate pollutants *(Source: K.B.S.N. Jinadasa, N. Tanaka, S.Sasikala, D.R.I.B. Werellagama, M.I.M. Mowjood and W.J. Ng; Impact of harvesting on constructed wetlands performance – a comparison between Scirpus grossus and Typha agustifolia, Journal of Environmental Science and Health Part A (2008), 43, 664-671).*

A study assessed the pollutant removal potential of horizontal subsurface flow(HSSF) constructed wetland systems under tropical conditions subjected to various hydraulic loading rates (HLRs). This study investigated the effects of HLR variation on treatment performance in HSSF constructed wetlands treating synthetic wastewater. Based on the obtained results, it is evident that the HLR had a critical

impact on pollutant removal and hence HLR is a significant design parameter determining the treatment efficiency in HSSF wetlands. Results reveal planted HSSF constructed wetlands are capable in substantial reduction of BOD_5, TSS, FC and TC concentrations with a good buffering capacity under varying flow conditions between 2.5 and 25 cm/day HLR range. This makes the HSSF constructed wetland systems as a useful alternative at places with high flow fluctuations, reducing the stringent land area requirement *(Source: G.M.P.R. Weerakoon, K.B.S.N. Jinadasa, G.B.B. Herath, M.I.M. Mowjood, J.J.A. van Bruggen; Impact of the hydraulic loading rate on pollutants removal in tropical horizontal subsurface flow constructed wetlands)*

In addition to plant materials, investigations were done to find out the potential of a naturally occurring goethite mineral for the removal of cadmium ion from aqueous solutions *(Source: N. Salami and F A Adekola at University of Ilorin, Nigeria, January 2002).*

The potential use of aquatic plants for improving river water quality was considered by Y. Zimmeis, F. Kirzhner, S. Roitman. Laboratory as well as pilot experiments indicated the viability of this approach, particularly for the section of the Kishon River polluted with waste water, not industrial effluents. This relates to a reduction in values of major water-quality indicators such as BOD, TSS, COD, and turbidity. The plants (primarily *E. crassipes*) were capable of reducing these variables to concentrations required by national and local guidelines as well as international standards for irrigation water. Furthermore, the plants eliminated the disturbing smell of wastewater, which poses serious problems in various locations throughout the country. The aquatic-plants system offers an environmentally friendly and cost-effective technology for treatment of urban and agricultural wastewater in Israel. In particular, this applies to small and medium-size communities and agricultural enterprises. In the case of the Kishon River, aquatic plants can be used to purify water coming from the upstream sections of the river. The treated stream can then be used to nourish new park areas in the downstream sections by splitting the stream

into two channels. One channel will continue to carry the heavily polluted industrial effluents, whereas the second channel will supply cleaner water to the water parks on both sides of the river. This is expected to rehabilitate the river and its ecosystem*(Source: Y. Zimmels, F. Kirzhner, S. Roitman, Water Environment Research, Volume 76, Number 3).*

A baseline survey of the Iriyawetiya freshwater wetland highlighted the fact that water flowing through the wetland undergoes a degree of purification. The plants confined to wetland inlets were site specific and were likely to be able to tolerate and absorb high concentrations of pollutants. This freshwater wetland displayed increased dissolved Oxygen(DO) values at the outlet and decreased values of phosphate, nitrate, Biochemical Oxygen demand(BOD) and turbidity, which decreased gradually from the inlet towards the outlets. The Iriyawetiya freshwater wetland removes nitrate and phosphate from ambient water and as such can reduce eutrophication downstream. Consequently, the Iriyawetiya fresh water wetland is an excellent example of a critical wetland whose benefits to the surrounding human communities can be readily quantified *(Source: Buddhika D. Madurapperuma, Mala D. Amarasinghe and Peter G. Oduor - Salient ecological functions of a tropical freshwater wetland, Lakes & Reservoirs: Research and Management 2013 18: 45–51)*

Removal of lead, cadmium, zinc, and copper from industrial wastewater by carbon developed from walnut, hazelnut, almond, pistachio shell, andapricot stone : In this work, adsorption of copper (Cu), zinc (Zn), lead (Pb), and cadmium (Cd) that exist in industrial wastewater onto the carbon produced from nutshells of walnut, hazelnut, pistachio, almond, and apricot stone has been investigated. All the agricultural shell or stone used were ground, sieved to a defined size range, and carbonized in an oven. Time and temperature of heating were optimized at 15 min and 800 degrees C, respectively, to reach maximum removal efficiency. Removal efficiency was optimized regarding to the initial pH, flow rate, and dose of adsorbent. The maximum removal occurred at pH 6-10, flow rate of 3 ml/min, and

0.1g of the adsorbent. Capacity of carbon sources for removing cations will be considerably decreased in the following times of passing through them. Results showed that the cations studied significantly can be removed by the carbon sources. Efficiency of carbon to remove the cations from real wastewater produced by copper industries was also studied. Finding showed that not only these cations can be removed considerably by the carbon sources noted above, but also removing efficiency are much more in the real samples. These results were in adoption to those obtained by standard mixture synthetic wastewater *(Source: Maryam Kazemipour, Mehdi Ansari, Shabnam Tajrobehkar, Majdeh Majdzadeh, Hamed Reihani Kermani, Journal of Hazardous Materials, 31 January 2008).*

Phytoremedition is a method used in other countries to clean up soil and water polluted by toxic substances including heavy metals. Phytoremediation has been defined as the use of plants to remove or inactivate pollutants from soils and wastewaters. It all started in 1948 when Pichi Sermolli, an Italian scientist observed an unusual accumulation of nickel in some plants. Today scientists know of hundreds of plant species capable of selectively absorbing and accumulating specific elements and substances without showing toxicity symptoms – they are known as hyper accumulators. For instance,tea plant (*Camellia sinensis*) is a well-known aluminium accumulator. Depending on the plant species, the actual mechanism of phytoaccumulation can be phytofiltration, phytostabilization, phytovolatilization, or phytodegradation.

As far as cadmium is concerned, scientists have already identified through research quite a number of plant species that can accumulate cadmium. Some examples are Athyrium yokoscense, Avena strigose, Bacopa monnieri (lunuwila), Brassica juncea, Valisnaria Americana, Crotalaria juncea (Andana hiriya), Eichchornia crassipes (water hyacinth), Helianthus annus (sun-flower), Hydrilla verticillata, Lemna minor (duck weed), Pistia stratiotes (water lettuce- diya gowa), Salx viminalis, Spirolelea polyrhiza (giant duck weed), Tagetes erecta, Thlaspi caaerulescenes (alpine pennycress) and Valisnaria spiralis (Eel grass).

It is important to create an awareness of new technologies such as phytoremediation among public so that restoration activities can be implemented as participatory projects.

It is also proposed to introduce phytoremediation into the curriculum of Plant Science Departments of all universities, if they have not done so already.

Research funding bodies such as National Science Foundation, National Research Council, and Sri Lanka Council for Agricultural Research Policy(CARP)are requested to award research grants to studies on phytoremediation on a priority basis particularly to find out more efficient local plant species.

Phytoremediation is not something entirely new and it has been there for years in other countries and they have made use of it clean up different types of contaminated situations. Now it is our turn though little overdue. Let us remember that phytoremediation is an attractive alternative to current clean-up methods that are energy intensive and very expensive. *(Source: Piyasiri Amilasith Yapa, Phytoremediation of soil and water in CKD affected areas , The Island Newspaper, P6, 16 December 2013).*

3. LITERATURE REVIEW ON *Terminalia arjuna*

In English it is named as white marudah, tropical almond, Arjun, Malabar almond and arjuna and in Tamil it is called as Vellai maruthu, Vellamatta marutae. In Bengali, India, this tree is named arjhan and in Gujarati as Vellamatta, Sadado, Sadada; in Hindi, koha, Arjun, arjuna, arjan, kahu. In Thailand dhanvi, rok faa khaao and kakubha.

Terminalia arjuna (Arjuna) is a deciduous large-sized tree which grows about 30m tall and 2 – 2.5m dbh, with an often buttressed trunk. It's superficial, shallow root system spreads readily along stream banks. The large, spreading crown produces drooping branches. Bark is grey or pinkish-green, thick, smooth and exfoliating in thin irregular sheets.

Leaves are simple, opposite to sub-opposite, 5-25 x 4-9 cm oblong or elliptic oblong, glabrous, hard, often inequilateral, margin often crenulated, apex obtuse or sub-acute, base rounded or sometimes cordate. The petiole is short (2-4cm long), sericeous, with 2 (or 1) prominent two glands at petiole apex.

Inflorescences are short axillary spikes or small terminal panicles, 9-13 cm long with 2.5-6 cm long branches. The rachis short, white and pubescent. Lower receptacle 0.8-1.5mm long, short sericeous, upper receptacle 1.5-1.75mm long, glabrous except at base where slightly pubescent. Flowers are small, bup-shaped, regular, sessile, polygamous, white, creamy or greenish-white and strongly honey-scented.

The fruit is 2.5-6 x 1.8-2.8cm long, obovoid-oblong, dark brown to reddish-brown fibrous woody, indehiscent drupe, glabrous with 5-7 equal thick narrow stiff-wings and striated with numerous upwards-curved veins.

The generic name *Terminalia* comes from Latin word ‘terminus’ or ‘terminalis’ (ending), and refers to the habit of the leaves being crowded or borne on the tips of the shoots.

Terminalia arjuna is usually an evergreen tree with new leaves appearing in the hot season (February to April) before leaves fall. Trees sometimes may be leafless for a very short period before flowering. Fruit bearing begins 6-7 years after planting.

Flowering begins in April and extends to May with the fruit ripening the following February-May, nearly a year after the appearance of the flowers. Generally, every third year is a good seed year. The pattern of flowering and fruiting is not markedly different in different regions *(Source: Orwa et al 2009, Agroforestry Database 4.0, P 1-5).*

Enormous amount of researches have been carried out throughout the world regarding this plant.

5.1 Terminalia arjuna as a medicinal plant

Pleaserefer the Appendix B. Details of Appendix B were extracted from various web-sites during the literature review.

In a study conducted by A Chaudhary, et al in 2010, the inhibitory potency of crude extracts or fractions of successive solvent extractions of *Terminalia arjuna* bark was evaluated on various stages of formation of calcium phosphate and on the growth of calcium oxalate monohydrate crystals in vitro. Results obtained indicated that *Terminalia arjuna* bark has the potential to inhibit the formation of both calcium phosphate and calcium oxalate crystals in vitro. Butanol fraction of *Terminalia arjuna* extract was the most effective in inhibiting formation of calcium phosphate and calcium oxalate crystals in vitro.*(Source:A. Chaudhary, S. K. Singla, and C. Tandon, In vitro Evaluation of Terminalia arjuna on Calcium*

Phosphate and Calcium Oxalate Crystallization, Indian J Pharm Sci. 2010 May-Jun)

5.2 Terminalia arjuna as a water purification plant

Removal of chromium (VI) from dilute aqueous solutions by activated carbon developed from *Terminalia arjuna* nuts activated with zinc chloride

Different structured activated carbons were prepared from *Terminalia arjuna* nuts, an agricultural waste, by chemical activation with zinc chloride for the adsorption of Cr(VI) from dilute aqueous solutions. The most important parameter in chemical activation was found to be the chemical ratio (activating agent/precursor, g/g). Carbonization temperature and time are the other two important variables, which had significant effect on the pore structure of carbon. A high surface area of 1,260m^2/g was obtained at a chemical ratio of 300%, carbonization time and temperature of 1 h and 500 °C, respectively. The activated carbon developed shows substantial capability to adsorb Cr(VI) from dilute aqueous solutions. The parameters studied include pH, adsorbent dosage, contact time, and initial concentrations. The kinetic data were best fitted to the Lagergren pseudo-first-order model. The isotherm equilibrium data were well fitted by the Langmuir and Freundlich models. The maximum removal of chromium was obtained at pH 1.0 (about 99% for adsorbent dose of 2 g/l and 10 mg/l initial concentration) *(Source: Kaustubha Mohanty, Mousam Jha, B.C. Meikap, M.N. Biswas; Elsevier, Chemical Engineering Science,Volume 60, Issue 11, June 2005, Pages 3049–3059).*

Removal of Phenol from Wastewater - Preparation and Characterization of Activated Carbons from *Terminalia Arjuna* Nut with Zinc Chloride Activation

Nuts of *Terminalia arjuna*, an agricultural waste, were used to prepare activated carbons by zinc chloride activation under four different activation atmospheres, to develop carbons with substantial capability, and to adsorb phenol from dilute aqueous solutions. Experiments were carried out at different chemical ratios (activating agent/precursor). Effect of carbonization temperature and time are the important variables, which had significant effect on the pore structure of carbon. Developed activated carbon was characterized by SEM analysis. Pore volume and

surface area were estimated by Hg porosimetry and BET surface area analyses. The carbons showed surface area and micropore volumes of around 1260 m^2/g and 0.522 cm^3/g respectively. The activated carbon developed shows substantial capability to adsorb phenol from dilute aqueous solutions. The kinetic data were fitted to the models of intraparticle diffusion, pseudo-second-order, and Lagergren model which followed more closely the pseudo-second-order chemisorption model. The isotherm equilibrium data were well-fitted by the Langmuir and Freundlich models. The maximum removal of phenol was obtained at pH 3.5 (about 93% for adsorbent dose of 10 g/L and 100 g/L initial concentration).*(Source: Kaustubha Mohanty, Mousam Jha, B. C. Meikap, and M. N. Biswas, Department of Chemical Engineering, Indian Institute of Technology (IIT), Kharagpur, Dist: Midnapur(W), West Bengal, Pin-721 302, India, Ind. Eng. Chem. Res., 2005, 44 (11), pp 4128–4138).*

Antimicrobial activity

In rural and backward area of West Bengal, India several plants are commonly used as herbal medicine for the treatment of infectious diseases. Four such plants commonly used by the people of the area were screened for potential antibacterial activity. Antibacterial activity of both aqueous and methanol extracts of the plants parts were used for screening. The plants screened were *Psidium guajava*, *Andrographis paniculata*, *Terminalia arjuna* and *Adhatoda vasica*. Antibacterial activity was tested against six strains of both Gram positive and Gram negative bacteria. The susceptibility of the microorganisms to the extracts of these plants was compared with each other and with selected antibiotics. The result showed that, the methanol extracts of selected medicinal plants exhibited high activity against the tested organisms rather than aqueous extract of those plants. So, the minimum inhibitory concentration (MIC) of the methanol extract of selected plants was studied. Extract from *Terminalia arjuna* showed higher antimicrobial activity than the extract of *Psidium guajava*. (*Source: Sankar Kumar Dey, Debdulal Banerjee, Sourav Chattapadhyay and Krishnendu Bikash Karmakar; Antimicrobial Activities of Some Medicinal Plants Of West Bengal, International Journal of Pharma and Bio Sciences, Vol.1/Issue-3/Jul-Sep.2010).*

Phytoremediation is one of the most ecofriendly and innovative techniques to remove pollutants from soil and water in agricultural areas. A study explored potentials of bioremediation for water purification at Tea Research Institute of Sri Lanka through monitoring water quality of St. Coombs lake and through several glasshouse and laboratory experiments for validating the results during the period of November 2004 to February of 2005.

The water quality parameters such as pH, nitrate, phosphate, iron and total coliforms at 35^0C/100ml and *Escherichia coli* at 44°C/100ml were monitored during dry and rainy periods. The possible causes for water pollution of the lake were also monitored. Nitrate pollution was greater during rainy periods since higher contribution of erosion and runoff. Higher levels of total coliforms and *Escherichia coli* were observed in both seasons. Five plant species traditionally known to have phytoremedial properties i.e. Kang kong (*Ipomea aquatica),* Giant reed (*Arundo donax*), Water hyacinth (*Eichhornia cracipes*), Bulrush (*Scirpus lacustris*) and **Kumbuk (*Terminalia arjuna*)** were evaluated for nutrient absorption. The histology of Kumbuk and Tea roots were assessed for their anatomical attributes to the bioremediation properties.

The differences in root anatomical traits in different plant species lead to differences in nutrient and water absorption. Kang kong, Water hyacinth and Bulrush showed better performances in nutrient absorption. **The results supported the potentials and technical attributes to common bioremediation plant species in purification of water.** These attempts would be environmentally and user friendly, cost effective as well as aesthetic advantages and long-term applicability compared to chemical treatments *(Source : Bioremediation for water purification• A case study at St. Coombs Lake, Talawakelle by P. G. D. S. Amarasena, K. M. Mohotti, G. Hitinayake, - extracted from the Proceedings of the International Forestry and Environment Symposium 2006 of the Dept. of Forestry and Environmental Science, University of Sri Jayewardenepura, Sri Lanka).*

Sri Lanka, as an island located near the southern tip of India and the Asian Continent and in the core area of the South Asian Monsoon has developed its own unique forms of Hydraulic Civilization. Sri Lanka is covered with a network of thousands of man-made lakes and ponds, known locally as "tanks," numbering more than 25,000. Some are in the functional mode and others still remaining abandoned type. Many are thousands of years old and almost all show a high degree of sophistication in their construction and design. Sri Lanka's tanks are fascinatingly distributed in the cascades of tanks one below the other conserving water and soil and most effectively, acting as buffers against droughts while giving due consideration to maintaining the ecosystem equilibrium.

In Pre-Christian times, the Sinhalese had attained the knowledge of managing the water of streams. King *Parakramabahu* the great enunciated one of the most ancient principles of water conservation and utilization as follows:

"Let not even a drop of rain water escape to the sea without benefiting the world"

As *Culavamsa* (historical chronicle) records the King constructed or restored 165 dams, 3,910 canals, 163 major tanks, and 2,376 minor tanks. This included his greatest legacy the *Parakrama Samudra*, with an embankment 81/2 miles long and rising to a height of 40ft.

