Sri Lanka Association for the Advancement of Science

Proceedings of the 72nd Annual Sessions
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Part II: Presidential Addresses

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General president's Address

Interdisciplinarity in Research, Education and Practice for Advancing Science and Society

Manjula Vithanapathirana

Introduction

Science is the basis for a better future and the foundation of a knowledge-based society and a healthy economy. Science has to be understood in a broader sense of Science, technology and innovation ranging from natural science to technologies, social sciences and humanities. Society is increasingly focusing attention to Science for answers to help solve and address current problems and future challenges. Knowledge is growing very fast across all sciences. Science has grown to many specializations the branches of which are commonly referred to as the scientific disciplines.

Some of the major problems society faces today are too complex to be dealt with adequately by a single discipline and can be grasped fully only by integrating the specializations of different academic disciplines (Newell, 2001).

The interest in working through solitary sciences is decreasing. In order to understand human problems, one must work without limiting to any single science. Of late there is a buzz around interdisciplinary science.

Interdisciplinary science is an integrated approach that synthesizes the perspectives of multiple individual disciplines during all phases of an investigation rather than a simple consideration of multiple and vairied view points focused on a particular inquiry which is commonly referred to as multidisciplinarity (Klien 1990). In multidisciplinarity approaches two or more disciplines work collaboratively on a common problem without modifying disciplinary approaches or developing synthetic conceptual frameworks.

Although the term interdisciplinary approach has entered first to the index of Education about six decades ago, the idea of Interdisciplinarity is said to have existed even before (Mc Cuskey and Conaway, 1955).

Interdisciplinary approaches refrain from breakdown of a problem into uni-disciplinary segments which would be solved independently. It values all disciplines and recognizes the inter-dependency of natural and social sciences. Interdisciplinarity does not undermine the importance of conventional disciplines which obviously contributed to build basic knowledge.

Interdisciplinarity values all disciplines and recognize their independence as well as their interdependency (Nature, 2015).

Interdisciplinarity has been discussed as a requirement for research, education and practice at all levels and scales. Interdisciplinary inquiry and the practice of integrating across disciplines require greater conversation among collaborators. Interdisciplinarity not only draws on multiple fields and/or disciplines but also serve multiple stakeholders and broader missions outside of academia.

Interdisciplinarity is considered as synonymous to innovation (Bavitz, 2015). Combining unrelated academic disciplines in a way that leads them to cross subject and social boundaries to create new knowledge would lead to innovation. Thus interdisciplinary research has a constructive quality and innovation is the incentive to promote collaboration (Obino, 2016).

Interdisciplinary research

The global research architecture had formed into the process of building to strengthen and organise interdisciplinary collaboration. The World Social Science Report 2013 in an urgent call for action to the international social science community requests to collaborate more effectively with each other, with colleagues from other fields of science, and with multiple stakeholders and users of science to deliver credible and legitimate knowledge for real-world problem solving (UNESCO, 2013).

UN Secretary General's Scientific Advisory Board highlights in the post–2015 agenda, the crucial role of science for sustainable development. As a response, the National Science Foundation (NSF) Advisory Committee for Environmental Research and Education (2015) has forwarded new priorities in interdisciplinary programs in their 10 year outlook report. The emphasis is placed on the need for understanding the interconnected nature of multiple environmental problems. Adressing such complex interdisciplinary environmental challenges need fostering interdisciplinary research teams in designing and testing solutions. https://en.unesco.org

World over the major direction for implementing Sustainable Development research is reported to be through collaboration across disciplines. Innovation is the incentive to promote collaboration. However the practice towards such collaboration is yet to be picked up. One reason is the emphasis given towards discipline focused academic training and research that is appreciated for career advancement.

One of the major areas of interdisciplinary research focuses on research addressing on environmental challenges which are often global in scale. (Amanda et al., 2012). In resolving bigger challenges such as climate change, food and water crisis, public health etc., research transcend the boundaries of disciplines, thus making headway for interdisciplinary research.

Another example of interdisciplinary approach to problem solving comes from Australia (Moxham, et al., 2015) where integration of theory and practice for innovative mental health clinical placement with a 'recovery philosophy' has been introduced by the Faculties of Science, Medicine and Health in a University. This innovation named as 'therapeutic recreation' is a treatment program designed to restore, remediate and rehabilitate a person's level of functioning and independence in routine life activities.

Innovation is a long process. It starts with research and development. However, it is necessary to bring together researchers towards 'speculative' research for innovation as early as possible.

Interdisciplinarity in education

Interdisciplinarity in education is a complex question to address. In the knowledge society of today there is a need for informed, self-confident and conscious citizens who can be critical consumers of

scientific knowledge. Science education is not only a question of responding to the demands for a scientifically qualified workforce, but is also a question of meeting social goals.

Traditionally discipline specific knowledge is considered as the only form of high quality knowledge. Crossing the boundaries of knowledge was considered as inferior. Some feel highly territorial about their subjects and are threatened as new views of their subject are promoted. There is a need for both interdisciplinary and discipline specific perspectives in curriculum design. Unlike the disciplines that have an inherent scope and sequence used by curriculum planners, there is no general structure in interdisciplinary curriculum format. Curriculum developers themselves must design a content scope and sequence for any interdisciplinary unit or course. In the synthesis of insights across disciplines, one can always decide on the degree of interdisciplinarity needed for any course of study (https://serc.carleton.edu). There is no recipe or a set pattern of disciplinary interactions and it is difficult to predict how disciplines will interact. For example, a study of nanobiotechnology cannot fit within any traditional academic discipline (Jacobs, 1989).

Interdisciplinary instruction helps students develop their cognitive abilities - brain-based skills and mental processes- that are needed to carry out tasks. Then all students will have some understanding of continuity across all disciplines and more importantly would understand the languages of several disciplines. With better understanding of each others' languages, collaborations across various disciplines would be more efficient. They need to develop a general interest in different areas of science and be open to collaborating with and learning from each other with varying interests. http://serc.carleton.edu/

The world renowned universities encourage students to solve local and regional problems that have a global impact. Students in interdisciplinary teams working towards service learning projects during the course of the academic year will develop insights and attitudes to address issues in the society.

A well established principle in education is that what is learned in one discipline will not be spontaneously transferred by the majority of learners. In educating the future scientists the quality of the teacher force is of extreme importance. It is important to develop teachers through preservice and inservice training enabling them to relate their practice of the profession to realities of life. Teacher education programs must help to gain confidence and broaden their outlook. So that they do not see things only from the point of view of their own discipline of study.

One of the problems identified in present day science education is the decreasing interest towards natural sciences. One of the reasons identified for this issue is the high emphasis given to solitary sciences. The need of a systemic approach combining natural and social sciences and technology is considered a major intervention (Lamanauskas, 2011).

Educational systems need to build their own interdisciplinary pathways. This approach would foster a love of learning, generate enthusiasm and address differences of potentials. The learners will be better positioned to understand challenging problems and to frame viable solutions.

Promoting Interdisciplinarity practice: SLAAS from multidisciplinarity to Interdisciplinarity?

Interdisciplinarity first emerges in an individual's mind. Three key psychological dimensions enabling successful Interdisciplinarity are: the cognitive-intellectual (most exclusively concerned with content); the emotional (concerned with reactions to individuals and ideas); and the socio-interactional (concerned primarily with interaction, meaning-making, and group styles).

Further, to be interdisciplinary, one must be able to be comfortable with multiple languages, and shift easily among them, be comfortable with a variety of world views, methods, tools, and theoretical perspectives having a readiness to shift perspectives easily and continually see things in new ways.

True collaboration between scientists, educators, leaders, and other stakeholders beyond mere cooperation is essential for successful interdisciplinary science that fosters wellbeing of the rapidly changing planet. The key word of the theme we agreed upon for 2016 is 'Interdisciplinarity' with the objective of working beyond the practice of multidisciplinarity of SLAAS. SLAAS is multidisciplinary in its structure. The sections/disciplines usually autonomously engage in activities towards the shared goal of 'a scientifically advanced nation'. We agreed among us that the Sections in SLAAS while retaining the original identity would work synergistically through the theme 'interdiciplinarity in research, education and practice for advancing science and society' to bring in collaborations and integrations. The expectation was that integrated practice would exceed the output of any single discipline.

In treading on the ground open to interdiscipinarity SLAAS managed to address a few issues through a basic interdisciplinary framework.

The first was by the section F SLAAS social sciences section. A panel discussion to make an analysis on the Economic and Technology Agreement (ETCA) with a view to integrate points of view through social sciences, medical sciences, architectural and information technology in order to formulate and evaluate public policy options was attempted. Members as well as non-members of SLAAS showed a high interest to participate in the event. Recommedations were made collectively by the multidisciplinary panel. However, the issue was too controversial and there were hessitations to continue the discussion which was a necessity to integrate analysis.

The second attempt was the workshop on 'Interdisciplinarity in Scientific Research: Commercialization and Technology Transfer' was held with stakeholders from the chemical sciences section, Section E2, attempted to integrate the methodologies of research and innovations in the food sector, polymer and rubber industry, open source development, biotechnology research, human resource management and technological innovations and commercialization. Transferring new technologies and innovative product ideas from research to commercialization being the key to gear our country towards development, the workshop brought together a cluster of disciplines. The syntheses of outcomes pointed out the need to encourage high tech research with excellent standards by state as well as non state sectors.

The Section D, the section on Life Sciences attempted an interdisciplinary analyses of the biggest challenge to health at the moment, the dengue outbreak. The mini symposium on 'Dengue Research

in Sri Lanka' reviewed the current and emerging trends that incorporated dengue vaccine research, architectural concepts of buildings for vector control, entomological and environmental aspects on dengue control, mathematical modeling to capture dengue severity and psychological models in dengue health education. The mix of disciplines in this attempt was not only rich but innovative.
Potential collaborations among the diverse fields were initiated by this event that included both presenters and participants. This suggests that there is need to extend medical and natural sciences models to mesh with social science frameworks to reach practical ways forward. Several interesting collaborations initiated in the discussion where the need for integration was felt, e.g., the entomologists of the Dengue Control Unit (Ministry of Health) in the audience and the health psychologist negotiated to work together in planning for awareness on dengue. A deeper interest on the architectural aspects contributing to the problem with dengue control will also lead to innovations.

Science and Technology Advisory Committee of SLAAS led by the General President in office has the mandate to advice the council and assist in the formulation of the national science and technology policy through identifying problem areas in which urgent studies are required. This year the issue selected was 'Agrochemical Use: Benefits, Risks and Social Impacts'. Agrochemicals have become an integral part of agriculture. Since most of these agrochemicals are derived from the petrochemical industry a crisis of use of such products has arisen among policy makers, general public, health practitioners, farmers, scientists etc. In order to address the issues of use and management of agrochemicals and fertilizer use and management a relaiable critical analysis across disciplines was attempted through three round-table discussions. A team with a range of disciplinary and stakeholder expertise came together in these round - table discussions to critically reflect on their practice and identify lessons about how to collaborate more effectively to address the issue of usage of agrochemicals.

Officials representing the Departments of Agriculture, Export Crops, Office of the Registrar of Pesticides, Ministry of Health, the Water Supply and Drainage Board; scientists from rice, tea, coconut and sugar cane research institutions and the National Institute of Fundamental Studies, Food Crops Development Institute; researchers in sociology, entomology, plant sciences, crop science, chemical sciences, agriculture economics and a represenative group of farmers gathered at the SLAAS. They discussed the role of agrochemicals, benefits, risks and social impacts seeking to improve engagement and collaboration in integrated science, management and policy initiatives.

The comprehensive outcomes include recommendations such as strengthening of chemical testing laboratory facilities to measure the levels of heavy metals and toxic metals in imported agrochemicals through establishing accredited laboratories, awarenss building towards use and misuse of fertilizer, strategies of promotion of organic fertilizers, since the highest use of chemical ferlizer is on rice the feasibility of introduction of new rice varieties which have the ability to grow

under low N, P, K levels, ensuring the objectivity in the quality control by the National Fertilizer Secretariet, the need to revise fertilizer acts, imposing standards on agrochemical imports, setting up field testing facilities for farmers for soil testing etc., developing suitable protective gear as imported clothing is not used by farmers as these are too warm and bulky, removing the most controversial

glyphosates from plantation crops and field crops, review of agricultural extension services.

Challenges to interdiscipliniarity and the way forward

The success of interdisciplinary practice rests not with the mixing of disciplines but the thinking which contributes to the integration of knowledge. In the inspiration to solve complex questions scientists need to meet at the interface of several disciplines and even would cross the boundaries to form new disciplines. Promoting interdisciplinary collaborations is a challenge.