As Chambers once observed, "Systems of knowledge are many. Among these, modern science is only one, though the most powerful and universal. Rural people's knowledge is in contrast 'situated', differing both by locality and by group and individual, and differing in its modes of experimenting and learning: different people know different things in different places, and learn new things in different ways" (Robert Chambers, 1994)*(Source : K.W.G. Rekha Nianthi and M.A.S. Jayakumara – Progress of Research on Cascade Irrigation Systems in the Dry Zones of Sri Lanka – extracted from Water Communities, Community, Environment and Disaster Risk Management, Volume 2, 109-137, 2010)*

Sustainability of the traditional tank, village system had been maintained in the past simply not only from structural maintenance but also every component of the eco-system was given due consideration. The attention was paid not only on macro-land uses such as paddy land, settlement area, *chena* lands, tank bed, etc. but also on micro-land components such as *Goda wala, Iswetiya, Gasgommana, Perahana, Kattakaduwa, Tisbambe, Kiul-ela,* etc. Descriptions and importance of them were discussed *(Rekha Nianthi & Dharmasena, 2009)* in details. They have referred to the Gasgommana as it is the naturally grown vegetation in the upstream land strip *(Vaan gilma)* above the tank bed, accommodating water only when spilling. Large trees such as ***Kumbuk (Terminalia arjuna)***,Nabedda (Vitex leucoxylon), maila, damba, etc. and climbers such as *kaila, elipaththa, katukeliya, kalawel, bokalawel*, etc. are found in this aea. This vegetation is natural and seeds are floating on water. The *Gasgommana* also acts as a wind barrier reducing evaporation from the tank and lowering water temperature. It gets closure to the bund from either side where roots of large trees make water habitats creating breeding and living places for some fish species. This strip of trees demarcates the territory between human and wild animals. *Perahana* is the meadow developed under *Gasgommana* and filters the sediment flow coming from upstream *Chena* lands. *Iswetiya* or *Potawetiya* is an upstream soil ridge constructed at either side of the tank bund to prevent eroded soil from entering tank bed. *Godawala* is a man-made water hole to trap sediment and it provides water to wild animals. This might had been a strategy to evade man-animal conflict. *Thawulla* is the *upper* part of the tank bed, where a shallow, water body is found in almost all flat area. Here water will disappear during 2-3 months after *Maha* rains. Following figure shows the *Thawulla* at *Paranahalmillewa* at Anuradhapura in the dry zone *(Rekha Nianthi, 2008)(Source : K.W.G. Rekha Nianthi and M.A.S. Jayakumara – Progress of Research on Cascade Irrigation Systems in the Dry Zones of Sri Lanka – extracted from Water Communities, Community, Environment and Disaster Risk Management, Volume 2, 109-137, 2010)*

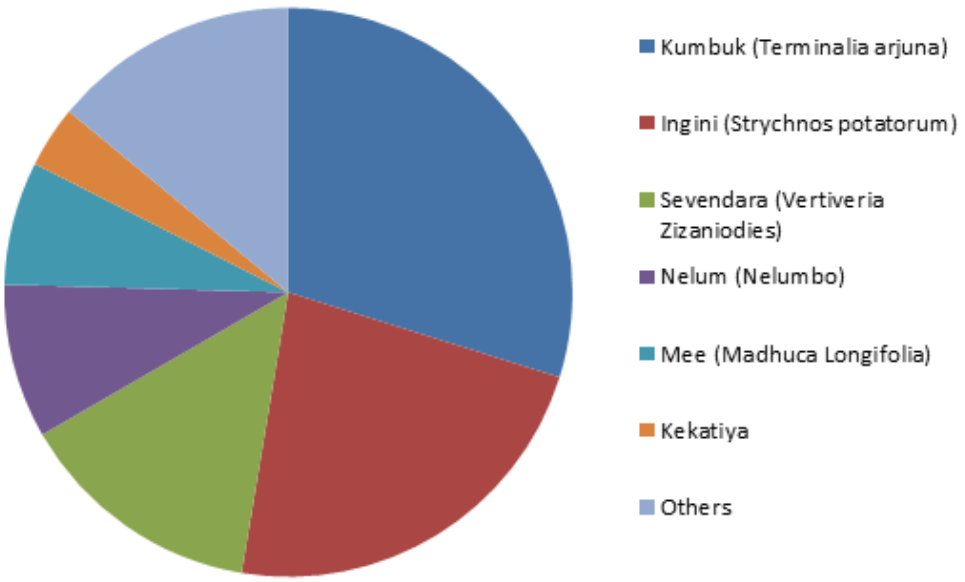
4. OPINION SURVEYS WITH TREDITIONAL/AYURVEDIC MEDICALPRACTIONERS

An opinion survey was carried out with Traditional Medicinal Practitioners on Water Purification plants in Sri Lanka. The questionnaire (Appendix A) was translated to local language and distributed among 18 local traditional medicinal practitioners, including the medicinal practitioners in the affected North Central Province.

According to the responses of the questionnaire, Terminalia arjuna (Kumbuk[S]), Strychnos potatorum (Ingini[S]), Vetiveria zizanioides (Sevendara[S]), Nelumbo (Nelum[S]), Madhuca longifolia (Mee[S]), Aponogeton (Kekatiya[S]) plants have been commonly used plants for water purification in Sri Lanka and are acceptable by the villagers.

Figure 2 presents the results of the opinion survey indicating the use of each species of plants in water purification.

Figure 2 : An opinion survey: Use of plants in water purification



It is an opinion of the medicinal practitioners that the nature selects the best suitable plants to be grown in particular areas, other than allowing a single variety to grow, when nature is given the freedom to decide. A significant percentage of medical practitioners have recommended the species Terminalia arjuna (Kumbuk[S]) as a good plant to purify water. Thereby Terminalia arjuna has been selected to study in detail for its water purification effect and also the sustainability of growing in the surroundings of reservoirs so that the village communities can benefit with better quality drinking water.

Another view point expressed in the opinion survey is the products prepared from naturally available materials under proper hygienic conditions using bamboo, clay and dry fruit pots and pans for cooking and storage of food and water, minimize chemical reactions as they are environment friendly, and would also absorb ions and minerals in water, being a means of purifying water naturally.

The views expressed by some of the domain experts in the field of indigenous knowledge stated that making use of natural means of food production such as organic farming and water purification by different plant species provide a sustainable solution for health problems created due to hazardous chemicals present in food and water. Most medical practitioners also pointed out that in rural areas, in ancient times, the villagers had prepared their food mostly from collecting fresh plant parts from their surrounding environment, which was the most suitable way according to their living environment and the climate.

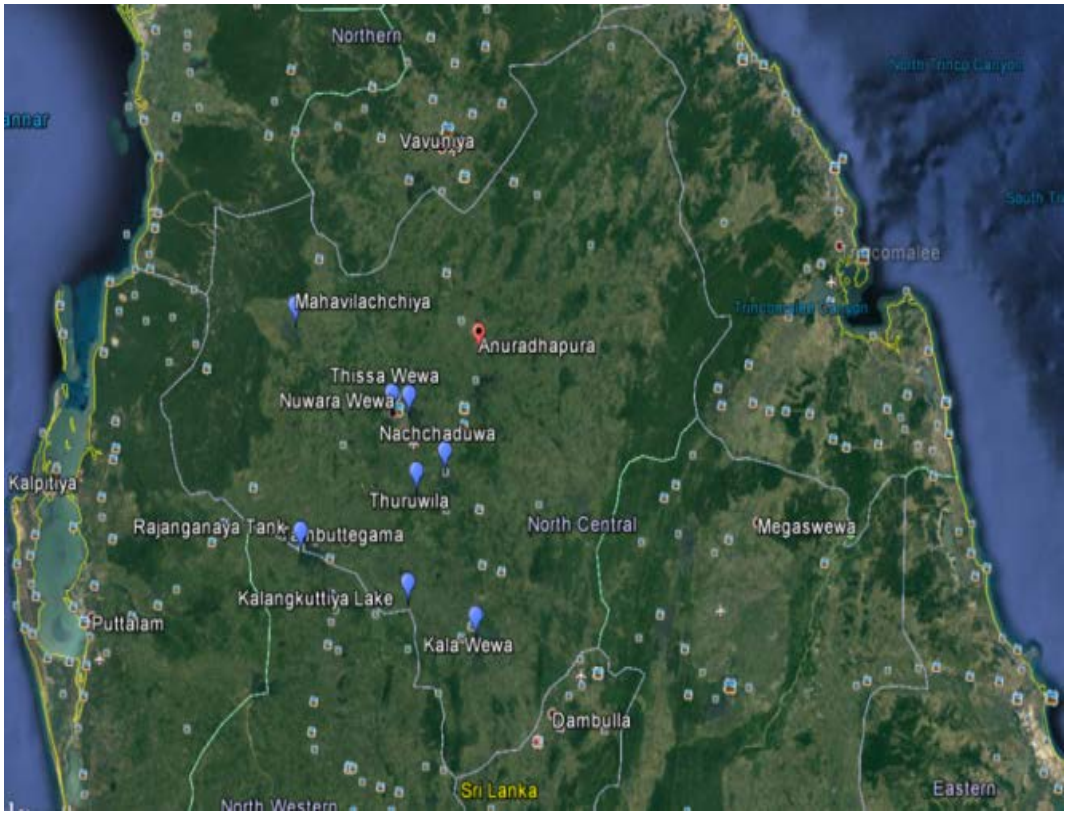
5. FEILD STUDIES ON *Terminalia arjuna*

Terminalia arjuna is a plant that is considered to be water purifying, among local communities which could be seen in almost all parts of Sri Lanka. As the issue of safe drinking water is critical in the dry zone areas of the country, field studies were carried out in some of the areas highlighted in the following map shown in Figure 3.

Figure 3 : Field Study Area in Sri Lanka Map

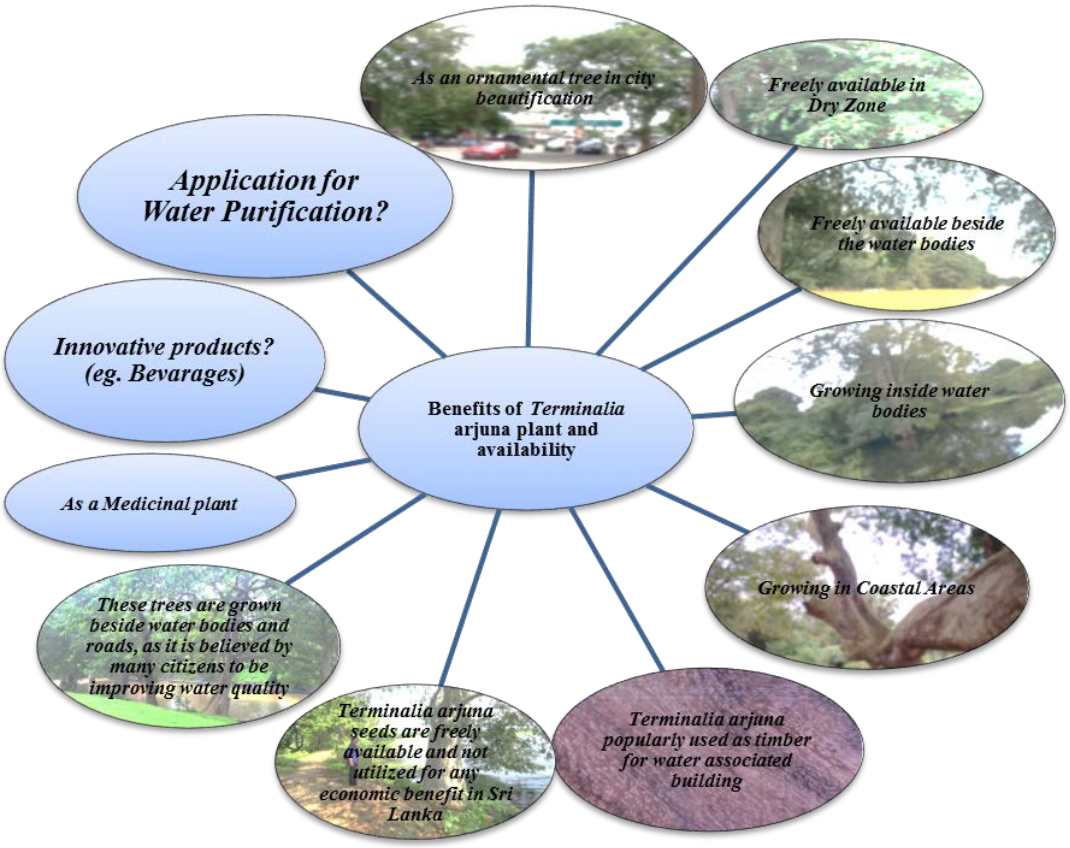
Field visits were conducted in Anuradhapura District (North Central Province) in the Dry Zone of Sri Lanka, and the Lake sites of (R1)Nuwarawewa, (R2)Thisawewa, (R3)MalwathuOya, (R4)Mahawilachchiya wewa, (R5)Mahawilachchiya oya, (R6)Nachchaduwawewa, (R7)Thuruwila, (R8)Kalawewa, (R9)Kalangkuttiyawewa, (R10)Rajanganaya,(R11) Thalawa wewa and (R12)Thambuttegama wewa were examined during these visits. Figure 4 indicates the locations of the selected reservoirs.

Figure 4 : Selected lake sites in Anuradhapura District in Sri Lanka map



The study revealed that Terminalia arjuna trees are being used as an ornamental and shading tree besides roads in the cities of Sri Lanka for a long period of time. These trees are freely available all over the country including the North Central Province, where farmers are heavily affected by the Chronic Kidney Disease of uncertain aetiology (CKDu). It is freely available close to the water bodies. These trees also could be seen growing in the middle of the reservoirs. The summary of the benefits of Terminalia arjuna trees is presented in Figure 5.

Figure 5 : Benefits of *Terminalia arjuna*and its' availability within Sri Lanka



Surrounding plant species and coverage of *Terminalia arjuna* trees in each lake sample site was identified and analysed during these visits with the help of elderly village citizens, an Ayurvedic medicinal doctor and the officials from the irrigation and water authorities. Water samples from the lakes were also collected during these field visits for laboratory on Cadmium concentration. Table 1 presents the data compiled from the field study on plant species in the surroundings of the sample of reservoirs.

Table 1: Plant Species available in the surroundings of selected reservoirs

ID	Name of Reservoir	Surrounding Trees, plants and shrubs
R1	Nuwara wewa	Ehetu(S) *Ficus*; Kohomba(S) *Azadirachta indica*; Karanda(S) *Pongamia pinnata*; Maila(S) *Bauhinia racemosa*; Ma Dam(S) *Syzygiurum cumniskeels*; Attikka(S) *Ficus racemosa*; Ela Kaluwara(S) *Diospyros ebenum*; Weera(S) *Drypetes sepiaria*; Maara(S) *Peltophorum ferrugineum*; Thal(S) *Borassus flabellifer*; Nabada(S) *Vitex leucoxylon*; Ehetu(S) *Ficus*; Tel Endaru(S) *Ricinus communis*; Wal Babila(S) *Sida cardifolia*; Pila(S) *Tephrosia purpurea*.
R2	Thisawewa	Godakirilla (S) *Holoptelea integrifolia*;Milla(S) *Vitex pinnata*; Burutha(S) *Chloroxylon swietenia;* Wa(S) *Cassia siamea*; Keeriya(S) *Acacia chundra*; Ehela(S) *Cassica fistula*; Divul(S) *Limonia acidissima;* Ehetu(S*) Ficus*; Thal(S) *Borassus flabellifer*; Wara(S) *Calotropis gigantean*; Katupila(S) *Fluggea leucopyrus*; Wal Anoda(S); Nidikumba(S) Mimosa pudica; Kekatiya(S) *Aponogeton crispus*; Pethithora(S) *Cassia tora*; Peni Thora(S); Welpenala(S) *Cardiospermum halicacabum; Damu(S)*
R3	Mahawilachchiya	Kohomba(S) *Azadirachta indica*; Katu Kihiri(S) *Acacia nilotica*; Divul(S) *Limonia acidissima*; Weera(S) *Drypetes sepiaria*; Palu(S) *Manikara hexandra*; Dam(S) Syzygium cuminiskeels; Maila(S) *Bauhinia racemosa*; Ehetu(S) *Ficus*; Wara(S) *Calotropis gigantean*; Kotta Pulun(S*) Ceiba pentandra*; Thal(S) *Borassus flabellifer;* Maara(S) *Albizia lebbek*; Siyambala(S) *Tamarindus indica*.
R4	Nachchaduwa	Karanda(S) *Carissa carandus*; Nabada(S) *Vitex leucoxylon*; Kaila(S) *Phyllanthus reticulatus*; Palu(S) *Manikara hexandra*; Midella(S) *Barringtonia acutangula*;Siyambala(S) *Tamarindus indica*; Bokala(S) *Derris scandens*; Maila(S) *Bauhinia racemosa*; Kayang(S) *Memecylon sylvaticum*; Nitulla(S) *Plumbago auriculata*;Killotapiyan/Wal alamudu(S);Keppettiya(S) *Croton armaticus;* Kaduru(S) *Strychnos nux-vomica*; Pila(S) *Tephrosia purpurea;* Nidikumba(S) *Mimosa pudica;* Kapuhanassa(S) *Abelmoschus angulosus*; Angunakola(S) *Wattakaka sp*.; Aswenna(S) *Alysicarpus vaginalis*; Wal rambuttan(S) *Xanthium indicum*; Wal Babila(S) *Sida cardifolia*; Podisingnomarn(S) *Eupatorium odoratum*; Bata Damba(S) *Cleistoccalyx nervosum*; Eraminiya(S) *Ziziphus napeca*;Wara(S) *Calotropis gigantean*; Keiriya(S) *Acacia ferruginea*; Kona(S) *Gliricidia sepium*; Iha(S) *Albizia amara*; Ilapatha(S) *Syzgiumcylindricum*; Goda manel(S) *Crinum latifolium*; Katupila(S) *Maytenus emarginata*; Thunpath Kurundu(S) *Pleiospermium alatum*; Hurimara(S) *Albizia odoratissima*; Welan(S) *Pterospermum suberifolium*; Painkuttiya (S); Ehela(S) *Cassica fistula;* Goda Kirilla(S) *Holoptelea integrifolia*; Kotakimbula(S);Ranawara(S) *Cassia auriculata;*Weera(S) *Drypetes sepiaria*;Ehetu(S) *Ficus*;
R5	Thuruwila	Kohomba(S) *Azadirachta indica*;Thal(S) *Borassus flabellifer*; Maara(S) *Peltophorum ferrugineum*;Mee(S) *Madhuca longifolia*; Wara(S) *Calotropis gigantean*; Ehetu(S) *Ficus*; Goda Kirilla(S) *Holoptelea integrifolia*; Midella(S) *Barringtonia acutangula*;Maila(S) *Bauhinia racemosa*;Nabada(S) *Vitex leucoxylon*; Siyambala(S) *Tamarindus indica*;Helamba(S) *Mitragyna tublosa*; Lolu(S) *Cordia monoica*; Madatiya(S) *Adenanthera pavonina*; Etteriya(S) *Murraya paniculata*; Gansuriya(S) *Thespesia populnea*; Hurimaara(S) *Albizia odoratissima*; Weera(S) *Drypetes sepiaria*
R6	Kalawewa	Maara(S) *Albizia lebbeka*; Burutha(S) *Chloroxylon swietenia*; Kone(s) *Schleichera Oleosa*; Kohomba(S) *Azadirachta indica*; Ketakela(S) *Bridelia retusa*; Ehetu(S) *Ficus*; Kiri kone(S) *Walsura trifoliolata*; Hurimara(S) *Albizia odoratissima*; Goda