Among the lessons learned the deeply rooted mono-disciplinary mindsets which results in hessitations to stretch beyond the boundaries is the major challenge.

However, even across the world interdisciplinary work is slow to take off the ground. Engaging in interdisciplinary work may be perceived as a risk, especially for early career researchers, due to the strong call for compartmentalized structure in our discipline specific research that is essential for career growth (Pfirman and Begg, 2012). In attempting to balance the strengthening of disciplines and developing interdisciplinary research, education and practice, many institutions are obstructed by traditions and policies that govern hiring, promotion, and resource allocation and existing reward structures.

SLAAS has no barriers for interaction and integration of disciplines. With its multidisciplinary structure, SLAAS allows a member who joins to a discipline specific section of SLAAS to collaborate with other disciplines or different sections. Thus, the attempts made by SLAAS members to get into collaborations taking the advantage of the professional freedom in SLAAS can be considered as more provocative than conclusive.

Gauging the quality of outcomes of interdisciplinary analysis is complex. The common view is that "the outcome of interdisciplinary analysis will not always be a neat, tidy solution with contradictions between the alternative disciplines completely resolved. Interdisciplinary study may indeed be 'messy'. The tensions between disciplines could be seen as a progressive step towards interdisciplinarity. Analysis which works through these tensions and contradictions between disciplinary systems of knowledge with the goal of creation of new knowledge often characterizes the richest interdisciplinary work" (Seipel, 2002).

"True interdisciplinary science cannot be rushed" (Nature, 2015). Interdisciplinary thinking develops over time with gaining experience. Scientists who stay on with the perspective would become mature collaborators and are able to innovate across disciplines and broader networks. The role of such experienced collaborators should be to support new colleagues into dynamic relationships. SLAAS having a membership of varying experience could mentor the new comers for successful dialogue between each other across the sections. If not, SLAAS would continuously face the challenge of finding ways to integrate and synthesize disciplinary depth with sufficient breadth of interests, visions and skills with its multidisciplinary membership.

It is also to be remembered that today's interdisciplinarity would end up as tomorrow's "traditional" discipline. My plea to the members of SLAAS is to work together across the range of portfolios undertaken to fulfill the SLAAS mission, without considering the discipline specific rewards and

incentive systems prevailing in academia through an interdisciplinary perspective which is enriching and socially responsible.

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https://en.unesco.org

Section A

Evolution of Dentistry to Art & Science of Dentofacial Aesthetics

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The field of Dentistry deals with the study, diagnosis, prevention and management of diseases and conditions of the oral cavity; dentition, oral mucosa and the adjacent and related structures; craniofacial complex, temporomandibular region other supporting structures and tissues of the maxillofacial region.

The history of dentistry may be traced back to 7000 BC in the Indus valley civilization. There is ample evidence that the Egyptians and Greeks treated fractures of the mandible and jaw dislocation. Hippocrates (400 BC) was credited with describing a bandage to support the chin which would stabilize in case of a fracture mandible. Several paintings and illustrations depict that in many ancient civilizations in both Asia as well as Europe, teeth were extracted (Ring, 1985).

The first professional European "dentists" were known as *barber-surgeons*. Guilds of barber-surgeons were prominent in Europe beginning in the thirteenth century. They were generally responsible for bleeding, cupping, leeching, giving enemas and extracting teeth. Only in the early eighteenth century did the exclusive profession of dentistry emerge (Jayaraman, 2013).

Pierre Fauchard of France (1678-1761) is known today as the "Father of Modern Dentistry." He became particularly interested in diseases of the mouth as he was exposed to various illnesses of sailors while at sea. Fauchard composed his own treatise on the foundations of dentistry, *Le chirurgien dentiste ou traité des dents* (The Surgeon-Dentist, or Treatise on the Teeth), in 1728. In it, Fauchard described the foundations of oral anatomy and physiology. His treatise included a detailed description of methods for removing decay and restoring teeth, treating periodontal disease, and performing orthodontic surgery and tooth replacement. His scientific, comprehensive approach was commended by fellow medical professionals and laid the groundwork for the future of dentistry (Jayaraman, 2013).

The dental technology made major inroads in early 1800s, with important breakthroughs in dental care, particularly in denture development; porcelain teeth and impression compound. In the early 19th century, a small number of people with medical or surgical diplomas from a Royal College of Surgeons or the Worshipful Society of Apothecaries practiced dentistry as an appendage to their main professions. Some others provided dental treatment as a sideline to their main business: barbers, wig-makers, blacksmiths, silversmiths or apothecaries. Ever increasing demand for dental treatment lead to more of both groups to practice dentistry exclusively. The established practices sometimes were passed from father to son, each generation training the next. Some opportunists picked up the tricks of the trade as they went along but had little or no skills with tales of malpractice abound.

Although "dentistry" is primarily associated with teeth among the general public, dentists are considered as tooth pullers, fillers and cleaners; the field of dentistry continued to expand rapidly throughout the 20th century. The field of Dentistry developed into several specialties; Dental public health, Forensic dentistry, Geriatric dentistry, Restorative dentistry and endodontics, Oral and maxillofacial pathology, Oral and maxillofacial radiology, Oral medicine, Orthodontics and dentofacial orthopedics, Paediatric dentistry, Periodontology, Prosthodontics and Special needs dentistry.

Oral and Maxillofacial Surgery (OMS) is the surgical specialty which has evolved from dentistry, deals with management of a wide spectrum of diseases, injuries, defects and aesthetic aspects of the mouth, teeth, jaws, face, head and neck. The facial bone anatomy is complex yet elegant, although this is a confined and relatively small area of the body it has a complex anatomical, physiological and pathological composition. It serves to protect the brain, house and protect the sense organs of smell, sight, and taste and also provides a basic structure on which the soft tissues of the face can act to facilitate multitude of functions; eating, breathing, speech and facial expression. There are also complex psychological issues associated with the appearance and function of the face and jaws. Hence, specialists practicing in the field of OMS need advanced basic science knowledge, detailed pathological and imaging knowledge, and broad surgical experience. The various surgical procedures in the OMS region require knowledge, training and experience from various disciplines including dental surgery, general surgery, plastic and reconstructive surgery, ear nose and throat surgery, orthopaedics and neurosurgery.