ID	Name of Reservoir	Surrounding Trees, plants and shrubs
		Kirilla(S) *Holoptelea integrifolia*;Wa(S) *Cassia siamea*; Mora(S) *Glenniea unijuga*; Damu (S); Welan (S) *Pterospermum suberifolium*; Godaratmal(S); Maila(S) *Bauhinia racemosa*;Kihiri(S) *Acacia nilotica*; Helamba(S) *Mitragyna tublosa*; Nitulla(S) *Plumbago auriculata*; Polpala(S) *Aerva javanica*; Angunakola(S) *Wattakaka sp*.; Wel badila(S); Karalheba(S) *Achyranthes aspera* L.; Diya meneriya(S) *Commelina benghalensis*; Rilatana(S) *Ischaemum timorense*; Wembadanga wel(S); Siriwedi bebila(S) *Sida mysorensis*; Bulu(S) *Terminalia bellirica*
R7	Rajanganaya	Kohomba(S) *Azadirachta indica*;Wara(S) *Calotropis gigantean*;Siyambala(S) *Tamarindus indica*; Maila(S) *Bauhinia racemosa*;Katupila(S) *Maytenus emarginata*; Andara(S) *Acacia eburnea*; Goda Kirilla(S) *Holoptelea integrifolia*; Lolu(S) *Cordia monoica*; Bibila(S); Rata Hinguru(S) *Lantana camara*; *Tridax procumbens*; Kaila(S); Killotapiyan/Wal alamudu(S); Kayan(S);Hurimara(S) *Albizia odoratissima*; Aralolu(S); Wara(S) *Calotropis gigantean*;Hik(S) *Lannea coromandelica*; Boradamana(S) *Grewia helicterifolia*; Demata(S) *Gmelina asiatica*; Pol(S) *Cocus nucifera*; Ipil Ipil(S/E) *Leucaena leucocephala*; Jam(S/E) *Muntingia calabura*; Bo(S) with red petiole Ficus sp.; Lunumidella(S); Badulla(S) *Semecarpus subpeltada*

However, during the discussions with the relevant government officials and villagers it was also noted that huge trees such as Terminalia arjuna cannot be planted near Lake Bunds (small dams) as they could pose a threat to the bunds/dams. When maintaining these bunds, it is of usual practice to remove huge trees like Terminalia arjuna to prevent seepage and leakage. It was also revealed that natural water purification methods by fauna and flora were applied to some extent in some water supply scheme intakes such as Labugama and Kalatuwawa, of Sri Lanka situated in the Western Province of the country.

Strengthening the idea of growing trees literature states that, "Trees along the embankment are generally in good to fair condition. They are well adapted to the site and protect the trees and structures behind them. Removal would be costly, disruptive and of unproven worth. Simple adherence to good design principles will allow these trees to continue to provide shade, stabilize the soil, increase property values, armor the embankment, and modify the microclimates at minimal cost without a proven risk"[1].

The Dodson-Lindblom Study titled "Buckeye Lake Dam Spillway Adequacy and Embankment Stability and Seepage Study", prepared under contract with Ohio Department of Natural Resources (ODNR) in 1987, states, "Because of the large size of many of the trees and depth of the root systems, removal of all the trees and repair of the large holes caused by this tree removal would possibly cause more problems than if the trees were left in place"[2]. Some of the large trees are grown near the coastal areas as well. "In areas where salinity is not associated with high water table conditions, tree species like Acacia auriculiformis, Terminalia arjuna and Leucaena lucocephala can be grown"[3]. Terminalia arjuna popularly used as timber, especially linked as a water associated building material. The fruits and seeds of this

[1]Sydnor, Davis; Letter to United States Army Corps of Engineers Huntington District on behalf of the Citizens of Buckeye Lake, 1995.
[2]John Sproat for Save Buckeye Lake; Trees help stabilize Buckeye Lake dam, The Buckeye Lake BEACON, 2013-11-30 / Editorials & Letters).
[3]O.S. Tomar and R.K. Gupta; Performance of some forest tree species in saline soils under shallow and saline water-table conditions, Plant & Soil 87, 329-335 (1985).

plant is seen freely available in the surrounding of it without it being utilized for any economic benefit in Sri Lanka.

6. EXPERIMENTAL PROGRAMME ON CADMIUM ABSORPTION BY *Terminalia arjuna*

In line with widely spreading CKDs among rural farming communities in the Dry Zone of Sri Lanka, increase of Cadmium ion concentration in water bodies has been identified as a main potential causative agent .

As far as cadmium is concerned, scientists have already identified through research quite a number of plant species, which are also available in Sri Lanka, that can accumulate cadmium. Some of the proven species for cadmium absorption are Athyrium yokoscense , Avena Strigose and Crotalaria juncea[(S) Andana hiriya] , Bacopa monnieri [(S)Lunuwila] , Brassica juncea[(S)Aba] , Valisnaria spiralis L. , Eichchornia crassipes , Helianthus annus , Hydrilla verticillata , Lemna minor(duck weed) , Pistia stratiotes (water lettuce- diya gowa) , Salx viminalis , Spirolelea polyrhiza , Tagetes erecta Thlaspi caaerulescenes(alpine pennycress .

Many research were carried out on effects of medicinal benefits of Terminalia arjuna plant parts, eg. Protective effect of the fruits of Terminalia arjuna against cadmium-induced oxidant stress and hepatic cell injury via MAPK activation and mitochondria dependent pathway. But it is still not proven whether Terminalia arjuna trees/parts are able to absorb Cadmium ion for water purification.

In order to develop a relationship between Cadmium concentration and the presence of Terminalia arjuna plant in the surroundings of the source reservoir, a laboratory testing programme was carried out. Three water samples were collected from the reservoir from each location and the approximate tree cover was worked out by observation. The Atomic Spectroscopic analysis using Graphite Furnace method was used to determine the cadmium concentration in the laboratory of Department of Chemistry, University of Colombo, Sri Lanka.

Table 2 presents the details of the sample of reservoirs and the concentration of associated Cadmium levels.

Table 2: Reservoir Capacity, Surrounding features, presence of *Terminalia arjuna* plants, and Cadmium concentration in water, near sample areas

ID number	Name of Reservoir	Reservoir Capacity (Acr/ft)	Approx. % coverage of *Terminalia Arjuna*	Cadmium Concentration of the samples (µg/L)
R1	Nuwara wewa	35,050	No *Arjuna* plants near the sample area	3.4
R2	Thisawewa	2,960	No *Arjuna* plants near the sample area	1.6
R3	Malwathu Oya		50%	2.3
R4	Mahawilachchiya	30,500	25%	1.3
R5	Mahawilachchiya Oya		50%	1.1
R6	Nachchaduwa wewa	45,051	10%	LDL*
R7	Thuruwila	5,190	No *Arjuna* plants near the sample area	0.6
R8	Kalawewa	100,000	50%	LDL
R9	Kalangkuttiya, Galnewa		90%	LDL
R10	Rajanganaya wewa	76,603	20%	LDL
R11	Thalawa wewa		30%	LDL
R12	Thambuttegama		95%	LDL

*LDL - Less than detection limit

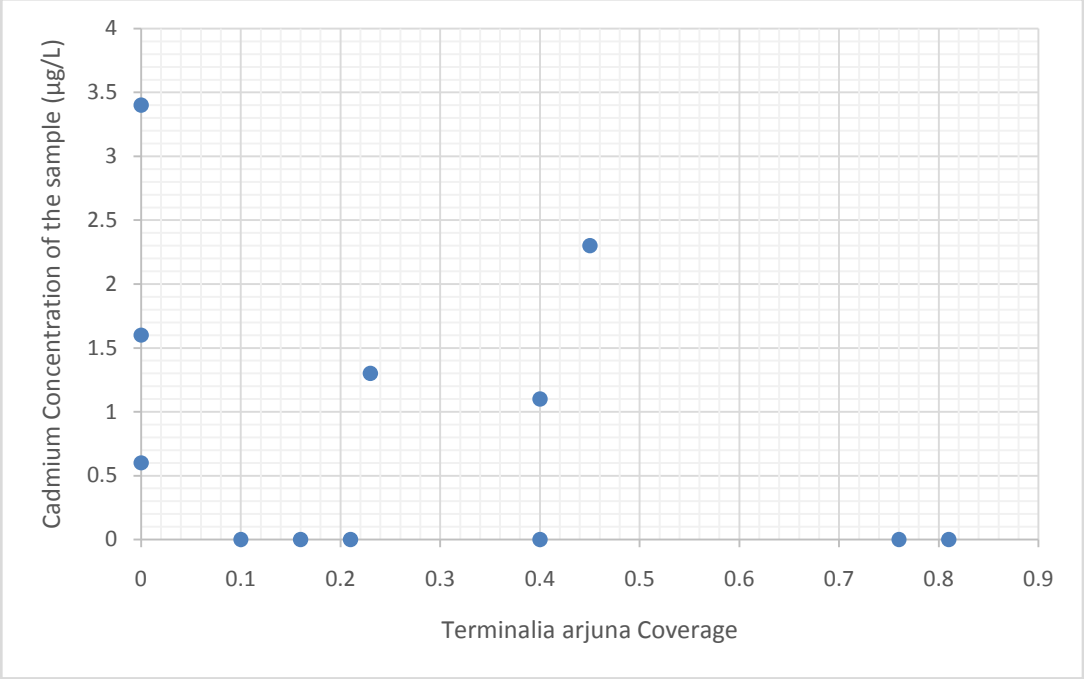
Table 3 presents the variation of Cadmium concentration with the total plant coverage and the coverage of *Terminalia arjuna*.

Table 3: Cadmium Concentration of the sample (µg/L) Vs. *Terminalia arjuna* Coverage

Reservoir Identification Number	Name of Reservoir	Total Plant Coverage exposed to reservoir as a % in Sample Area	Proportion of *Terminalia arjuna* Trees as a (%) of the total plant cover	*Terminalia arjuna* Coverage	Cadmium Concentration of the sample (µg/L)
R1	Nuwara wewa	70	0	0.00	3.4
R2	Thisa wewa	70	0	0.00	1.6
R3	Malwathu Oya	90	50	0.45	2.3
R4	Mahawilachchiya wewa	90	25	0.23	1.3
R5	Mahawilachchiya Oya	80	50	0.40	1.1
R6	Nachchaduwa wewa	95	10	0.10	0
R7	Thuruwila	50	0	0.00	0.6
R8	Kalawewa	80	50	0.40	0
R9	Kalangkuttiya, Galnewa	90	90	0.81	0
R10	Rajanganaya wewa	80	20	0.16	0
R11	Thalawa wewa	70	30	0.21	0
R12	Thambuttegama tank	80	95	0.76	0

Figure 6 graphically represents the variation of Cadmium level with coverage of *Terminalia arjuna*.

Figure 6 : Variation of Cadmium Concentration with Proportion of *Terminalia arjuna* coverage



7. RESULTS, DISCUSSIONS AND RECOMMENDATIONS

Although there is a scatter in the Cadmium concentration, there is a near trend of lower cadmium levels at the locations where Terminalia arjuna tress present. Reservoirs R1 and R2 are not surrounded by the Terminalia arjuna trees and showing higher cadmium concentration. Moreover, the locations where higher plant coverage is available, such as reservoirs R9 and R 12, the cadmium concentrations were found to be lower than the detection levels or reported as zero.

However, there are two Oya R 3 and R5 which can be termed as rivers indicting higher cadmium levels even with 25% to 50% Terminalia arjuna coverage. The samples were collected from the flowing water from these two rivers and unlike the other reservoirs the water in these two river has a considerable velocity. Further to that R3 and R5 are located in highly populated urban areas where the other factors could contribute toward pollution.

Reservoir R4 has shown a cadmium level of 1.3 µg/L with 25% Terminalia arjuna coverage. This has shown a result which is slightly outside the trend of reducing cadmium levels with higher plant coverage.

Considering all the findings of this research the trend of reducing pollutants by the coverage of *Terminalia arjuna*plant has to be investigated with an in-depth research study with more laboratory testing under controlled conditions for the plant coverage.

8. CONCLUDING REMARKS

Poor quality drinking water has caused health issues to the rural communities in developing countries. Most of the villagers consisting of farmers use unsafe drinking water. Using plant coverage to purify water is a sustainable way of improving the drinking water quality for the village community who mainly rely on reservoirs as the main source.

The opinion survey carried out among the traditional medicinal practitioners has highlighted the importance of protecting the natural forest in these water polluted rural villages and to carry out research on traditional food patterns and consumption.

According to the literature review, it is already proven by many scientists that many plant varieties are specialized in absorbing/adsorbing different kind of ions. These data should be analysed, and it is also important to have a national plant list with the details of research carried out internationally and locally on inhibition, absorption and adsorptions abilities of ions.

Conclusion drawn from the Opinion survey, Terminalia arjuna tree has been considered as a water purification plant for many generations in the country, and grown besides the water bodies for water purification. Terminalia arjuna trees are available in many parts of the country and freely available fruits and barks are not effectively utilized for economic benefits. It is observed that Terminalia arjuna could withstand a range of climatic conditions. Therefore, the benefits of these trees could be applied easily all over the country.

It is high time for the nations to consider practicing effective and economical agricultural methods to minimize the environment pollution and maximize the value addition, differentiation and specialization of natural products. Plant varieties should carefully be selected for cultivation, with multi-disciplinary approach, which could be used for environment protection with food, medicinal, construction and useful for

any other purposes. The agricultural sector should not depend on only a few varieties of crops. In order to do this, it is important to research on the historical traditional knowledge on environment and combine this knowledge with the new technological findings to maximize the economic, social and environmental benefits to the society.

Awareness and knowledge sharing programs should be conducted among the farmers to minimize the chemical and inappropriate water usage with practical solutions along with required infrastructure facilities with Government support.

Conclusion drawn from the field visits in Sri Lanka, Terminalia arjuna is growing in many areas, beside roads, near wells and water bodies, and is mainly used as an ornamental tree and for timber production. Though these tree parts are used for medicinal purposes in Ayurvedic Medicine in Sri Lanka, it is done in a miniature scale. Though value added products could be processed from the bark and seeds, it is not utilized, and these economic opportunities are not considered in the country, which could be a very valuable income generation method.

According to the correlation between laboratory test results and collected data there is a fair probability of an effect of Terminalia arjuna trees on Cadmium concentration in water.

But further analysis need to be done, due to limited number of sample tested. A general assumption was taken by examining the percentage of Terminalia arjuna coverage in the field visited. For further accuracy the number of trees and the life span of the tree, the exact distance between the trees and the water body and sample, the sample water taken area environment and social parameters need to be taken into consideration.