In the USA, the development of Dentistry as an academic discipline brought its skills to the pathology and surgery of the jaws. In the German speaking parts of Europe, many of the now standard operations on the face and jaws were developed from a medical background. Improvement in dental practice developed late in Europe. For example the profession of Dentistry in Italy was only formally established in 1981. The pioneering German surgeons were very skilled, swift and brave, as were their patients, because the early operations were usually performed without anaesthesia. It is beyond modern comprehension to countenance trying to surgically close a cleft palate in a baby without general anaesthesia. Not surprisingly, the mortality rate was high, between nineteen and forty-three per cent. The European surgeons of the nineteenth and early twentieth century had much experience of war surgery, particularly as in trench warfare the head and face were the first areas to be exposed. There were parallel developments in the United Kingdom particularly at the

outset of the First World War when dedicated Maxillofacial Surgery Units were established; they were also needed again in the Second World War.

What is Beauty?

Beauty has been described as everything from a 'social necessity' to a 'gift from God', with facial beauty being perhaps the most valued aspect of human beauty. The poet John Milton refers to the 'strange power' of beauty, describing beauty as 'Nature's brag'. Thus beauty as a concept can be perceived but not explained, as it is has high subject variability. Beauty is that ''which gives the highest degree of pleasure to the senses or to the mind and suggests that the object of delight approximates one's conception of an ideal'' (Webster, 1988).

The writer Margaret Wolfe Hungerford (1878) states that "beauty may be considered a mystifying quality that some faces have, or may be", 'in the eye of the beholder'. Plato (428−348 BC) describes 'Beholding beauty with the eye of the mind' in his concept on beauty. Shakespeare says 'Beauty is bought by judgment of the eye' in his Love's Labour's Lost. The philosopher Immanuel Kant (1790), in a treatise entitled Critique of Judgment stated 'The beautiful is that which pleases universally without a concept'. The case of "beauty" is different from mere "agreeableness" because, "If he proclaims something to be beautiful, then he requires the same liking from others; he then judges not just for himself but for everyone, and speaks of beauty as if it were a property of things".

The human perception of facial beauty involves the interpretation of harmony of the facial features which may have genetic, environmental or multifactorial foundations. Evidence to support a genetic theory is that infants, from newborns until two years of age, when simultaneously presented with two facial photographs, have a tendency to stare longer at the face previously rated as more attractive by adults (Langlois *et al*, 1987). The evolutionary basis is that facial beauty is a requirement for sexual selection, leading to improved opportunity for reproduction (Jones, 1999). A considerable quantitative meta-analysis undertaken by Langlois *et al* (2000) seems to confirm that there is also cross-cultural agreement regarding facial beauty. Studies in the late 1800s by Sir Francis Galton, the cousin of Charles Darwin, accidentally found evidence to support what came to be known as the 'averageness hypothesis' of facial beauty, with composite facial photographs gaining higher attractiveness ratings than their individual facial photographs (Langlois *et al*, 1990). However, Perrett *et al* (1994) have shown that attractive composite faces were made more attractive by exaggerating the shape differences from the sample mean. Therefore, an average face shape is attractive but may not be optimally attractive (Arvystas, 2003). Facial symmetry also seems to be an important aspect of facial beauty, although mild asymmetry is essentially normal (Grammer *et al*, 1994).

An "ideal beauty" is an entity which is admired, or possesses features that is widely attributed to beauty in a particular culture. Facial beauty may be a subjective matter or experience, it is often said that "beauty is in the eye of the beholder". In its most profound sense, beauty may engender a salient experience of positive reflection about the meaning of one's own existence.

The awareness of physical beauty remains a subjective perception linked into our being from birth and influenced by numerous societal and interpersonal factors; youthfulness, physical

attractiveness, personality and health and by recognized or unrecognized assessment of facial proportions. The perception of facial symmetry as a facial beauty is only one of the number of aesthetic traits. But it becomes one of the most influencing factors for influencing the physical beauty of a person, as achieving the symmetry of shape of the face increases rating of attractiveness for both male and female faces.

Mathematical laws and laws of proportion

The concept that 'ideal' proportions are the secret of beauty is perhaps the oldest idea regarding the nature of beauty (Peck, 1970). The ancient Egyptians had a great interest in art and beauty and they immortalized the beauty of their kings and queens by depicting them, perhaps unrealistically, with 'ideal' facial proportions.The famous painted limestone figure of Queen Nefertiti (c. 1350 BC) in an excellent example (Figure 1). In fact, the name Nefertiti literally means the 'Perfect One'. Lesser dignitaries had more realistic depictions in art and sculpture, as they were not so honoured.

Figure 1. Queen Nefertiti - The famous face with her harmonious facial proportions and symmetry

The Egyptian law of proportions, used grids with meshes of equal-sized squares. This was to change with the age of Greek sculpture which, rather than featuring fixed units, described proportion between the parts of the whole human figure. The Greek mathematician Pythagoras (6th century BC) is extremely likely to have come into contact with the mathematical treatise of the Egyptians in the course of his travels. He postulated that beauty could be explained through mathematical laws and laws of proportion. He proposed an explanation of beauty through a significant finding that plucking taut strings of proportionately different lengths produces harmonious notes. The difference in the proportionate lengths of the strings followed mathematical laws, and hence his explanation of laws of proportion. The term Pythagoras used to describe beauty was 'cosmos' as he felt that beauty was part of the mathematical order of the universe, hence the origin of the word 'cosmetic'. Throughout the ages, painters and sculptors have attempted to establish ideal proportions for the human form, however, possibly the most famous of all axioms about ideal proportions is that of the Golden Proportion (Ricketts, 1982).