Reference List

1. *A. Chaudhary, S. K. Singla,[1] and C. Tandon, Indian J Pharm Sci. 2010 May-Jun 15*
2. *Bioremediation for water purification• A case study at St. Coombs Lake, Talawakelle by P. G. D. S. Amarasena, K. M. Mohotti, G. Hitinayake, - extracted from the Proceedings of the International Forestry and Environment Symposium 2006 of the Dept. of Forestry and Environmental Science, University of Sri Jayewardenepura, Sri Lanka 17*
3. *Buddhika D. Madurapperuma, Mala D. Amarasinghe and Peter G. Oduor - Salient ecological functions of a tropical freshwater wetland, Lakes & Reservoirs: Research and Management 2013 18: 45–51.....10*
4. *Dezeen Book of Interviews, 17 September 2013, Plant based water-purifying system named "Idea that will change the world 6*
5. *G.M.P.R. Weerakoon, K.B.S.N. Jinadasa, G.B.B. Herath, M.I.M. Mowjood, J.J.A. van Bruggen; Impact of the hydraulic loading rate on pollutants removal in tropical horizontal subsurface flow constructed wetlands.....9*
6. *Hand book on Medicinal & Aromatic Plants [NEDFI]from web 81*
7. *K.B.S.N. Jinadasa, N. Tanaka, S.Sasikala, D.R.I.B. Werellagama, M.I.M. Mowjood and W.J. Ng; Impact of harvesting on constructed wetlands performance – a comparison between Scirpus grossus and Typha agustifolia, Journal of Environmental Science and Health Part A (2008), 43, 664-671 .....8*
8. *K.W.G. Rekha Nianthi and M.A.S. Jayakumara – Progress of Research on Cascade Irrigation Systems in the Dry Zones of Sri Lanka – extracted from Water Communities, Community, Environment and Disaster Risk Management, Volume 2, 109-137, 2010.....19*
9. *K.W.G. Rekha Nianthi and M.A.S. Jayakumara – Progress of Research on Cascade Irrigation Systems in the Dry Zones of Sri Lanka – extracted from Water Communities, Community, Environment and Disaster Risk Management, Volume 2, 109-137, 2010) 18*
10. *Kaustubha Mohanty, Mousam Jha, B. C. Meikap, and M. N. Biswas, Department of Chemical Engineering, Indian Institute of Technology (IIT),*

Kharagpur, Dist: Midnapur(W), West Bengal, Pin-721 302, India, Ind. Eng. Chem. Res., 2005, 44 (11), pp 4128–4138 16

11. *Kaustubha Mohanty, Mousam Jha, B.C. Meikap, M.N. Biswas; Elsevier, Chemical Engineering Science,Volume 60, Issue 11, June 2005, Pages 3049–3059* 15
12. *Maryam Kazemipour, Mehdi Ansari, Shabnam Tajrobehkar, Majdeh Majdzadeh, Hamed Reihani Kermani, Journal of Hazardous Materials, 31 January 2008* .11
13. *N. Salami and F A Adekola at University of Ilorin, Nigeria, January 2002* 9
14. *Orwa et al 2009, Agroforestry Database 4.0, P 1-5* 14
15. *Piyasiri Amilasith Yapa, Phytoremediation of soil and water in CKD affected areas , The Island Newspaper, P6, 16 December 2013* 12
16. *Rekha Nianthi, 2008* 19
17. *Robert Chambers, 1994*.....18
18. *S.K. Weragoda, K.B.S.N. Jinadasa, Dong Qing Zhang, Richard M. Gersburg, Soon Keat Tan, Norio Tanaka, Ng Wun Jeron – Tropical Application of Floating Treatment Wetlands*.....8
19. *Sankar Kumar Dey, Debdulal Banerjee, Sourav Chattapadhyay and Krishnendu Bikash Karmakar; Antimicrobial Activities of Some Medicinal Plants Of West Bengal, International Journal of Pharma and Bio Sciences, Vol.1/Issue-3/Jul-Sep.2010* 16
20. *Tanner and Headley 2011* 7
21. *Tanner and Headley 2011: Fonder and Headley 2010*.....7
22. *Vidyodaya J. of Sci. (2001) Vol.10 pp 167-182, M A A W Moramudali, P Fernando and P A J Yapa, University of Sri Jayawardenepura, May 2001* 7
23. *Y. Zimmels, F. Kirzhner, S. Roitman, Water Environment Research, Volume 76, Number 3* 10

.

Appendix A : Questionnaire

1. Questionnaire (English Version)

A. i. Do you know about trees/plants which could purify water? Yes/No

ii. If Yes, What are the species that you know and details?

iii. Do you know any studies carried out on above species? Yes/No

iv. If yes, please specify the details (study done by whom/organization and contact details)

v. How and for what can these trees could use for? (eg. town and country planning?)

B. i. Do you know about *TerminaliaArjuna* (Sinhala :Kumbuk, Tamil:Marutamaran)? Yes/No

ii If Yes, please specify

ii. Do you know any studies carried out on *TerminaliaArjuna*? Yes/No

iii. If yes, please specify the details (study done by whom/organization and contact details)

iv. Do you know locations of *TerminaliaArjuna*near a natural water resource? Yes/No

v. If yes, please specify

C. i. Can Kumbuk Tree grow as a plantation? Yes/No

ii. If Yes, Reason/Benefits :

iii. If No, Reason:

D. i. Is there any information/recommendations relevant to above that you could share with? Yes/No.

ii. If yes, please state

2. Questionnaire in Local Language (Sinhala)

දත්ත සටහන

A. i. ජලය පිරිසිදු කරන පැල හෝ ශාක පිළිබඳව ඔබ දන්නවාද? (ඔව් / නැත)

ii. ඔබෙ පිලිතුර "ඔව්" නම් එම වර්ග මොනවාද? ඒ පිළිබඳව විස්තර කරන්න.

.....
.....
.....
.....
.....

iii. මෙම ශාක පිලිබඳ කර ඇති අධ්‍යනයන් පිලිබඳ ඔබ දන්නවද? (ඔව් / නැත)

iv. ඔබෙ පිලිතුර "ඔව්" නම් ඒ පිළිබඳව විස්තර කරන්න. (ඒ පිළිබඳව තොරතුරු ඉදිරිපත්කල තැනැත්තෙක් හෝ ආයතනයක් හා සම්බන්ද විය හැකි මාර්ගයක් දක්වන්න.)

.....
.....
.....
.....
.....

v. මෙවැනි ශාක නගර හා රටවල් සැලසුම් කිරීමට යොදා ගන්නෙ කෙසේද?

B. i. ඔබ කුඹුක් ශාකය දන්නෙහිද? (ඔව් / නැත)

ii. ඔබෙ පිලිතුර "ඔව්" නම් ඒ පිළිබඳව විස්තරයක් ලබා දෙන්න.

.....
.....
.....
.....
.....

iii. ඔබ කුඹුක් ශාකය පිළිබඳ කර ඇති අධ්‍යනයන් පිලිබඳ ඔබ දන්නෙහිද? (ඔව් / නැත)

iv. ඔබෙ පිලිතුර "ඔව්" නම් ඒ පිළිබඳව විස්තර කරන්න. (ඒ පිළිබඳව තොරතුරු ඉදිරිපත්කල තැනැත්තෙක් හෝ ආයතනයක් හා සම්බන්ද විය හැකි මාර්ගයක් දක්වන්න.)

.....
.....
.....
.....
.....
.....

1

v. කුඹුක් ගාක වැඩෙන ස්වභාවික ජලාශය ස්ථාන ඔබ දන්නවා ද? (ඔව් / නැත)

vi. ඔබේ පිලිතුර "ඔව්" නම් ඒ පිළිබඳව විස්තරයක් ලබා දෙන්න.

.....
.....
.....
.....
.....

C. i. කුඹුක් වගාවක් ලෙස ව්‍යාප්ත කල හැකිද? (ඔව් / නැත)

ii. ඔබේ පිලිතුර " ඔව් " නම් ඊට හේතු සහ ප්‍රයෝජන දක්වන්න.

.....
.....
.....
.....
.....

iii. ඔබේ පිලිතුර " නැත" නම් ඊට හේතු සපයන්න.

.....
.....
.....
.....
.....

D. i. ඉහත සඳහන් විස්තරවලට අදාල බෙදා ගත හැකි කොරකුරු ඔබ ලග තිබෙද?
(ඔව් / නැත)

ii. ඔබේ පිලිතුර "ඔව්" නම් ඒ පිළිබඳව විස්තරයක් ලබා දෙන්න.

.....
.....
.....
.....

නම : තනතුර :

....

දුරකතන අංකය : ..... ජංගම දුරකතන අංකය : .....
e-mail : ....

ලිපිනය :

.....
.....
.....

Appendix B : Research on Benefits of *Terminalia arjuna* and Reference Guide on Studies − Extracted from Examin.com Medical Disclaimer

Terminalia arjuna (Arjuna) also known asArjuna, Dhavala, Kakubha, Nadisarja, Veeravriksha, Partha, Indradru, is a tree that has its bark used medicinally, usually for the purposes of cardioprotection. It appears to reduce pressure and pulse rate, and may increase aerobic exercise capacity.

Terminalia arjuna (usually simply referred to as Arjuna) is a tree bark that is used medicinally in Ayurveda for the purposes of cardiovascular health pertaining to the heart itself. It has a large variety of bioactives, with the water extract showing promise at improving left ventricle function of the heart without any observable toxicity of side effects when taken at 500mg thrice a day (every 8 hours).

There are numerous human studies conducted on Arjuna bark, although many of them are low in sample size. Nevertheless, the water extract appears to be effective in improving cardiac function in persons who have recently undergone cardiac trauma or injury; Myocardial Infarction is the most commonly researched ailment in this regard. Only one study exists on otherwise healthy persons, but Arjuna showed benefit in improving left ventricle function in an exercise test and the benefits may affect a person regardless of health state.

In animal models, this extract appears to exert protection on cardiac tissue in response to various cardiac insults including beta(2)adrenergic agonists (like Ephedrine, although isoproterenol was used in the studies) and catecholamine's themselves.

The water extract appears to be effective for improving cardiovascular health, particularly at the level of left ventricle function. The studies in humans are underpowered at this moment in time and only one in healthy humans (preliminary evidence), but all evidence appears to be promising and in the same positive direction. The water extract appears to be quite safe.

Other extracts such as ethanolic or acetone, with different bioactives, may not have similar cardio protective effects (no human trials, but some *in vitro* evidence suggesting the bioactives are not in these extracts) yet appear to be somewhat cancer protective. Tumour growth in animal models is reduced with either the ethanolic

extract or isolated Arjunolic Acid (commonly seen as the main bioactive) as is reduced DNA damage in response to mutagens, and these are attributed to the antioxidative capacity of Arjuna which is comparable to Vitamin C on a per weight basis. Due to the anti-cancer effects of the ethanolic extract having some cytotoxic properties, and LD_{50} has actually been established with this extract and it is possible that side-effects may occur. Additionally, the anti-cancer evidence is somewhat limited as although cytotoxicity has been established in cancer cells a lack of evidence exists to assess healthy cells (a good anti-cancer drug will be highly selective in killing cancer cells, which Arjuna does, and not healthy cells, which Arjuna has not been sufficiently tested for).

Other possible uses of Arjuna include ulcer protection in the stomach with potency similar to Rantidine in one study (associated with the ethanolic extract), protection to the liver and kidney likely mediated by antioxidative properties (ethanolic extract) and the cardiovascular properties may increase anaerobic cardiovascular performance in healthy persons (with the one study using sprinting as a test) although this last claim has a lone study in support of it and no replication.

Ethanolic extracts have potent antioxidative and potentially potent anticancer effects, but although there are no reported side effects with the ethanolic extracts currently (due to a lack of human interventions) it is theoretically plausible that higher than recommended doses could be harmful related to the anticancer effects (cytotoxicity)

Things to Note

- The water extract (used for cardiovascular health) and ethanolic/acetone extracts (used for cancer prevention and antioxidant purposes) are markedly different and, for all intents and purposes, should be treated as different supplements

Goes Well With

- Ashwagandha (appears to benefit cardiovascular function on parameters that Arjuna does not, and combination therapy in health persons has at once been shown to confer additive benefits to exercise capacity with both being effective in isolation)

How to Take (recommended dosage, active amounts, other details)
A standard dose for the purposes of cardiac health appears to be 500mg of the bark (water extract) taken daily in the morning without food (no evidence exists to suggest that taking it *with* food is bad or anything). For persons who suffered cardiac trauma (such as Myocardial Infarction), this dose tends to be taken thrice a day every 8 hours

The leaf extracts and ethanolic extracts appear to be more related to the cytotoxic and anti-tumor effects, but not enough evidence exists to recommend an active dose of these extracts for human consumption.

Table of Contents:

3. Oral Cancer
4. Breast Cancer
5. Lung
6. Hepatocellular Carcinoma

10. Safety and Toxicity

Edit1. Sources and Composition

1.1. Sources

Terminalia arjuna (of the *Combretaceae* family) is a tree; a deciduous evergreen tree standing up to 20-30m above ground level.[1] The bark of the tree appears to have medicinal properties, mostly touted to be a cardioprotective agent.[2][3][4][5] It has been used in Ayurveda under the names of *Arjuna, Dhavala, Kakubha, Kumbuk, Nadisarja, Veeravriksha, Partha, and Indradru*.[6][7] Other notable species in the *Terminalia* family include *bellerica* and *chebula*.[8]

Beyond being used for its cardioprotective/cardiotonic abilities, Arjuna has also been reportedly used for genital health (leucorrhoea, Spermatorrhoea), urinary astringent, expectorant, and some Aphrodisiac properties.[7]

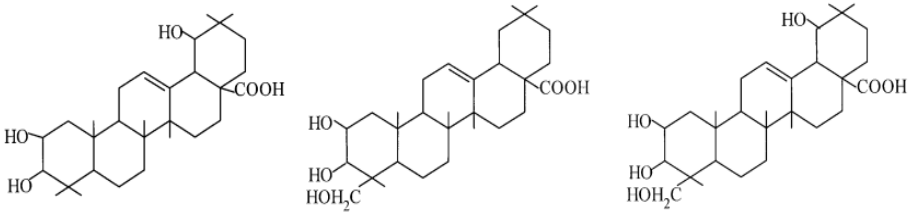
Traditional administration of Arjuna involves a decoction made with the bark and milk drank in the morning, or at least the powder of the tree bark; in the cases of fractures or contusions with echymosis, honey tends to be recommended.[9] Usually 1-3g of the bark is used per day.[10]

1.2. Composition

The tree bark, the main medicinal component, contains:

- The triterpenoids Arjunic acid and Arjunolic Acid,[11][7] up to 3% and 1.5% (respectively) of an Ethyl acetate extract or 2% and 0.9% of a diethyl ester extraction. Minimal quantities (0.2-0.3% of each) in acetone, methanol, and ethanol extracts with a 60:40 ethanol:water extract reaching up to 0.72% and 0.48%, respectively.[7] Arjunic acid has bioactive metabolites as well[12]
- Arjugenin and Arjunetin,[12] the former being an aglycone similar to Arjunic and Arjunolic Acids[13]
- Arjunasides A-E (Triterpenoid monoglycosides)[14] and Arjunetoside[15]
- Ajunglycosides IV and V in the butanolic/methanolic fractions,[16] also in the fruits of *Terminalia chebula*

- Arjunaphthanoloside, a napthanol glycoside[17]
- Termiarjunoside I and II (Oleanane Glycosides),[18] Terminoside A,[19] and Terminolitin[20]
- Pelargonidin, an anthocyanin[21]
- The cardenolide 16,17-dihydroneridienone 3-O-beta-D-glucopyranosyl-(1->6)-O-beta-D-galactopyranoside[22] and the structurally related xylopyranosyl(1->3)[23]
- Ursane triterpenoids (*2α,3β-dihydroxyurs-12,18-dien-28-oic acid 28-O-β-D-glucopyranosyl ester*)[24]
- Tannin structures (Gallic and Ellagic acids),[25] *3-O-methylellagic acid 4'-O-α-L-rhamnopyranoside*,[24] Casuarinin,[26] and Arjunin[27]
- (-)-epicatechin[24]
- Luteolin,[25] Quercetin, Kaempferol and Baicalein[21]
- Vitamin C at 1.47mg/100g (hydroalcoholic extract)[1]
- Vitamin E at 0.58mg/100g (hydroalcoholic extract)[1]



Arjunic Acid **Arjunolic Acid** **Arjugenin**

The three above triterpenoids are commonly seen as the main active ingredients, with other compounds with names related to this plant (Terminoside or Arjunoside as examples) tend to be glycosides of the three above aglycones. That being said, there is no evidence to support that these are the compounds that underlie the cardiovascular health properties although they appear to be causative of anti-cancer and anti-oxidative properties

And the fruits that the tree bears may contain:

- Arjunglucoside I-III and Arjunetin[28]

- Hydrolyzable tannin structures (Ellagic acid, Gallic acid, Corilagin, Chebulagic acid, etc.)[28]
- Chebuloside II and Bellericoside[28]
- Dietary minerals of Calcium, Magnesium, Zinc, and Copper[10]

Total phenolics may reach up to 8.05mg/100g in hydroalcoholic extracts of the bark; tannins may reach 5.1mg/100g.[1]

Edit2. Cardiovascular Health

2.1. Cardiac Tissue

In vitro, the water extract of Arjuna bark appears to have cardiotonic effects with 50ug/mL having similar potency (accessed via amplitude of CS (cell shortening), indicative of contractility) to 100nM Isoproteronol and 1mM Ouabain.[25] The mechanism appears to be different, as a decrease in the decay time during relaxation was noted with both Isoproterenol and Arjuna (not with Ouabain) and both Arjuna and Ouabain (not Isoproterenol) caused an increase in the rise time during contraction.[25] This was only observed with the water extract, with various organic extractions (ethanolic, ethyl acetate) causing varying effects and isolated Arjulinolic acid being arrhythmogenic (causing arrythmia).

Appears to have cardiotonic effects in vitro with isolated heart cells, seems to be associated with the water extract mostly

One month of treatment of 500mg/kg Arjuna bark extract (50% ethanolic) to normal and diabetic rats, reflex bradycardia (a reduction in heart rate in response to high blood pressure, which attempts to normalize blood pressure) was improved in the diabetic rats;[29] the state of diabetes being known to reduce this reflex.[30] The alterations in reflex tachycardia (an increase in heart rate in response to low blood pressure) were not improved by Arjuna over 30 days.[29] The beneficial effects on baroreflexivity has also been noted in isoproterenol (beta-2-adrenergic agonist; like Ephedrine) induced cardiac failure,[31]where Arjuna was able to exert rehabilitative and prophylaxtic protection and reduce both cardiac hypertrophy and fibrosis.

Reflex Bradycardia (Baroreflex) is a mechanism where the heart slows its pulsatile power when blood pressure gets too high, which acts to normalize blood pressure.