The Golden Ratio

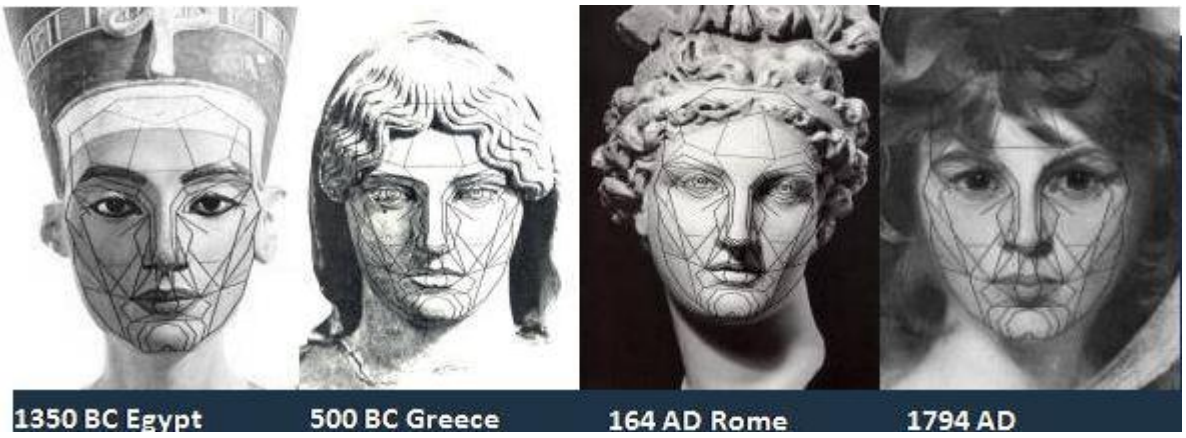
Beautiful faces have ideal facial proportion. Ideal proportion is directly related to divine proportion (golden ratio), and that proportion is 1 to 1.618. The Great Pyramid, temples, domestic articles and adornments from Tutankhamen's tomb prove that Egyptian craftsmen used the golden section In their work. This proportion has classically been described as pleasing to the eye, the emphasis being upon the proportion of the parts to the whole.

The prominent mathematician Euclid (c. 325−265 BC) described this in his treatise The Elements. In his edition of Euclid's Elements, the mathematician Luca Pacioli (1509) re-named the Golden Proportion the 'Divine Proportion' as he felt the concept could not be fully explained, and published a treatise entitled De Divina Proportione (On Divine Proportion) for which Leonardo da Vinci drew figures of symmetrical and proportionate faces and bodies (Naini FB *et al*, 2006). Maestlin in 1957 gave the first known calculation of the Golden Proportion as a decimal in a letter to his former pupil, the famous astronomer Johannes Kepler (Herz-Fischler, 1998).

The distinguished mathematician Leonardo of Pisa (1170−1240), also known as Leonardo Fibonacci, devised a number sequence in which each number is the sum of the two preceding numbers, i.e. 1, 1, 2, 3, 5, 8, 13, 21, 34, 55 etc. The mathematician Edouard Lucas in the 19th century, coined the term Fibonacci sequence, and scientists began to discover the numbers in nature, such as in the spirals of sunflower heads, the logarithmic spiral in snail shells and in animal horns. As the numbers increase in magnitude, the ratio between succeeding numbers approaches the Golden Proportion (Ricketts, 1982). In biological research carried out in the 70s-90s, it was shown that the golden section typical of structural proportions and harmony is found everywhere all living organisms, from microbes and flora including humans, are genetically encoded to develop to the proportion because there are extreme aesthetic and physiological benefits. The golden section is recognized as the universal law of living systems.

The Golden Proportion can be applied in dental aesthetics and smile to the apparent mesiodistal width of the anterior teeth when viewed from the frontal aspect. This can be useful in designing the relative width of teeth in a beautiful smile and correlate ideal facial proportions with the Golden Proportion. However, the faces of professional models have not been found always to fit the Golden Proportion, (Moss *et al*, 1995) and a study looking at the aesthetic improvement of patients undergoing orthognathic surgery found that, while most subjects were considered more aesthetic after treatment than before, the proportions were equally likely to move away from, or toward, the Golden Proportion (Baker *et al*, 2001).

Historical background



Canons of Proportion

The idealization of human proportions was a major preoccupation of Greek sculptors. One of the most famous, Polycleitus (late 5th century BC), wrote the Canon, a theoretical work that discussed ideal mathematical proportions for the parts of the human body. The mathematical proportions and laws described by Polycleitus were possibly based on those initially described by Pythagoras, originally based on harmonious musical intervals. Roman copies of one of his most famous statues, the 'Doryphorus' ('Spear Bearer'), still exist. This statue is itself often referred to as the 'Canon' because it embodies Polycleitus' views on the correct proportions of the ideal male form (Figure 2). In the 2nd century AD, the prominent Greek physician and philosopher Galen said, 'Beauty does not lie in the individual parts, but in the harmonious proportion of all the parts to all the others, as is stated in the Canon of Polycleitus'.

Figure 2. Doryphorus ('Spear Bearer'). In this statue, also often referred to as the 'Canon', Polycleitos created the archetype of the Greek ideal of male beauty.

Figure 3. Aphrodite of Melos (known in French as 'Venus de Milo') is a representation of the classic Greek facial profile.

Phidias (c. 490−430 BC), a contemporary of Polycleitus, was an Athenian famous as one of the most outstanding of all sculptors. He directed the construction and design of the Parthenon, the chief temple of the Greek goddess Athena on the hill of the Acropolis at Athens. The Parthenon itself, and the statues contained within it, were said to conform to 'ideal' proportions, with Phidias incorporating the Golden Proportion into the architectural design (Green, 1995). In ancient Greece, sculpture of the human form was used to represent the many gods. As these sculptures were constructed with ideal proportions, the belief arose that the better 'mortals' looked, the more god-like they were (Figure 3).

Polycleitus also described the importance of the concept of symmetry in the human form combined with ideal proportions, which he referred to as 'symmetria'. The Roman architect Marcus Vitruvius Pollio (1st century BC) is well known for describing the facial trisection. He referred to the 'symmetrical harmony' of the 'ideal' human body and compared this to 'perfect buildings' (Howe, 1999). Vitruvian concepts of proportion and symmetry were essentially Hellenistic, being based on those of the Greeks. Vitruvius' influence continued through his ten-volume work De architectura. Leonardo da Vinci later immortalized aspects of Vitruvian concepts, regarding the proportions and symmetry of the human body.

Leonardo da Vinci (1452–1519), the Renaissance genius who excelled as a painter and sculptor, in addition to architecture, engineering, human physiology and anatomy, defined proportion as the ratio between the respective parts and the whole (Pedretti, 2001). His notebooks reveal his quest for the ideal facial proportions. He produced studies of the proportions of the human head (Figure 4), a table of possible nose types, and combinations of various forms of foreheads, chins, noses and mouths. The figure of Vitruvian man (Figure 5), which Leonardo based on guidelines described by Vitruvius, represents 'ideal' male proportions based on man's navel as the centre of a circle enclosing man with outstretched arms. This shows the importance of proportions in the human form. The distance from the hairline to the inferior aspect of the chin (soft tissue menton) is one-tenth of a man's height. The distance from the top of the head to soft tissue menton is one-eighth of a man's height.

The clinical implication is that, when planning treatment changes, for example to the vertical face height of a patient, it can be misleading to base the intended result on absolute numeric values based on population norms. People are not necessarily 'average'. It is prudent, therefore, to plan treatment bearing in mind the patient's standing height and stature, and aim to correct the individual's proportions.

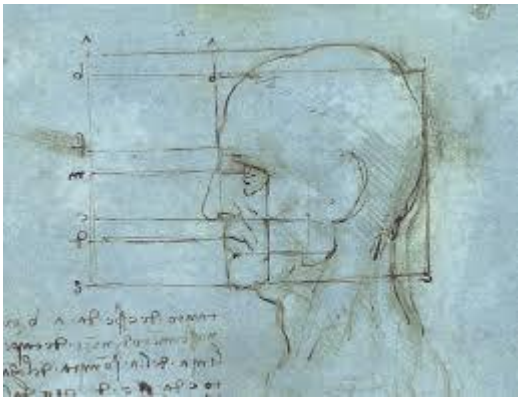


Figure 4. Leonardo da Vinci's male head in profile with proportions, ca. 1490.

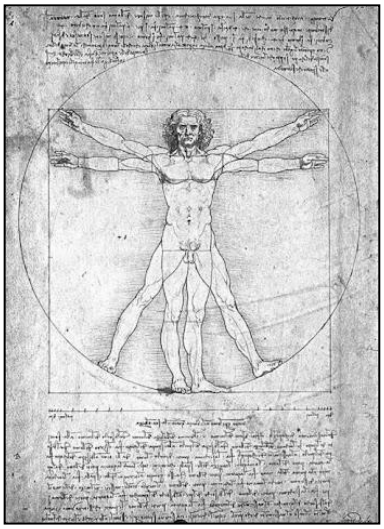


Figure 5. Leonardo da Vinci's Vitruvian man. The famous figure shows that the proportionate human form fits perfectly in perfect geometric shapes, the circle and the square.

Albrecht Durer (1471–1528), generally acknowledged as the greatest German Renaissance artist, maintained the importance of studying facial proportions. His Treatise on Human Proportions, published posthumously in 1528, contained illustrations depicting perfect proportions of the aesthetically 'ideal' human face and figure (Figure 6). Durer maintained that disproportionate human faces were unaesthetic, whereas proportionate features were acceptable if not always beautiful (Proffit *et al*, 2003). Therefore, clinicians can make the assessment of facial aesthetics more objective by diagnosing and helping to correct facial disproportions.

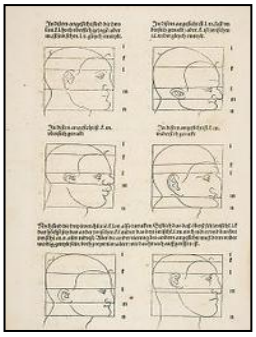


Figure 6. Albrecht Durer's representation of facial proportions.

Therefore, the guidelines used by clinicians today are based on those initially described in art and sculpture, even though somewhat modified from the original (Naini *et al*, 2006). What clinicians would today refer to as evidence for what constitutes 'ideal' facial measurements, based on population averages, comes from growth studies using cephalometric radiography (Bishara, 2000) and anthropometry (Farkas, 1981). However, it has its own limitations (Edler, 2001).

Importance of facial aesthetics

One's own perception of their facial appearance and any associated disfigurements is important in the self image and negative self-perception. Also there is considerable individual variation in people's abilities to adapt to their facial deformity. Some individuals remain comparatively unaffected, while others may have significant difficulties, which affect their quality of life. Although an individual's facial appearance contributes to the opinions other people form of them, obviously these opinions may well change as interpersonal relationships form. Nevertheless, an individual's first impression on others may well affect their own self-esteem and quality of life (Macgregor, 1979).

The facial deformity may be a 'social disability', as its impact is not only on the individual affected, but is noticed by and reacted to by others (Macgregor, 1979). Attractive children tend to be perceived more positively by their parents (Langlois *et al*, 1995), by teachers who perceive more attractive children as being more smarter and intelligent and more likely to succeed (Clifford & Walster, 1973) and, in professional life, attractive men and women tend to have higher paying and more prestigious jobs where less attractive adults are perceived as having fewer qualifications and less potential for employment success (Hosoda *et al*, 2003). School children can be hostile to those with visible differences, with teasing and bullying being everyday occurrences. The frequency of teasing directed at those with dentofacial differences is significant. Thus, there should be no question that it is advantageous in our society for individuals to make every effort to optimize their appearance (Goldstein, 1993).

The psychological distress caused by a facial deformity is not proportional to its severity. Research seems to indicate that facial deformities of a mild to moderate nature actually cause patients greater psychological distress than severe facial deformities (Macgregor, 1970). This is thought to be

because other people's reactions towards milder deformities are more unpredictable, whereas more severe deformities tend to evoke more consistent reactions, though negative, allowing the patient to develop better coping strategies. The variability in people's reactions to milder facial deformities also results in considerable patient distress.

One would conceptualize the facial appearance based on others facial appearance (Langlois *et al*, 2000). For example, individuals with significant Class II malocclusions and mandibular retrognathia/retrogenia may be seen as weak and possibly idle, whereas individuals with significant Class III malocclusions and mandibular prognathism may be seen as aggressive personality types. It is important to note that the majority of patients seeking orthodontic treatment or orthognathic surgery fit into the mild/moderate category in terms of facial deformity, as opposed to craniofacial malformation syndromes or severe facial trauma/ disease (Naini *et al*, 2006).

Dentofacial Analysis

The clinician's first goal is to determine the patient's perception of the dentofacial appearance, motivation for seeking treatment, practicality of the expectations from treatment and likely level of co-operation, as well as the support of the family. The clinician has to assess whether a dentofacial deformity exists and, if so, whether the patient's perception of the deformity ties in with the clinician's assessment, which is based on patient's presenting complaint. But will need several sittings as patients may find it difficult to convey their concerns for seeking advice or treatment.