Arjuna, although the mechanisms are unknown, appears to preserve this reflex in situations where the reflex would be hindered (cardiotoxicity, diabetes). The opposite (reflex tachycardia) may not be influenced

In regards to cardiotoxicity, Arjuna appears to be protective against beta-2-adrenergic agonist induced cardiotoxicity (usually using isoproteronol as a means to induce toxicity) in the range of 100-200mg/kg water or water:ethanolic extracts in rodents;[31][32] this appears to extend to catecholamine-induced cardiotoxicity as well.[33]

Other studies in animal models have noted cardioprotection against sodium fluoride-induced oxidative stress,[34] the chemotherapeutic Doxorubicin,[35] ischemia-reperfusion,[36][37] and Carbon tetrafluoride.[38]

Appears to be protective against catecholamine and stimulant-induced cardiotoxicity after oral ingestion to rodents, and protective against other general stressors such as oxidative stress

Specifically looking at human interventions, in persons with myocardial infarction or ischaemic cardiomyopathy given 500mg of the bark extract after operation and for a subsequent 8 weeks in addition to standard therapy (relative to control, receiving only standard therapy of nitrates and aspirin/beta-blockers) noted an increase in left ventricular ejection fraction (12.32% versus 2.52%) and a reduction in left ventricle mass (20% versus no change) only in the Arjuna group without any observable toxicity.[39] Higher doses tend to be used, with *thrice* daily dosing of Arjuna bark water extracts showing benefit in persons with acute myocardial infarction (AMI) by reducing mitral regurgitations (independent risk factor for mortality in persons with AMI[40]) at 1 month (49%) and 3 months (72%) relative to baseline as assessed by echocardiography,[41] with improvements in diastolic function (E/A ratio) at 1 month (29%) and 3 months (48%).[42] 2 weeks of thrice daily dosing of 500mg Arjuna bark water extract alongside standard therapy noted improvements in left ventricle function including ejection fraction, and end diastolic and systolic volume (11 persons with AMI, 1 person with peripartum cardiomyopathy) and benefit to cardiovascular health remained when an open-label follow-up was conducted for 20-28 months.[43] The study recording mitral regurgitations[42] made note that a placebo group was given, but the placebo and its relations to active control were not elaborated on.

A trial with a larger sample (58 persons with chronic stable angina and provocable ischemia on a treadmill test) using 500mg Arjuna extract thrice daily against 40mg isosorbide mononitrate (vasodilating drug) as active control noted improved performance on a treadmill test (maximal cardiovascular exercise duration and recovery time) as well as cardiac function (maximal ST depression) where Arjuna was comparable to Isosorbide mononitrate.[44]

The thrice daily dosing of 500mg Arjuna water bark extract has also been used in one case study on Beta-Thalassemia where a reduction of Lp(a) from 51.8 to 39mg/dL was recorded;[45] the paper made note of a conference presentation (does not appear to be a publication) where a similar observation was noted.

In regards to human trials on cardiovascular health, a once (but more commonly thrice) daily dosing with even intervals between doses shows benefit to cardiovascular and left ventricle function in persons who have suffered myocardial infarctions, with the benefits appearing to extend to other cardiac conditions (Angina in one trial, Beta-Thalassemia according to a case study). Numerous studies, although many are used alongside standard cardiovascular drug treatment rather than monotherapy and most have small sample sizes and statistical power

2.2. Cholesterol and Lipids

In a research model of hypercholesterolemic rabbits the ethanolic extract of Arjuna (100-200mg/kg) over 72 days was able to attenuate the increases in triglycerides, LDL-C, HDL-C, and attenuate the increase in the artherogenic index by 49-80%; when compared to 10mg/kg Atorvastatin, 200mg/kg Arjuna tended to underperform nonsignificantly on all parameters.[46]

Triglyceride lowering effects have been noted in rats in response to Poloxamer 407, with the ethanolic outperforming the ethyl acetate fraction when 175-350mg/kg is taken alongside P-407.[47] P-407 is an experimental tool to assess high triglyceride levels by inhibiting LPL activity and preventing cellular uptake of triglycerides.[48] Another study using chemically induced high triglycerides (triton WR-1339) noted similar effects with only the ethanolic fraction being statistically significant, and was replicated in a diet-induced hypertriglyceridemia model where 250mg/kg of the ethanolic extract over one week.[49]

2.3. Endothelium

One study in smokers using Arjuna extracts at 500mg daily for 2 weeks noted that the impaired flow mediated vasodilation (FMD) seen in smokers is somewhat normalized with Arjuna, but not placebo; the authors attributed this to the antioxidative effects of Arjuna, as they are noted also with Vitamin C.[50]

Edit3. Interactions with Glucose Metabolism

3.1. Absorption

The 50% methanolic extract of the bark of Arjuna appears to be able to inhibit alpha-amylase with an IC_{50} of 302+/-0.55µg/mL, with the bioactives (currently unknown) possibly existing in the water component as the 100% methanolic extract has less inhibitory potential.[51]

3.2. Interventions

A study using the methanolic leaf extract in streptozotocin-induced diabetic mice noted that 100-200mg/kg bodyweight for 15 days was able to dose-dependently reduce elevated fasting blood glucose, with 100mg/kg attenuating 89% of the increase in blood glucose seen in diabetic control and both 200mg/kg Arjuna as well as the active control of 0.5mg/kg Glibenclamide both normalizing blood glucose.[52] Similar to the potency observed with glucose, both Arjuna at the higher dose and Glibenclamide drastically reduced serum liver enzymes and cholesterol to near control levels.[52]

Edit4. Interactions with Physical Performance

4.1. Interventions

A study assessing the effects of Arjuna (500mg water extract of the bark) with or without Ashwagandha (500mg water extract of the roots) in normal weight young adults over 8 weeks noted that, relative to placebo, maximal oxygen consumption capacity was increased 4.8% and average maximal power output (assessed by Sprinting and measured by a Kinematic Measuring System) increased 3.6% with a decrease of blood pressure from 123.00+/-2.87mmHg to 117.80+/-1.48mmHg (4.3%).[53]Pairing with Ashwagandha increased the power output to 11.6% with a 10% increase in relative power, and also induced significant improvements in VO2 max and oxygen carrying capacity (both seen with Ashawgandha in isolation).[53]

At least one study has noted improvements in anaerobic cardiovascular exercise performance (high intensity cardio), and the benefits appear to be somewhat additive with Ashwagandha

Edit5. Interactions with Hormones

5.1. Thyroid Hormones

An ethanolic extract of Arjuna at 21.42mg/kg and 42.84mg/kg in rats (human equivalents of 3.4 and 6.8mg/kg) who were administered thyroxine (T4, a thyroid hormone at 0.5mg/kg for two weeks) noted that the serum increase in T3 and T4 was attenuated by 42% and 79% by administration of Arjuna; the increase in lipid peroxidation of cardiac and liver tissue by T4 was simulatenously abolished.[54] Similar effects were noted in euthyroidic rats, but an increase in hepatic lipid peroxidation occurred.[54] The authors noted that similar effects with the antithyroid drug *Propyl thiouracil* and hypothesized that Arjuna ethanolic extract has anti-thyroid effects, and due to hyperthyroidism causing cardiac tissue enlargment[55][56] it is thought this may contribute to the cardioprotective effects observed with Arjuna.

Possible thyroid reducing properties, which need to be replicated with a water soluble extract (and mechanisms explored more). May possibly contribute to cardioprotective effects, although not likely to be the only mechanism (as cardioprotection has been noted in persons with normal thyroid status)

Edit6. Interactions with Organ Systems

6.1. Stomach

The methanolic extract of Arjuna appears to protect gastric tissue from lipopolysaccharide (LPS) from *Heliobactor Pylori*, which is known to induce ulcers.[57] This protective effect has been noted against Alcohol (7 day preload), Dexamethasone (10 day preload), and diclofenac sodium (single dose) where 100-200mg/kg of an 80% ethanolic extract conferred absolute protection against ulcer formation from Dexamethasone and alcohol, while 400mg/kg of an acute dose conferred absolute protection against Diclofenac Sodium.[58] The positive control in this study, Rantidine (35mg/kg Diclofenac, 50mg/kg alcohol, 4mg/kg Dexamethasone) also conferred absolute protection,[58] and these protective effects

against Diclofenac have been replicated with a methanolic extract and thought to be related to the anti-oxidative potential.[59]

6.2. Ears

One study noted that Arjuna extracts, especially acetonic extraction, was able to cause death of *Staphylococcus aureus*bacteria and extended to *Escherchia Coli*, *Acinetobacter sp*, *Proteus mirabilis*, and *Candida albicans*;[60] the authors hypothesized that the results suggest that Arjuna may be useful against ear infections (although admittedly preliminary).[60]

6.3. Liver

In isolated hepatocytes (HepG2), 5-100mcg/mL of the water extract of Arjuna is able to concentration dependently reduce the biomarkers of oxidation induced by TERT (pro-oxidative agent), with free radicals (ROS) and lipid peroxidation (TBARS) being reduced up to 69% and 62% respectively.[61] The reduction of antioxidant enzymes by TERT was also significantly attenuated up to 60% (SOD), 82% (Catalase), and Glutathione enzymes (62-65% for peroxidase and reductase; fully preventing any reduction in Glutathione S-transferase).[61] These antioxidant effects are thought to underlie results achieved with 50mg/kg water extract of Arjuna for 7 days prior to CCL_4 induced hepatotoxicity, where Arjuna significantly prevented the rise in GPT (dose dependent reductions up to 50mg/kg, no added benefit at 100mg/kg), normalized ALP, and increased hepatic levels of antioxidant levels either to control levels (Catalase and Glutathione S-Transferase) or above control (SOD), a potency similar toVitamin C at the same oral doses.[62]

6.4. Kidneys

250-500mg/kg of a hydroalcoholic extract of Arjuna bark (not an oral study, but the equivalent injected into perfused kidneys) appears to reduce oxidation and concomitantly increase antioxidant enzymes (Catalase and Glutathione).[1] A preservation of anti-oxidant enzymes in response to CCL_4 is observed to be of similar potency to Vitamin C[62] and has noted protective effects in the kidneys of Alloxan-induced diabetic rats at oral doses of 250-500mg/kg of the water extract.[63][64]

Molecules that are found in Arjuna that have been noted to exert protective effects on kidney cells include Casuarinin, a tannin structure, with more potency than the water soluble form of Vitamin E known as Trolox.[65]

6.5. Urinary Tract

In vitro, Arjuna appears to be able to reduce formation rates of calcium-based kidney stones (calcium oxalate and calcium phosphate tested) with the butanol extract being most effective.[66]

6.6. Testicles

One study using arsenic-induced testicular damage in rats noted that 4 days pre-treatment with isolated Arjunolic acid can prevent oxidative testicular damage and histological changes in response to arsenic.[67] This study noted that, *in vitro,* the antioxidant potential of Arjunolic Acid peaked at a concentrated of 0.4mg/mL and this appeared to correlated with an oral intake of 20mg/kg (as 50mg/kg did not confer additional protective benefits) and that the overall protective benefit was near absolute, and sligtly less effective than 100mg/kg Vitamin C.[67]

Edit7. Inflammation and Immunology

7.1. Mechanisms

One study has noted that Arjunic Acid and arjungenin, as well as their glycosides (Arjunetin and Arjunglucoside II) are able to scavenge free radicals without significantly influence superoxide release from polymorphonuclear immune cells.[68]

Edit8. Interactions with Oxidation

8.1. Mechanisms

Arjuna, particular Arjunic and Arjunolic acids, possesses anti-oxidative properties directly and in a DPPH assay (*in vitro* assay of antioxidative potential) has more potency than Vitamin C[69] or at least comparable at the same concentrations.[62] This is thought to underlie various protective effects of Arjuna in response to compounds with toxic effects mediated by oxidation such as Adriamycin[70] cadmium,[71] and arsenic.[72] Despite the aforementioned study showing more potency from Arjunolic relative to Vitamin C, studies that compare the two in living systems either note

similar protectiv effects[72] or more from Vitamin C (although this latter study used a much higher dose of Vitamin C relative to Arjunic Acid).[67]

Arjunic and Arjunolic acid appear to have direct anti-oxidative potential and sequester free radicals; the potency of it appears to be similar to Vitamin C (a few studies suggest more or less, but for the most part is similar)

Edit9. Interactions with Cancer Metabolism

9.1. Genotoxicity/Mutagenicity

Arjuna bark extracts have been found to exert antigenotoxic (protective) properties in response to 4-nitroquinoline-N-oxide,[6] 2-aminofluorene,4-nitro-o-phenylenediamine,[73] and Adriamycin,[70] with the bioactives appearing to be concentrated in the acetone and methanolic extracts.[6][73] Compounds in the ethanolic/acetone extracts appear to protect the DNA from damage induced by mutagens; the bioactives are currently unknown, and this does not appear to occur with the water extract (which is used for cardiovascular health)

9.2. Tumors (Overview)

Oddly, a bacteria that has been noted to produce Taxol (Paclitaxel; chemotherapeutic) has been noted to occur on Arjuna bark;[74][75] this is differnt from the bacteria has been previously found on *Taxus brevifolia* that herb which has a bacterial strain synthesizing Taxol.

Possesses a novel bacteria on the tree which produces the chemotherapeutic Taxol; practical significance unknown, and Arjuna extracts may not have a Taxol content regardless

In response to incubation with an Ehrlich ascites carcinoma (an undifferentiated carcinoma tumor used in research with high differentiation rates and easy transplantation following injections [76]) noted that 9 days of Arjuna *leaf* methanolic extract was able to reduce tumor size (43-67%; nonsignificantly less effective than 20mg/kg 5-fluorouracil) and survival time was extended 43.9% and 87.9% at 100mg/kg and 200mg/kg, with the higher dose not being significantly different than the active control of 5-fluorouracil at 20mg/kg.[9] Arjuna leaf extract appeared to have similar effects on white and red blood cell counts as did 5-fluorouracil.

In vitro, the main bioactive Arjunic Acid at 100mcg concentration appears to induce up to 70% cytotoxicity in these cells and has been noted to influence another cancer cell line (Dalton's lymphoma),[77] with the latter cell line showing up to 90% cytotoxicity with 200mcg/mL of an ethanolic extract of Arjuna Bark[78] and later being confirmed to reduce DLA tumor cell count in a mouse model by 45% and increase lifespan by 60.42% (50mg/kg) and 60% reduce cell count with a 87.50% increase in lifespan (100mg/kg) following oral ingestion of Arjuna bark extract for 10 days, although the higher dose appears to reduce white blood cell count (50mg/kg not affecting WBCs), 2-10mg/kg were also effective on both parameters, but to a lesser degree.[78] One other study using 3-4g/kg Arjuna water extract in mice did not specifically measure tumor size, but in a Dalton's Lymphoma cell line the alterations of anti-oxidant enzymes (Catalase, SOD, Glutatione S-Transferase) effectively normalized the reductions, and reduced LDH levels in serum by 71% (relative to tumor control) at the higher dose.[79]

9.3. Oral Cancer

In a rodent model of DMBA-induced oral carcinogenesis, the water extract of the bark of Arjuna at 500mg/kg appeared to suppress the development of tumors from 100% in control to 30% and reduced average tumor size to 33% of control.[80] This was associated with less adverse histological changes (keratosis, hyperplasia and dysplasia) and improvments in oxidative biomarkers such as TBARS, and the protective effects were thought to be related to anti-oxidant mechanisms.[80]

9.4. Breast Cancer

One study noted that a constituent of Arjuna, the hydrolyzable tannin *Casuarinin*, appears to have anti-proliferative effects in MCF-7 breast cancer cells associated with apoptosis at the G0/G1 phase of cell division.[26]

9.5. Lung

One study has suggested that Casuarinin may induce apoptosis in human non-small cell lung cancer cells (A549) related to apoptosis at G0/G1 from inducing p21/WAF1 via p53.[81]

9.6. Hepatocellular Carcinoma

In isolated HepG2 carcinoma cells, 60-100mg/mL of the ethanolic extract of Arjuna Bark is able to induce an apoptotic morphology unto cells in a concentration dependent manner associated with induction of p53.[82]

In research models of Hepatocellular Carcinoma induced by N-nitrosodiethylamine (one study[83] duplicated in Medline[84]) the ethanolic extract of Arjuna bark at 400mg/kg for 28 days was able to normalize TBARS (indicative of lipid peroxidation) in the liver but not serum of animals bearing N-nitrosodiethylamine tumors; this study did not measure size of tumors *per se*, but suggested this to be a protective effect.[83]

Edit10. Safety and Toxicity

An acute oral toxicity test in rats failed to find any toxicity with up to 2000mg/kg of an ethanolic extract from Arjuna.[46] This lack of harm at the level of 2000mg/kg has been noted elsewhere in rats using bark extracts,[47] although one study using a leaf extract noted that an LD_{50} occurred at 900mg/kg,[9] suggesting higher toxicity associated with leaf based supplements; another Medline entry, which appears to be another publication of the same trial (same authors, sourcing, and introduction) also notes this 900mg/kg LD_{50}.[52]

Scientific Support & Reference Citations

References

1. Raj CD, *et al*. Terminalia arjuna's antioxidant effect in isolated perfused kidney. *Res Pharm Sci*. (2012)
2. Dwivedi S. Terminalia arjuna Wight & Arn.--a useful drug for cardiovascular disorders. *J Ethnopharmacol*. (2007)
3. Mahmood ZA, *et al*. Herbal treatment for cardiovascular disease the evidence based therapy. *Pak J Pharm Sci*. (2010)
4. Maulik SK, Katiyar CK. Terminalia arjuna in cardiovascular diseases: making the transition from traditional to modern medicine in India. *Curr Pharm Biotechnol*. (2010)
5. Miller AL. Botanical influences on cardiovascular disease. *Altern Med Rev*. (1998)
6. Scassellati-Sforzolini G, *et al*. Antigenotoxic properties of Terminalia arjuna bark extracts. *J Environ Pathol Toxicol Oncol*. (1999)

7. Verma SC, *et al*. Microwave extraction and rapid isolation of arjunic acid from Terminalia arjuna (Roxb. ex DC.) stem bark and quantification of arjunic acid and arjunolic acid using HPLC-PDA technique. *J Sep Sci*. (2012)
8. Sarwat M, Das S, Srivastava PS. Estimation of genetic diversity and evaluation of relatedness through molecular markers among medicinally important trees: Terminalia arjuna, T. chebula and T. bellerica. *Mol Biol Rep*. (2011)
9. Biswas M, *et al*. Antitumour activity of Terminalia arjuna leaf against Ehrlich ascites carcinoma in mice. *Nat Prod Res*. (2012)
10. [No authors listed. Terminalia arjuna. *Altern Med Rev*. (1999)
11. The chemistry of extractives from hardwoods. Part XVIII. The constitution of arjunolic acid, a triterpene from Terminalia arjuna
12. Saxena M, *et al*. Cytotoxic agents from Terminalia arjuna. *Planta Med*. (2007)
13. Singh DV, *et al*. Quantitative determination of oleane derivatives in Terminalia arjuna by high performance thin layer chromatography. *Phytochem Anal*. (2002)
14. Wang W, *et al*. 18,19-secooleanane type triterpene glycosyl esters from the bark of Terminalia arjuna. *Planta Med*. (2010)
15. Upadhyay RK, *et al*. Triterpene glycoside from Terminalia arjuna. *J Asian Nat Prod Res*. (2001)
16. Wang W, *et al*. Triterpenoids from two Terminalia species. *Planta Med*. (2010)
17. Ali A, *et al*. A novel naphthanol glycoside from Terminalia arjuna with antioxidant and nitric oxide inhibitory activities. *Pharmazie*. (2003)
18. Alam MS, *et al*. Two new bioactive oleanane triterpene glycosides from Terminalia arjuna. *Nat Prod Res*. (2008)
19. Ali A, *et al*. Terminoside A, a new triterpene glycoside from the bark of Terminalia arjuna inhibits nitric oxide production in murine macrophages. *J Asian Nat Prod Res*. (2003)
20. Singh B, *et al*. A new triterpene glycoside from Terminalia arjuna. *Planta Med*. (1995)
21. Dwivedi S, Aggarwal A. Indigenous drugs in ischemic heart disease in patients with diabetes. *J Altern Complement Med*. (2009)
22. Yadav RN, Rathore K. A new cardenolide from the roots of Terminalia arjuna. *Fitoterapia*. (2001)
23. Yadava RN, Rathore K. A new cardenolide from the seeds of Terminalia arjuna (W&A). *J Asian Nat Prod Res*. (2000)
24. Wang W, *et al*. Ursane triterpenoids from the bark of Terminalia arjuna. *Fitoterapia*. (2010)
25. Oberoi L, *et al*. The aqueous extract, not organic extracts, of Terminalia arjuna bark exerts cardiotonic effect on adult ventricular myocytes. *Phytomedicine*. (2011)
26. Kuo PL, *et al*. Casuarinin from the bark of Terminalia arjuna induces apoptosis and cell cycle arrest in human breast adenocarcinoma MCF-7 cells. *Planta Med*. (2005)
27. Kandil FE, Nassar MI. A tannin anti-cancer promotor from Terminalia arjuna. *Phytochemistry*. (1998)
28. Avula B, *et al*. Simultaneous Determination and Characterization of Tannins and Triterpene Saponins from the Fruits of Various Species of Terminalia and

Phyllantus emblica Using a UHPLC-UV-MS Method: Application to Triphala. *Planta Med*. (2013)
29. Khaliq F, *et al*. Terminalia arjuna Improves Cardiovascular Autonomic Neuropathy in Streptozotocin-Induced Diabetic Rats. *Cardiovasc Toxicol*. (2013)
30. Dall'Ago P, *et al*. Baroreflex and chemoreflex dysfunction in streptozotocin-diabetic rats. *Braz J Med Biol Res*. (1997)
31. Parveen A, *et al*. Terminalia arjuna enhances baroreflex sensitivity and myocardial function in isoproterenol-induced chronic heart failure rats. *J Cardiovasc Pharmacol Ther*. (2012)
32. Parveen A, *et al*. Mechanistic clues in the cardioprotective effect of Terminalia arjuna bark extract in isoproterenol-induced chronic heart failure in rats. *Cardiovasc Toxicol*. (2011)
33. Kumar S, *et al*. Catecholamine-induced myocardial fibrosis and oxidative stress is attenuated by Terminalia arjuna (Roxb.). *J Pharm Pharmacol*. (2009)
34. Sinha M, Manna P, Sil PC. Terminalia arjuna protects mouse hearts against sodium fluoride-induced oxidative stress. *J Med Food*. (2008)
35. Singh G, *et al*. Protective effects of Terminalia arjuna against Doxorubicin-induced cardiotoxicity. *J Ethnopharmacol*. (2008)
36. Karthikeyan K, *et al*. Cardioprotective effect of the alcoholic extract of Terminalia arjuna bark in an in vivo model of myocardial ischemic reperfusion injury. *Life Sci*. (2003)
37. Gauthaman K, *et al*. Terminalia arjuna (Roxb.) protects rabbit heart against ischemic-reperfusion injury: role of antioxidant enzymes and heat shock protein. *J Ethnopharmacol*. (2005)
38. Manna P, Sinha M, Sil PC. Phytomedicinal activity of Terminalia arjuna against carbon tetrachloride induced cardiac oxidative stress. *Pathophysiology*. (2007)
39. Dwivedi S, Jauhari R. Beneficial effects of Terminalia arjuna in coronary artery disease. *Indian Heart J*. (1997)
40. Lehmann KG, Francis CK, Dodge HT. Mitral regurgitation in early myocardial infarction. Incidence, clinical detection, and prognostic implications. TIMI Study Group. *Ann Intern Med*. (1992)
41. Ischemic mitral regurgitation: mechanisms and echocardiographic classification
42. Dwivedi S, *et al*. Role of Terminalia arjuna in ischaemic mitral regurgitation. *Int J Cardiol*. (2005)
43. Bharani A, Ganguly A, Bhargava KD. Salutary effect of Terminalia Arjuna in patients with severe refractory heart failure. *Int J Cardiol*. (1995)
44. Bharani A, *et al*. Efficacy of Terminalia arjuna in chronic stable angina: a double-blind, placebo-controlled, crossover study comparing Terminalia arjuna with isosorbide mononitrate. *Indian Heart J*. (2002)
45. Dwivedi S, Kumar V. Beta-thalassemia, hyperlipoproteinemia(a), and metabolic syndrome: its low-cost holistic therapy. *J Altern Complement Med*. (2007)
46. Subramaniam S, *et al*. Anti-Atherogenic Activity of Ethanolic Fraction of Terminalia arjuna Bark on Hypercholesterolemic Rabbits. *Evid Based Complement Alternat Med*. (2011)

47. Subramaniam S, *et al*. Anti-hyperlipidemic and antioxidant potential of different fractions of Terminalia arjuna Roxb. bark against PX- 407 induced hyperlipidemia. *Indian J Exp Biol*. (2011)
48. Johnston TP, Palmer WK. Mechanism of poloxamer 407-induced hypertriglyceridemia in the rat. *Biochem Pharmacol*. (1993)
49. Chander R, *et al*. Antidyslipidemic and antioxidant activities of different fractions ofTerminalia arjuna stem bark. *Indian J Clin Biochem*. (2004)
50. Bharani A, Ahirwar LK, Jain N. Terminalia arjuna reverses impaired endothelial function in chronic smokers. *Indian Heart J*. (2004)
51. Saha S, Verma R. Inhibitory potential of traditional herbs on α-amylase activity. *Pharm Biol*. (2012)
52. Biswas M, *et al*. Antihyperglycemic activity and antioxidant role of Terminalia arjuna leaf in streptozotocin-induced diabetic rats. *Pharm Biol*. (2011)
53. Sandhu JS, *et al*. Effects of Withania somnifera (Ashwagandha) and Terminalia arjuna (Arjuna) on physical performance and cardiorespiratory endurance in healthy young adults.*Int J Ayurveda Res*. (2010)
54. Parmar HS, *et al*. Cardio-protective role of Terminalia arjuna bark extract is possibly mediated through alterations in thyroid hormones. *Pharmazie*. (2006)
55. Watanabe H, *et al*. Thyroid hormone regulates mRNA expression and currents of ion channels in rat atrium. *Biochem Biophys Res Commun*. (2003)
56. Donatelli M, *et al*. Cardiac changes in subclinical and overt hyperthyroid women: retrospective study. *Int J Cardiol*. (2003)
57. Devi RS, *et al*. Effect of methanolic extract of Terminalia arjuna against Helicobacter pylori 26695 lipopolysaccharide-induced gastric ulcer in rats. *J Pharm Pharmacol*. (2008)
58. Devi RS, *et al*. Ulcer protective effect of Terminalia arjuna on gastric mucosal defensive mechanism in experimental rats. *Phytother Res*. (2007)
59. Devi RS, *et al*. Gastroprotective effect of Terminalia arjuna bark on diclofenac sodium induced gastric ulcer. *Chem Biol Interact*. (2007)
60. Aneja KR, Sharma C, Joshi R. Antimicrobial activity of Terminalia arjuna Wight & Arn.: an ethnomedicinal plant against pathogens causing ear infection. *Braz J Otorhinolaryngol*. (2012)
61. Shivananjappa MM, Mhasavade D, Joshi MK. Aqueous extract of Terminalia arjuna attenuates tert-butyl hydroperoxide-induced oxidative stress in HepG2 cell model. *Cell Biochem Funct*. (2012)
62. Manna P, Sinha M, Sil PC. Aqueous extract of Terminalia arjuna prevents carbon tetrachloride induced hepatic and renal disorders. *BMC Complement Altern Med*. (2006)
63. Ragavan B, Krishnakumari S. Effect of terminalia arjuna stem bark extract on the activities of marker enzymes in alloxan induced diabetic rats. *Anc Sci Life*. (2005)
64. Raghavan B, Kumari SK. Effect of Terminalia arjuna stem bark on antioxidant status in liver and kidney of alloxan diabetic rats. *Indian J Physiol Pharmacol*. (2006)
65. Chen CH, *et al*. Casuarinin protects cultured MDCK cells from hydrogen peroxide-induced oxidative stress and DNA oxidative damage. *Planta Med*. (2004)

66. Chaudhary A, Singla SK, Tandon C. In vitro Evaluation of Terminalia arjuna on Calcium Phosphate and Calcium Oxalate Crystallization. *Indian J Pharm Sci*. (2010)
67. Manna P, Sinha M, Sil PC. Protection of arsenic-induced testicular oxidative stress by arjunolic acid. *Redox Rep*. (2008)
68. Pawar RS, Bhutani KK. Effect of oleanane triterpenoids from Terminalia arjuna--a cardioprotective drug on the process of respiratory oxyburst. *Phytomedicine*. (2005)
69. Sun FY, *et al*. Arjunic acid, a strong free radical scavenger from Terminalia arjuna. *Am J Chin Med*. (2008)
70. Reddy TK, *et al*. Effect of Terminalia arjuna extract on adriamycin-induced DNA damage. *Phytother Res*. (2008)
71. Pal S, *et al*. Involvement of both intrinsic and extrinsic pathways in hepatoprotection of arjunolic acid against cadmium induced acute damage in vitro. *Toxicology*. (2011)
72. Manna P, *et al*. Arjunolic acid, a triterpenoid saponin, ameliorates arsenic-induced cyto-toxicity in hepatocytes. *Chem Biol Interact*. (2007)
73. Kaur K, *et al*. Antimutagenic activities of acetone and methanol fractions of Terminalia arjuna. *Food Chem Toxicol*. (2002)
74. Gangadevi V, Muthumary J. A novel endophytic Taxol-producing fungus Chaetomella raphigera isolated from a medicinal plant, Terminalia arjuna. *Appl Biochem Biotechnol*. (2009)
75. Gangadevi V, Muthumary J. Taxol production by Pestalotiopsis terminaliae, an endophytic fungus of Terminalia arjuna (arjun tree). *Biotechnol Appl Biochem*. (2009)
76. Ehrlich ascites carcinoma
77. Ramesh AS, *et al*. Isolation, characterisation and cytotoxicity study of arjunolic acid from Terminalia arjuna. *Nat Prod Res*. (2012)
78. Ganesan R, Kamalraj P, Muthuchelian K. Protective effects of ethanolic extract residue isolated from the bark of Terminalia Arjuna against DLA tumour cells. *Asian Pac J Cancer Prev*. (2010)
79. Verma N, Vinayak M. Effect of Terminalia arjuna on antioxidant defense system in cancer. *Mol Biol Rep*. (2009)
80. Dhanarasu S, *et al*. Terminalia Arjuna (Roxb.) Modulates Circulatory Antioxidants on 7,12-dimethylbenz(a)anthracene- induced Hamster Buccal Pouch Carcinogenesis. *Oman Med J*. (2010)
81. Kuo PL, *et al*. Induction of cell cycle arrest and apoptosis in human non-small cell lung cancer A549 cells by casuarinin from the bark of Terminalia arjuna Linn. *Anticancer Drugs*. (2005)
82. Sivalokanathan S, Vijayababu MR, Balasubramanian MP. Effects of Terminalia arjuna bark extract on apoptosis of human hepatoma cell line HepG2. *World J Gastroenterol*. (2006)
83. Sivalokanathan S, Ilayaraja M, Balasubramanian MP. Antioxidant activity of Terminalia arjuna bark extract on N-nitrosodiethylamine induced hepatocellular carcinoma in rats. *Mol Cell Biochem*. (2006)

84. Sivalokanathan S, Ilayaraja M, Balasubramanian MP. Efficacy of Terminalia arjuna (Roxb.) on N-nitrosodiethylamine induced hepatocellular carcinoma in rats. *Indian J Exp Biol*. (2005)

(Common phrases used by users for this page include terminalia arjuna health benefits, terminalia arjuna calcium content, research+on+benfits+of+arjuna+, bioactivity of terminalia species, as per structure arjunolic acid is aglycone in nature?, arjuna terminalia medicinal uses)

(Users who contributed to this page include Sol, Kurtis Frank)

Appendix C : A Draft Methodology Designed for a laboratory experiment

A laboratory experiment was designed for further analysis to Find the Cadmium absorption property/capacity of *Terminaliaarjuna* seedlings, bark and seed powder.

Aim: Is it possible to use *T. arjuna* Plant to purify water to absorb Cadmium?

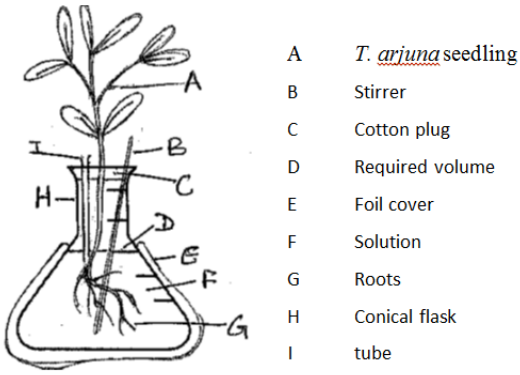


Figure A

Theory:

5.1 Finding the lethal dosage of Cadmium for *T. Arjuna*

Hoagland's Complete Nutrient Solution (25%) is to be prepared (as described inAppendix D)

Prepare series of known concentration of Cadmium and add it to the nutrition solutions. 0, 25, 50, 100, 200,400, 800, 1000 ppm

Introduce *T. arjuna* seedlings to these concentration series,and observe for about one week and find out the maximum concentration(**X**) of Cadmium that will not kill the plant.

Two control solutions

(a) With nutrition solution and Cadmium Xmg/l concentration only without seedling

(b) Distilled water and Cadmium Xmg/l only without seedling

5.2 Finding the Cadmium intake of *T. Arjuna* seedlings

Series (SDL): Known concentration of Cadmium series, **which is less than the lethal dosage** for***T. Arjuna***add to the series of nutrition solutions with known concentration. Place the seedling one each in sealed covered conical flasks (as shown infigure A). Keepthe volume (400 ml) of the solution constant throughout the experiment by adding same nutrition. After carefully stirring the solution, periodically (Once in 3 days) extract samples from the solution and analyse for Cadmium concentration of the sample to identify the Cadmium intake of the seedlings, if any.

Four control solution Series:

(c) With nutrition solution and CadmiumXmg/l concentration only without seedling

(d) Distilled water and CadmiumXmg/l only without seedling

(e) Nutrition solution and seedling only

(f) Distilled water and seedling only

Series of seedlings and solutions

(g) Three replication from 25% Hoagland solution with CadmiumXmg/l with a seedling in each

(h) Three replication from 25% Hoagland solution with CadmiumX-5 mg/l with a seedling in each

(i) Three replication from 25% Hoagland solution with CadmiumX-20 mg/l with a seedling in each

(j) Three replication from 25% Hoagland solution with CadmiumX-50 mg/l with a seedling in each

(14 seedlings)

Determine the Cadmium concentration of these at every 3days or weekly intervals for about 5 weeks, provided plants won't die during this period.

Objective- this will show the absorption of Cadmium by the seedlings with time (if there is any absorption!)

5.3 Finding of Cadmium absorption in *T. Arjuna* seed powder

Series (SD): Add known concentration of Cadmium series to the distilled water. Mix the constant amounts of seed powder (5 mg) to each in sealed covered conical flasks. Keep the constant volume (200ml) of the solution throughout the experiment by adding distilled water. After carefully stirring the solution, periodically (Once in 3 days) extract samples from the solution and analyse the Cadmium concentration of the sample solution to identify the Cadmium intake of the ***T. Arjuna***seed powder.