If a patient has excessive concerns regarding a minor or imperceptible dentofacial deformity, has seen a number of other clinicians and treatment has been refused, or if the concerns are vague, it is advisable to get an opinion from a clinical psychologist, as these may suggest evidence of a psychiatric disorder, such as Body Dysmorphic Disorder. Patients who have 'external' motivation involving, for example, the need to please others or have a more successful career, are less likely to be happy with treatment than patients who have 'internal' motivation, which is that they want to look better for themselves (Proffit *et al*, 2003). It is important for patients to have realistic expectations, as the yearning to look like their favourite film star is often neither realistic nor achievable! Every face has disproportions and asymmetries, as does every smile and its associated dentition. Therefore, an educated eye of a clinician is required in clinical assessment to arrive 'at the correct diagnosis. A number of important soft tissue landmarks are used in the assessment of facial aesthetics (Figure 7). The patient must be examined for facial proportions and symmetry in full face and in profile view.

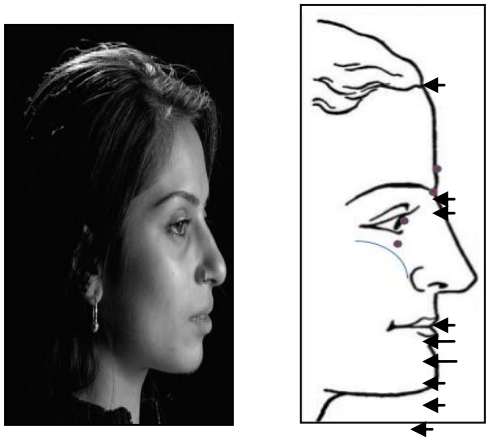


Figure 7. Facial soft tissue landmarks in the mid sagittal plane (profile view) from top to bottom; Trichion (hairline); Glabella; Soft tissue nasion; Subnasale; Labrale superioris; Labrale inferioris; Labiomental fold; Soft tissue pogonion; Soft tissue menton

Frontal facial analysis gives us the facial type that is the facial height to width ratio (Facial index) and the proportionate facial height to width ratio is 1.35:1 for males and 1.3:1 for females (Figure 8a). The knowledge of vertical proportions (Figure 8b) is important in planning dentofacial surgery.

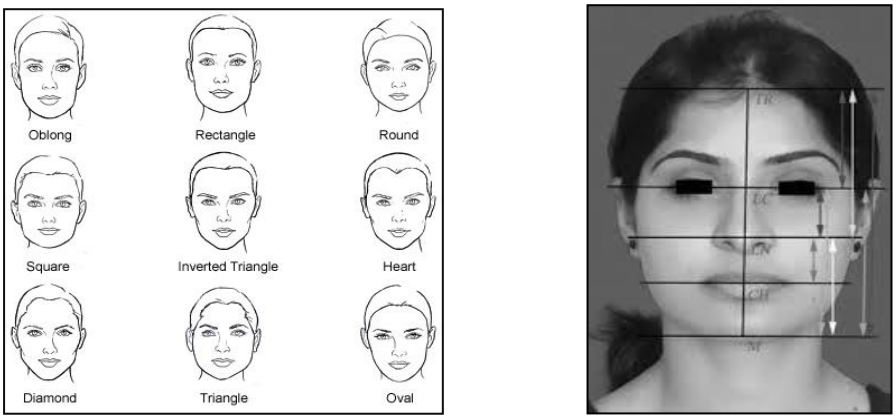


Figure 8 (a & b). Vertical facial proportions. The facial trisection and anterior lower facial third proportions are shown. The anterior lower facial height is often slightly greater than the middle third, especially in males. Facial index gives the overall facial type, such as 'long' or 'short' or 'square' face.

An increased anterior lower facial height may be due to vertical maxillary excess (VME), resulting from excessive inferior development of the maxilla (Figure 9). This is mostly accompanied by excessive gingival display at rest and on smiling, referred to as 'gummy smile'. The treatment would be based on superior repositioning of the maxilla. In certain cases, anterior VME may be due to excessively over-erupted maxillary incisors, which will need either an anterior segmental impaction of the maxilla, or orthodontic intrusion of the maxillary incisors and associated gingivae. A 'gummy smile' may also be due to excessive gingival tissue, in which case a gingivectomy to remove excess gingival tissue, and thereby move the gingival margin apically, would be the treatment of choice. The treatment for increased vertical chin length (Figure 10) will centre on vertical reduction genioplasty.

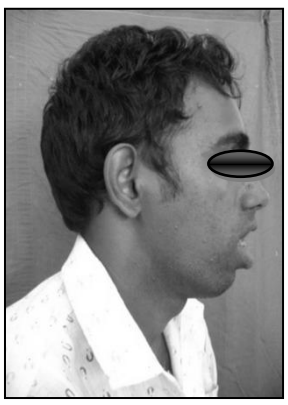


Figure 9. Vertical maxillary excess (VME) causes increased gingival show 'gummy smile'.

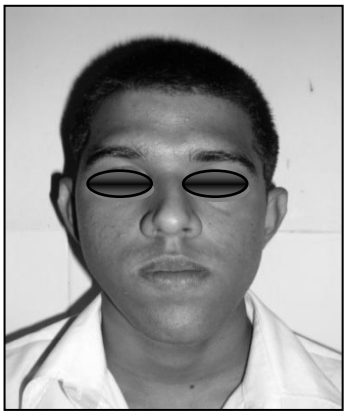


Figure 10. Increased vertical chin height leading to an increase in the anterior lower facial height.

The 'rule of fifths' describes the ideal transverse proportions of the face to comprise equal fifths, each roughly equal to one eye width (Figure 11). This is important clinically as anterior repositioning of the maxilla tends to increase the alar base width.

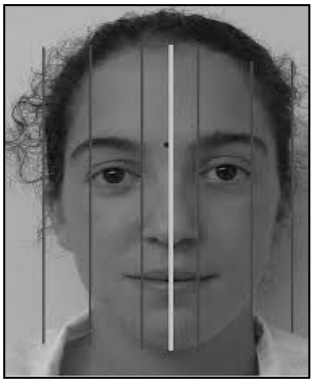


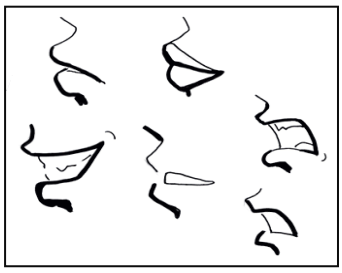
Figure 11. Transverse facial proportions. The 'rule of fifths' states that transverse facial dimensions can be divided into equal fifths, each the width of an eye. The nasal alar base width should be equal to the intercanthal distance. Also of note, the mouth width is equal to the distance between the medial iris margins.