Control solution Series:

(k) Distilled water and CadmiumXmg/l only (4 for all Cadmium Concentrations)

Series of following solutions mixed with 5mg seedpowder

(l) Three replication of Distilled water with CadmiumXmg/l

(m) Three replication of Distilled water with CadmiumX-5 mg/l

(n) Three replication of Distilled water with CadmiumX-20 mg/l

(o) Three replication of Distilled water with CadmiumX-50 mg/l

(Do we need three replications? If we are adding same amount of seed powder?eg. 5 mg?)

Determine the Cadmium concentration of these series at every 3days or weekly intervals for about 5 weeks.

Objective- this will show absorption of Cadmium by the seed powder with time (if there is any absorption!)

5.4 Finding of Cadmium absorption in *T. Arjuna* bark powder

Series (BK): Add known concentration of Cadmium series to the distilled water. Mix the constant amounts of bark powder (5 mg) to each in sealed covered conical flasks. Keep the constant volume (200 ml) of the solution throughout the experiment by adding distilled water. After carefully stirring the solution, periodically (Once in 3 days) extract samples from the solution and analyse the Cadmium concentration of the sample solution to identify the Cadmium intake of the ***T. Arjuna***bark powder.

Control solution Series:

(p) Distilled water and CadmiumXmg/l only (Do we need 4 for all Cadmium Concentrations?)

Series of following solutions mixed with 5mg bark powder

(q) Three replication of Distilled water with CadmiumXmg/l

(r) Three replication of Distilled water with CadmiumX-5 mg/l

(s) Three replication of Distilled water with CadmiumX-20 mg/l

(t) Three replication of Distilled water with CadmiumX-50 mg/l

(Do we need three replications? If we are adding same amount of seed powder?eg. 5 mg?)

Determine the Cadmium concentration of these series at every 3days or weekly intervals for about 5 weeks

Objective- this will show absorption of Cadmium by the bark powder with time (if there is any absorption !)

Calculations:

a. Volume of Nutrition Solution required

For Experiment 5.1

Volume required per conical flask (X) 400 ml

No. of Flasks requires for 8 Cadmium concentrations with 1control with nutrient = 9 Nos.

Therefore Nutrition Solution requirement for flasks 9 Nos. x 400 ml =**3.6 litres**

For Experiment 5.2

Volume required per conical flask (X) 400 ml

No. of Flasks requires for 4 Cadmium concentrations with 3 seedling replications (Y)

12 Nos.

No. of Control Flask with Nutrient and seedling only 1 No.

No. Control Flask with Nutrient and Cadmium only 4 No.(Or else 1 No.)

Therefore Total No. of 500 ml Conical Flasks 17 Nos.(or else 14)

Therefore Nutrition Solution requirement for flasks 17 Nos. x 400 ml =**6.8 litres**

Nutrition Solution requirement to maintain constant volume? Approx. **3 litres**

Therefore total Nutrition Solution requirement Approx. 15 litres

b. Volume of Distilled water required

For Experiment 5.1 and 5.2

For preparation of Nutrition Solution requirement Approx. 15 litres
For Control Flasks (b,d&f) 400 ml x 3 = 1.2 litres

For Experiment 5.3 and 5.4

Volume required per conical flask (X) 200 ml
No. of Flasks requires for 4 Cadmium concentrations with 3 seed powder replications (Y)
12 Nos.
No. of Control Flask 4 No.
Therefore Total No. of 250 ml Conical Flasks 16 Nos.
Therefore Distilled water requirement for flasks 16 Nos. x 200 ml = 3.2litres
Distilled water requirement to maintain constant volume ? 1litres
Therefore total Distilled water requirement Experiment 5.3 Approx. 5 litres
Therefore total Distilled water requirement **Experiment 5.3 & 5.4 Approx. 10 litres**
Therefore total Distilled water requirement Approx. 26 litres

c. No. of Conical flasks required

For Experiment 5.1 = 10 Nos. 500 ml Conical flasks (Could re-use for Experiment 5.2)
For Experiment 5.2 = 19 Nos. 500 ml Conical flasks
For Experiment 5.3 = 16 Nos. 250 ml Conical flasks
For Experiment 5.4 = 16 Nos. 250 ml Conical flasks
Therefore total *No. of Conical flasks* requirement= *19 Nos. 500 ml Conical flasks and 32 Nos. 250 ml Conical flasks*

d. Plant Material Requirement

For Experiment 5.1 = 8 Seedlings

For Experiment 5.2 = 14 Seedlings

For Experiment 5.3 =60 mg seed powder

For Experiment 5.4 = 60 mg bark powder

Therefore total number of 22 seedlings, 60 mg seed powder and 60 mg bark powder required.

e.*Chemical requirement for preparation of 25% Hoagland Solution (Nutrition Solution) Approx. 15 litres*

		Chemical requirement for preparation of 25% Hoagland Solution[HS] (Nutrition Solution) Approx. 15 litres						
		Chemical	Concentration	Required Volume per liter (in ml)	Required Volume of HS in liter	Therefore Required Volume in ml for 100% solution	Required HS Concentration	Therefore Required Volume in ml
1		$NH_4H_2PO_4$	1 M	1	15	15	25%	3.75
2		KNO_3	1 M	6	15	90	25%	22.5
3		$Ca(NO_3)_2$	1 M	4	15	60	25%	15
4		$MgSO_4$	1 M	2	15	30	25%	7.5
				Required Volume per liter (in gm)*				
5	i.	H_3BO_3		2.86				
	ii.	$MnCl_2.4H_2O$		1.81				
	iii.	$ZnSO_4.7H_2O$		0.22				
	iv.	$CuSO_4.5H_2O$		0.08				
	v.	$H_2MoO_4.H_2O$		0.02				
		* Only 1ml to be added from 5th Mixture per liter						
				(in ml)				
6		Iron Stock (Assaying 85% MoO_3)		0.25	15	3.75	25%	0.9375

f.* $Cd(NO_3)_2.4H_2O$ *Requirement

Preparation of Cadmium concentration solutions

For Experiment 5.1

Volume of the Nutrition Solution per Flask = 400 ml to be decided

Cadmium series of 0, 25, 50, 100, 200,400, 800, 1000 ppm to be prepared

1 mol of Cadmium = 112.411 g

1 mol of $Cd(NO_3)_2.4H_2O$ = 308.48 g

(a) To prepare 1000 ppm Cadmium concentration;

308.48/112.411 X 1g = 2.744g of $Cd(NO_3)_2.4H_2O$ in 1 litre (1000ml)

= 1000 ppm = 1/308.48 X 2.744 M = 0.009 M

Volume of the Solution per Flask = 400 ml

Therefore; Amount of $Cd(NO_3)_2.4H_2O$ to be added;

2.44g/1000mlx 400 ml = **0.976 g$Cd(NO_3)_2.4H_2O$ per flask = 976 mg**

Amount of ***Cadmium*** *added = 112.411g/308.48g X 0.976 g= 0.00324g = 3.24 mg per flask*

(b) To prepare 800 ppm Cadmium concentration;

Volume of the Solution per Flask = 400 ml

Therefore; Amount of $Cd(NO_3)_2.4H_2O$ to be added;

0.976g/1000ppm X 800 ppm = **0.781g per flask = 781 mg**

(c) To prepare 400 ppm Cadmium concentration;

Volume of the Solution per Flask = 400 ml

Therefore; Amount of $Cd(NO_3)_2.4H_2O$ to be added;

0.976g/1000ppm X 400 ppm = **0.390g per flask = 390 mg**

(d) To prepare 200 ppm Cadmium concentration;

Volume of the Solution per Flask = 400 ml

Therefore; Amount of $Cd(NO_3)_2.4H_2O$ to be added;

0.976g/1000ppm X 200 ppm = 0.**195g per flask = 195 mg**

(e) To prepare 100 ppm Cadmium concentration;

Volume of the Solution per Flask = 400 ml

Therefore; Amount of $Cd(NO_3)_2.4H_2O$ to be added;

0.976g/1000ppm X 100 ppm = **0.098g per flask = 97.5 mg**

(f) To prepare 50 ppm Cadmium concentration;

Volume of the Solution per Flask = 400 ml

Therefore; Amount of $Cd(NO_3)_2.4H_2O$ to be added;

0.976g/1000ppm X 50 ppm = **0.049g per flask = 48.8 mg**

(g) To prepare 25 ppm Cadmium concentration;

Volume of the Solution per Flask = 400 ml

Therefore; Amount of $Cd(NO_3)_2.4H_2O$ to be added;

0.976g/1000ppm X 25 ppm = **0.024g per flask = 25 mg**

Therefore; Total Amount of $Cd(NO_3)_2.4H_2O$ for *Experiment 5.1* =

976 mg + 781 mg + 390 mg + 195 mg + 97.5 mg + 48.8 mg + 25 mg

=2,513 mg = 2.51 g

For Experiment 5.2(Lethal concentration to be determined for calculations)

Four Nutrition Solutions (Hoagland's) with different Cadmium concentrations (X mg l^{-1}; X-5 mg l^{-1};X-20 mg l^{-1};X-50 mg l^{-1})

For Experiment 5.3 and 5.4

Four Distilled water solutions with different Cadmium concentrations (X mg l^{-1}; X-5 mg l^{-1};X-20 mg l^{-1};X-50 mg l^{-1})

(Approx - 2.0g x 10 = 20 g ? for *Experiment 5.2, 5.3 and 5.4*)

Equipment and Material Requirement :

a. Total Nutrition Solution requirement Approx. 15 litres

b. Total Distilled water requirement Approx. 26 litres

c. Total *No. of Conical flasks* requirement = *19 Nos. 500 ml Conical flasks and 32 Nos. 250 ml Conical flasks*

d. Total number of 22 seedlings, 60 mg seed powder and 60 mg bark powder required.

e. Chemical requirement for preparation of 25% Hoagland Solution (Nutrition Solution) Approx. 15 litres are as follows;

		Chemical	Concentration	Required Volume
1		NH4H2PO4	1 M	3.75 ml
2		KNO3	1 M	22.5 ml
3		Ca(NO3)2	1 M	15 ml
4		MgSO4	1 M	7.5 ml
5	i.	H3BO3		2.86 g
	ii.	MnCl2.4H2O		1.81 g
	iii.	ZnSO4.7H2O		0.22 g
	iv.	CuSO4.5H2O		0.08 g
	v.	H2MoO4.H2O		**0.02 g**
6		Iron Stock (Assaying 85% MoO3)		0.9375 ml

f.* $Cd(NO_3)_2.4H_2O$ *Requirement

Total Amount of $Cd(NO_3)_2.4H_2O$ for *Experiment 5.1* =2.51 g

For Experiment 5.2, 5.3and 5.4 (Lethal concentration to be determined for calculations)

(Approx - 2.0g x 10 = 20 g ? for *Experiment 5.2, 5.3 and 5.4*)

g. Cotton Wool - To seal the conical flasks

h. Black cartridge paper to cover the Conical Flasks

i. Tube and extraction syringes (do we need 1 each per flask?)

j. string sticks

Procedure:

Exp. 5.1

Sterilized 10 Conical flasks of 500 ml labelled with different concentrations were kept under the room temperature.Added different concentrations of Cadmium to each relevant flask carefully(eg: 25 mg of$Cd(NO_3)_2.4H_2O$ to 25ppm flask). Added the nutrient solution up to 400ml level marked.

8 healthy T. arjuna seedlings taken from Plant Nursery of NavinnaAyurvedic Research Centre and 10 dead culms/ekelscarefully washed of any foreign matters.

Inserted 1 ekel/dead culm in each flask to stir the solution.

Sealed the conical flasks from cotton plugs and covered the flasks with a black cartridge paper.

Observed the plants for about 1 week to determine the approximate maximum concentration which will not be killed the plant (Xmg/lof $Cd(NO_3)_2.4H_2O$)

Exp. 5.2

Four nutrient solutions prepared with different Cadmium concentrations. Another Four solutions of Cadmium concentrations prepared in normal water without the nutrient.

Added 350ml of the nutrient solution for each conical flask with 3 replicates of seedlings for each Cadmium concentrations.

Added 350ml of the solutions of Cadmium concentrations prepared in normal water without the nutrient for each conical flask with 2 replicates of seeds for each Cadmium concentrations.

2 control flask were prepared (a) with Cadmium(Concentration?) with nutrient and (b) with Cadmium with normal water.

Placed a tube in each flask in order to extract the solution for sampling.

Sealed the top of the conical flask with Paraffin Oil and covered the each flask with a foil.

Collection of samples:

X ml of solution was extracted from once in two days from each flask for analysing of Cadmium level(X - Quantity sufficient to analyse Cadmium concentration. Is it necessary to add more solutions?). Added the preservative to the samples, label and stored till analysing for Cadmium concentration.

Preparation of Nutrition Solution:

Hoagland's Complete Nutrient Solution is prepared as per the Recipe of Appendix D

Preservative Method/Solution:

Apparatus:

Measurement of Cadmium level

Measurement of BOD level ?

(From where?Availability of Cadmium testing equipment (Moratuwa/Peradeniya)

Table 1 : Recording of Reading

Cadmium Concentration (per liter)	Seedling (SDL)/ Seed(SD) No.	First week				Second Week				Third Weeek				Fourth Week			
		Mon.	Wed.	Fri.	Sun.	Mon.	Wed.	Fri.	Sun.	Mon.	Wed.	Fri.	Sun.	Mon.	Wed.	Fri.	Sun.
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
5 mg	SDL-5-1-A																
	SDL-5-2-B																
	SDL-5-3-C																
	SD-5-1-D																
	SD-5-2-E																
10 mg	SDL-10-1-F																
	SDL-10-2-G																
	SDL-10-3-H																
	SD-10-1-I																
	SD-10-2-J																
20 mg	SDL-20-1-K																
	SDL-20-2-L																
	SDL-20-3-M																
	SD-20-1-N																
	SD-20-2-O																

Cadmium Concentration (per liter)	Seedling (SDL)/ Seed(SD) No.	First week				Second Week				Third Weeek				Fourth Week			
		Mon.	Wed.	Fri.	Sun.	Mon.	Wed.	Fri.	Sun.	Mon.	Wed.	Fri.	Sun.	Mon.	Wed.	Fri.	Sun.
40 mg	SDL-40-1-P																
	SDL-40-2-Q																
	SDL-40-3-R																
	SD-40-1-S																
	SD-40-2-T																
Control	CL - Nu-U																
	CL - Wa-V																

It is important to do a budgetary allocation of expenses before proceeding with the experiment.

Appendix D : Hoagland Solution Recipe

Recipe for Hoagland's Complete Nutrient Solution

This is made essentially according to the following reference: D.R. Hoagland and D.I. Arnon. The water-culture method of growing plants without soil.Calif.Agr. Expt. Sta. Circ. 347. 1950. There is one change and that is in the form of iron added.

Prepare the following stock solutions (1-6) and use the amounts indicated to prepare 1 liter (final volume) of nutrient solution:

1. 1.00 M $NH_4H_2PO_4$ use 1 ml/l of nutrient solution

2. 1.00 M KNO_3 use 6 ml/l of nutrient solution

3. 1.00 M $Ca(NO_3)_2$ use 4 ml/l of nutrient solution

4. 1.00 M $MgSO_4$ use 2 ml/l of nutrient solution

Micronutrient stocks: combine the following amount of salts in a total volume of one liter of water, and then use 1 ml/ of this entire stock mixture (5) along with the stocks above (1-4) and the iron stock (6) described below to make up a total of 1 litre of nutrient solution.

5. 2.86 gm H_3BO_3

1.81 gm $MnCl_2 .4H_2O$

0.22 gm $ZnSO_4 .7H_2O$

0.08 gm $CuSO_4 . 5H_2O$

0.02 gm $H_2MoO_4 . H_2O$

(Assaying 85% MoO_3)
6. Iron stock: to the above 5 stocks add 0.25 ml of this iron stock for 1 liter of nutrient solution.

To make up the iron stock, take 26.1 g EDTA and dissolve in 286 ml water that has ~19 g KOH. Then dissolve 24.9 $FeSO_4.7H_2O$ in ~ 500 ml water. Slowly add the iron sulfate solution to the potassium EDTA solution and aerate this solution overnight with stirring. The pH rises to about 7.1 and the solution is wine red and very little precipitation occurs. Make to 1 liter final volume and store in a bottle covered with foil (dark).
Note: Hoagland's recipe called for 1 ml of 0.5% iron tartrate stock per liter of nutrient solution but we use the above substitution.

Appendix E : Economic Analysis

1. Background

This appendix provides an assessment of the economic impact of utilizing freely available natural resources for water purification and processing of value added consumable products to introduce income generating methods to vulnerable poor communities in isolated rural areas. The rationale of the project is to improve health condition of vulnerable poor communities by providing safe drinking water and introduce self-sustainable income generating methods which could improve their social and economic standards.

The expected output of the project is as follows:

- Component A: Strengthened research and quality control capacity on applying traditional knowledge on water purification combining with new technological findings
- Component B: Capacity developed in established rural community based organizations on knowledge sharing, application, protection and dissemination
- Component C: Supported in project management and administration
- Component D: Produced value added products from natural resources:
    a. water purification product
    b. beverage/medicine/consumable/any other appropriate product

2. Current Economic Situation in Isolated Vulnerable Poor Communities

The project will be implemented in selected isolated rural areas for vulnerable poor communities.

Majority of these poor communities in Sri Lanka are traditional farmers. They either cultivate paddy or commonly found verities of grain and vegetables under ‘chena’ cultivation. Some of them collect the common vegetable varieties from the forest or

surrounding environment and market those in weekly “Pola” markets in the town areas. Their produces are collect by intermediate vendors for very cheap prices as these communities do not have enough common transport facilities. Some of the villagers work as a construction labourers in town areas, who normally come back to their residence during the weekends, or during the festival seasons. During the day time elderly citizens and mothers with infants are at home. Children travel through long distances to reach schools. The family income of these communities is hardly enough for their daily expenses. Most of these villagers cannot afford at least to travel to hospitals in town areas for medical treatments. The capacities of local hospitals are so poor they prioritized the treatment for patients according to age and influence. Therefore, patients ignore their medical condition till it leads to worse conditions.

3. Project Economic Benefits

The projects aim is to reduce contamination of drinking water sources and maximum utilization of natural resources for adsorption/absorption of chemicals using biological medicinal plants applying traditional/indigenous knowledge on environment combining with finding of new technology.

It is vital that this environmental knowledge among rural communities with its limited resources is utilized efficiently using these methods for a sustainable environment with long term benefits. This environment knowledge could lead to differentiation and specialization of products reducing competition which will lead to the harmony of the society and its health and wellbeing.

There is a very limited amount of sources for safe drinking water in isolated areas where women have to travel long distances to fetch drinking water to their families. Productive time of the nation could be saved, if it is possible to invent a small scale water purification method for safe drinking water for isolated poor rural communities.

In most conventional drinking water supply schemes, at least Chlorine is added for water purification. With the high contamination of water intakes, the utilization of chemicals for water purification levels also rises.

Saving in Chemical cost for Water Treatment

In most of conventional water treatment plants, the basic stages of water purification are aeration, coagulation, flocculation/sedimentation, filtration, disinfection, storage and safe distribution to the consumer.

With the pollution of natural water bodies, the government has to spend enormous amount for water treatment to produce safe drinking water to the nation.

Mainly alum, lime and chlorine are used as chemicals for water treatment. Lime for pH adjustments, alum as coagulant and chlorine for disinfection.

"As an example the total chemical cost for Hiriwadunna water treatment plant is 3.98 US$ / 1000 m^3 of water. The Hiriwadunna water treatment plant is owned and operated by the National Water Supply & Drainage Board (NWSDB) of Sri Lanka. Commissioned by the Government of Sri Lanka in 1963, the plant was rehabilitated in 1997 with financial assistance from Asian Development Bank. The rehabilitation work was conducted between 1993 and 1997, with a total investment cost of US$ 3 million."*(Source: NewTap funded by JWRC, prepared by Lalith Wijesinghe, Chief Engineer, NWSDB/http://www.jwrc-net.or.jp/aswin/en/newtap/report/NewTap_002.pdf , June 2015)*

Following is a table which shows the current urban and rural access to safe water supply in Sri Lanka

URBAN AND RURAL ACCESS TO SAFE WATER SUPPLY, SRI LANKA, 2006–2011

	2006	2007	2008	2009	2010	2011
Population (million)	20.03	20.23	20.43	20.63	20.84	21.05
Pipe-borne coverage (NWSDB &municipalities)	31.10%	32.00%	33.90%	36.50%	38.20%	40.30%
Pipe-borne coverage (other agencies)	1.00%	1.00%	1.00%	1.00%	0.90%	0.80%
Coverage by protected dug wells	34.00%	33.00%	32.00%	31.00%	31.00%	30.00%
Coverage by hand pumps on tube wells	8.00%	8.00%	8.00%	8.00%	8.00%	8.00%
Coverage by rainwater harvesting	2.00%	2.40%	2.70%	3.00%	3.30%	3.60%
Overall access to safe water	76.10%	76.40%	77.60%	79.50%	81.40%	82.60%

Source: NWSDB, MoFP

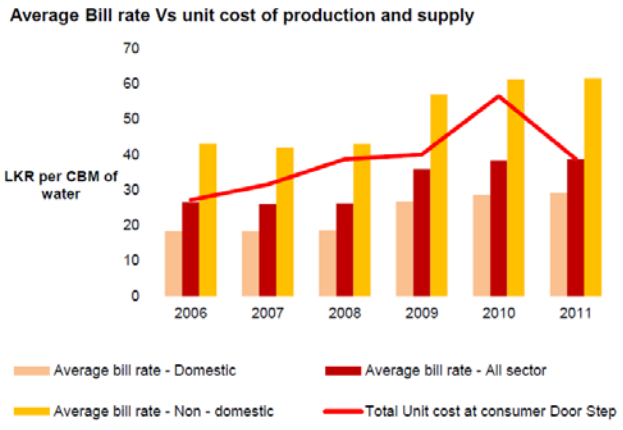
This data clearly depicts that the main way of providing access to safe drinking water is through pipe-bone coverage and protected dug wells.

Following data table shows the capacity and the production of main water supply schemes in Sri Lanka.

Water Treatment Plant	Capacity m^3/day	Production m^3/day
Labugama	59,000	44,300
Kalatuwawa	91,000	83,000
Ambatale	500,000	547,000
Kosgama	2,750	1,100
Penrithwatta	3,000	1,100
Kotabodawatta	3,800	N/A
Kelani Right Bank	180,000	N/A
Raddolugama	N/A	9,000
Pugoda	7,500	7,500
Ranpokunagama	N/A	N/A
Kirindiwela	3,000	750
Kethhena	56,800	N/A
Kandana	60,000	N/A
Ingiriya	450	N/A
Mathugama	200	N/A

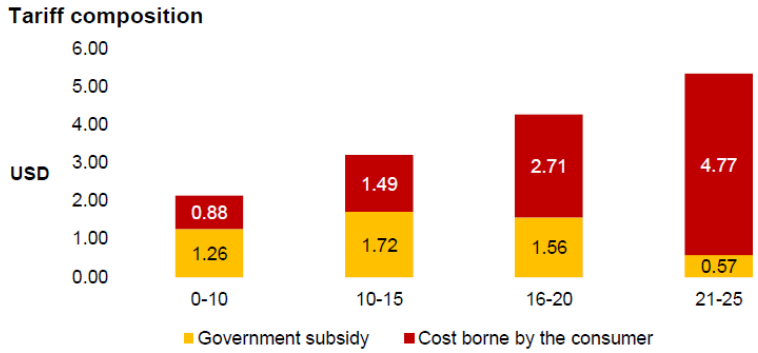
Source: NWSDB

Following data table shows the increase of the Average bill rate for safe drinking water supply.



Source: MoFP Annual report

Following table shows the increase of cost borne by the consumer for water.



Source: MoFP Annual Report

Saving in Loss of Income

Due to unavailability of safe drinking water, inappropriate usage of fertilizers and consumption of unhealthy dietary products, productive life period of communities are shortened.

Savings in Costs to the Health System

" Every year there are 2 million diarrhoeal deaths related to **unsafe water**, sanitation, and hygiene—the vast majority among children under 5. More than one billion people lack access to an improved water source.

Household water treatment and safe storage (HWTS) interventions can lead to dramatic improvements in drinking water quality and reductions in diarrhoeal disease—making an immediate difference to the lives of those who rely on water from polluted rivers, lakes and, in some cases, unsafe wells or piped water supplies." *(Source: World Health Organization Website, Household Water Treatment and Safe Storage. http://www.who.int/household_water/en/, April 2016).*

Economic Benefits from selling Processed Food

Eg. *Terminalia arjuna*

Economic life : More than 60 years

Economics of cultivation / ha No. of plants = 275

Cost of cultivation	:	Rs. 25,000
Maintenance for 15 years	:	Rs. 15,000 to Rs. 25,000

Bark:

Yield dry bark/ha/year after 15 years	:	4 to 4.5 MT
Gross return/ha @ Rs. 50/kg of dry bark	:	Rs. 2000,000 to Rs. 225,000
Net return after 15 years of planting	:	Rs. 160,000 to Rs. 175,000

Yield: From a full-grown tree about 15-20 kg of dry bark is obtained. Production increases upto 25-30 years. About 3 kg fresh bar gives 1 kg on drying.

Medicinal uses:

The bark is of great economic value as it contains 20-24% tannin and used for tanning and dying. It is used in hypertension, and ulcers. The bark is astringent, cooling, anti-dysenteric urinary astringent, anaemia and vitiated conditions of pitta. The bark is popularly used as a cardiac tonic. The bark is useful in diseases of the heart, allays thirst and relieves fatigue. Consumption of barks or bark powder alone will lead to constipation. To avoid this it is to be taken with milk.

(Source: Hand book on Medicinal & Aromatic Plants [NEDFI]from web)

An income generating source:

Currently, other than as timber, the leaves, fruits and plant parts are not commercially used for processing value added products in Sri Lanka. Following photograph witnesses than the timber, after pruning the trees other ***Terminalia arjuna*** plant parts, in a location in North Central Province, are loaded in a truck for disposal.

These leaves, fruits and plant parts could be used for preparation of value added products (eg. Organic fertilizers, beverages, medical and chemical extractions) which will be an income generating method for village communities.

4. Conclusion

Proposed further research on water purification plants, traditional knowledge and finding ways to combine new technology for processing value added products to purify water from natural products and other appropriated products, with involvement of isolated vulnerable communities will improve the economic and social wellbeing of these societies and nation. The finding of innovative methods could be applied as pilot project to find new products to the market which could also improve the health conditions and enhancement of knowledge on nature of the nation.

Appendix F : Project Design and Monitoring Framework

Estimated Project Period (3 Years – from Year 2017 to Year 2019)

1. Impacts of the Project are aligned with:

- Improved health and well-being in selected vulnerable communities in isolated villages
- Increased contribution of the research based indigenous knowledge combined with new technological findings to the economic growth.

2. Outcomes

2.1. Increased consumption of Healthy Drinks and Food Products by Nation

Indicators

By 2021,

a. number of CKD/food poisoning patients reduced in selected vulnerable communities by 20% *(Baseline to be find out from relevant hospitals)*
b. consumption of SLS certified Healthy Drinks in market increased by 20% *(Baseline survey to be carried out)*

Data Sources/Reporting Mechanisms

Central & Local Government Health Inspecting/ MonitoringSystem

Survey Department / Marketing Regulatory Authorities

Independent Surveys

Risks

a. Difficulty in competing with established popular products
b. Resource constrains in the Government
c. Lack of transport and logistic issues

2.2. Increased Safe Drinking Water availability in selected isolated areas with vulnerable communities

Indicators

By 2021,

a. Overall access to safe drinking water increased from 82% to 100% in rural selected communities

Data Sources/Reporting Mechanisms

Annual/Progress reports of NWSDB and Community Development Societies.

Risks

Changes and lack of capacities and facilities of assigned staff, contractors and consultants.

2.3. Increased Income Opportunities in vulnerable communities

Indicators

At least 5,000 members selected from vulnerable communities trained, engaged and received income generated opportunity.

Data Sources/Reporting Mechanisms

Government/Provincial Local Authority reports
Community Development Society Progress reports

Risks

Sustainability of Developed Capacity
Difficulty in selection/retention of long term committed participants

3. Outputs

3.1. Strengthened Research and Quality Control Capacity

Activities

a. *Establish and maintain strong national team for research guidance and activities (Consist of Academic Expertise, University and School Students, Village Representatives including young and elderly citizens with indigenous knowledge)(Q4,2017 – Q4,2019)*
b. *maintain infrastructure/laboratory facilities (Q4,2017 – Q4,2019)*
c. *Conduct Survey (Q4,2017 – Q1,2018)*
d. *EnableLaboratory facilities/Guidance to conduct Research on naturally available products for processing value added products (eg. Water purification / Fertilizer /Food & Beverages)(Q4,2017-Q4,2019)*
e. *Establish Data System for Storage of Research outcome (Q1,2018 – Q4,2019)*
f. *Dissemination of Research outcome, Conduct Training, Development and Awareness Program (Q2, 2018 – Q4,2019)*

g. *Establish supporting legal system for patent, trademark, branding, and permit system for the invented products (Q1,2018)*
h. *Maintain quality controls of products (Q3,2018)*

Indicators

a. *Strong National Research and Quality Control team formed as Consultants (by Q1, 2018)*
b. *Infrastructure and well equipped laboratory facilities allocated from available National Institutions for research activities (by Q1,2018)*
c. *System established for guidance/consultations for Research activities under the project (by Q1,2018)*
d. *Finalized the products formulation to be research under the project (by Q2, 2017)*
e. *Established the Data Management System (by Q1, 2018)*
f. *Conducted Survey and Data Collected on selected natural resources (Q3, 2017)*
g. *Conducted laboratory testing of selected product processed (by, Q1, 2018)*
h. *Established legal system (patent/trademark/branding or permit system for invented products (by Q3, 2018)*
i. *Disseminated Research outcome, Conducted Training, Development and Awareness Program for selected communities (by Q4, 2018)*
j. *90% of invented products in the market are within the quality standards (by Q4, 2018)*

Data Sources/Reporting Mechanisms

a. *National Research and development team quarterly progress reports*
b. *Training workshop course evaluation survey reports*

Risks

To retain the expertise due to limited resources in the country.

3.2. Established and Capacity Developed in Rural Community Based Organizations

Activities

a. *Establish Community Based Organization consist with Vulnerable Rural Communities (Q4,2017)*
b. *Establish a simple data base system, office and product processing setup (Q4,2017)*
c. *Collect the data on available natural resources which are currently not in use and the impact of these resources and coordinate with the Research Unit (Q1,2018)*
d. *Select a Natural Product, Collect it and Process the value added Products with the Guidance of Research Unit (Q2,2018)*
e. *Establish a method of Price control and income generation out of these produce (Q2, 2018)*
f. *Consumption/Market and Distribute these Products under quality control system of Research Unit (Q4,2018)*

Indicators

a. *About 2,000 villagers are involved in collection, processing and value addition of natural products (Q1, 2018)*
b. *About 4,000 families are members of set-up community organization (Q4, 2018)*
c. *At least 4,000 villagers continue to be employed/self-employed and income generated from the knowledge and training they received from the project (Q4, 2019).*

Data Sources/Reporting Mechanisms

a. *Independent monitoring and evaluating specialist reports*
b. *Minutes of the meetings of community organizations*
c. *Quarterly construction reports from engineering firms and provincial local authorities*

Risks

Lack of transport facilities, Cultural practices in rural areas and family commitments could be an obstacle for unemployed community members to group-up and attend training sessions.

3.3. Project Management and Administration Supported

Activities

a. *Appoint PMU and SPCU staff including Project Management Consultant for implementation (Q2, 2017)*
b. *Setup a coordinating, monitoring and implementing system/PPMS (Q3,2017)*
c. *Procure furniture, equipment and vehicle for PMU (Q3, 2017)*
d. *Submit project progress report to Government Control body Monthly (Q2,2017 –Q4,2019)*
e. *Establish the project coordinating committee to review the project progress quarterly basis and submit report to Central Government, Donor and Beneficiaries (Q2, 2017 – Q4, 2019)*
f. *Establish Independent Audit Committees and Annual Audit and Management Review (Q3, 2017 – Q4, 2019)*
g. *Establish a Web-based System to disseminate project news to stakeholders (Q2, 2017)*
h. *Conduct the Project Completion Report (Q1, 2020)*

Indicators

a. *Timely and effective support provided for smooth project implementation*
b. *PMU and SPCUs fully staffed on time*
c. *Quarterly progress/Environment & Social Safeguard/Gender Monitoring reports of satisfactory quality submitted on time*
d. *Project Staff trained on application of best practices of project management in complaint handling, procurement & disbursement, environment and social safeguard and gender*
e. *Timely completion of project activities including Project Completion Report*

Data Sources/Reporting Mechanisms

Quarterly Progress Reports provided by PMU

Risks

a. *Budgetary allocations and Capital Resource constrain within the Country*
b. *Coordination and Finalization of relevant management set up of Executing and Implementing Agencies would be complex*

3.4. Produced value added products from natural resources (eg. Beverage /Water Purification Materials / Organic Fertilizer out of *Terminalia arjuna*)

Activities

a. *Select and Assign specific product and individual responsibilities for Specific Group formed out communities and Research teams (Please refer table **A**for a sample)(Q2,2017)*
b. *Procurement of equipment and materials including laboratory facilities for research (Q4,2017)*
c. *Collection of natural products for research (Q3, 2017)*
d. *Conduct research (Q1,2017 – Q4,2018)*
e. *Finalize the Value added Product/ preparatory method (Q1,2019)*
f. *Community Trained on preparation and utilization of product (Q2, 2019)*
g. *Community market/utilize the product (Q3, 2019)*

Indicators

a. *At least 500 freely available natural products are processed as value added products*

Data Sources/Reporting Mechanisms

a. *Independent monitoring and evaluating specialist reports*
b. *Minutes of the meetings of community organizations*
c. *Project Management Unit Quarterly Progress Report*
d. *Government / Provincial Local Authority reports*

Risks

a. *Differences in preferences of selected products by the communities*
b. *Team agreement for selection of variety of product*
c. *Balancing environment without over usage of a particular resources*

Inputs

Government

Private Sector Group 1

Private Sector Group 2

Donor Agency Group 1

Donor Agency Group 1

Community

Table A : Assignment of Work for Selected Group

	Group A - Beverages			***Group B - Medicine***			***Group C - Water Purification Product***		
Out of Terminalia arjuna	***Assigned work***	***Specific Members***	***Budget In LKR***	***Assigned work***	***Specific Members***	***Budget In LKR***	***Assigned work***	***Specific Members***	***Budget In LKR***
Members from related Government Institute					*Ministry of Health /Ministry of Indigenous Medicine*			*MoWSCT/NWSDB*	
Members of Research Team	*(a) Provide knowledge and guidance* *(b)Design research methodology* *(c)Support and Quality control*						*Chemical Engineering*		
Members from University	*(a) Support/Conduct for research and initial processing* *(b)Training communities with best practices for processing and application*								
Members from School Children	*(a) Support for collection* *(b) Support/Conduct research* *(c) Support for data base* *(d) Support for processing*								
Members of Community	*(a) Knowledge of Traditional/Possible Beverages* *(b) Knowledge of Available sites* *(c) Collection of materials* *(d) Support for processing* *(e) Support for Marketing/employment*								