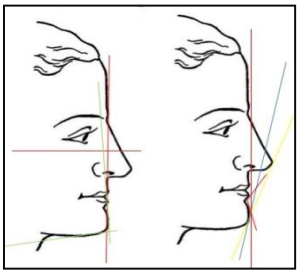
The face must be examined for symmetry, bearing in mind that a small degree of asymmetry is present in most individuals and essentially normal (Figure 12).

Figure 12. Facial asymmetry (a) following correction (b)

One also has to assess the position of dental midline to their respective jaws and to the facial midline and the transverse angulation of the maxillary incisors, as increased transverse angulation in frontal view reduces dentofacial aesthetics. In addition assessment of the lips in regard to its lines, activity, morphology and posture is essential.

Upper lip to maxillary incisor relationship depends on a number of factors; upper lip length; 'smile curtain', defined as the muscular capacity to raise the upper lip; vertical position of the anterior maxilla and incisor teeth; anteroposterior position of the anterior maxilla and incisor teeth; inclination of the maxillary incisor teeth; maxillary incisor crown length; vertical level of the gingival margins on the labial surface of the maxillary incisor crowns.





The 'buccal corridor' or 'negative space' is the space created between the buccal surface of the posterior teeth and the commissures of the lips when a patient smiles. The presence of dark buccal corridors may be due to transverse narrowing of the maxilla, especially in the premolar region and expansion of the maxillary arch is required in order to fill the corners of the smile; palatal angulation of the maxillary posterior dentition, which can be rectified by increased palatal root torque and/or expansion of the posterior maxillary dentition, primarily the premolar region or by increasing the thickness of the buccal aspect of ceramic restorations on the premolar teeth; retro-positioned maxilla, which will need maxillary advancement (Figure 13).

Figure 13. 'Buccal corridor' or 'negative space'

Facial profile analysis would indicate the underlying skeletal pattern. Facial profile convexity is an indication of an underlying Class II skeletal pattern either due to maxillary prognathism, or more likely due to mandibular retrognathism. Facial profile concavity is an indication of an underlying Class III skeletal pattern either due to maxillary retrognathism or mandibular prognathism, or both (Figure 14). The paranasal hollowing (Figure 15) is a sign of midface deficiency, as are a flattened upper lip and an obtuse nasolabial angle. Increased sclera show above the lower eyelid, is also a sign of midface deficiency.

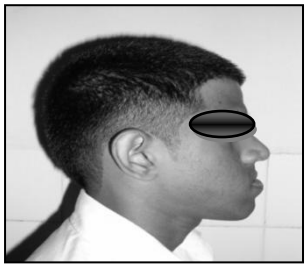


Figure 14. The facial profile may be: (a) concave (Class III skeletal pattern, due to a prognathic mandible, retrognathic maxilla, or both) (b) convex (Class II skeletal pattern, due to a retrognathic mandible, prognathic maxilla, or both).

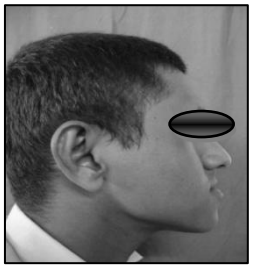


Figure 15. Paranasal hollowing is a sign of anteroposterior maxillary deficiency

The clinical examination is supported by lateral and posteroanterior cephalometric radiographs with in-depth analyses to assess the soft tissues and underlying hard tissue relationships further (Fig 16). Three dimensional imaging may also be used to assess more complicated cases, including severe asymmetries and craniofacial deformity.

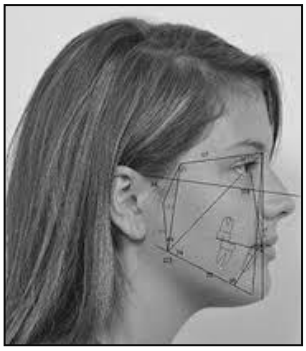
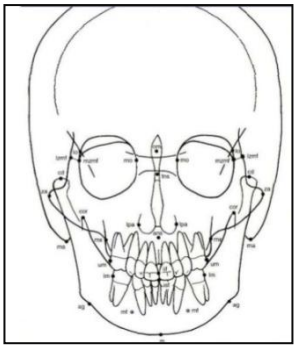



Figure 16. Cephalometric radiographs

Conclusion

The assessment of dentofacial aesthetics is an art and science and must act in unison. It is very important to assess the patient's expectation followed by detailed clinical assessment to arrive at

the overall clinical judgement regarding both the suitability for treatment and the type of treatment required. The clinician must be able to discuss every treatment option with the patient, both in terms of its effects on dental aesthetics and its potential effect on facial aesthetics, be it positive or negative.

The multidimensional nature of beauty creates a significant challenge for facial surgeons to provide patients with a satisfactory perception of attained personal beauty; as such facial surgeons must rely not only on technical skills, but also on the complementary integration of artistry to achieve symmetry, harmony, balance, and proportion. When planning facial surgery, the goals of the patient are of paramount importance. Although it is important to understand the ways in which people of different ethnicities and ages differ in their facial proportions as a group, facial harmony must be pursued on an individual basis.

"Everything has beauty, but not everyone sees it!"

- Confucius

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Section B

Possibilities of safe Agriculture in Sri Lanka

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The agriculture sector in Sri Lanka has always been a major economic force, making a significant contribution to the national economy, food security and employment. At the same time, agriculture is the livelihood of the majority in the rural areas providing sustenance for more than 70% of the population and by contributing 20% to the Gross Domestic Production (GDP) in 2015 (Sri Lanka Socio Economic Data, 2015). Rapid agricultural productivity growth is fundamental for reducing poverty in Sri Lanka as nearly 90% of the poor depend on rural agricultural economy. In addition, Sri Lanka needs to address the issue of the increasing demand for food. The Nutrition Country Profile for Sri Lanka indicates that approximately 25% of people in Sri Lanka are undernourished. Therefore, steps should be taken to increase the crop production in the country by paying attention to non-availability of good quality seeds/planting material, declining soil fertility, soil degradation, high incidence of pests and diseases and water shortage, high costs of inputs such as seeds, fertilizers, pesticides, labour, insufficient value addition/processing and difficulty of marketing at reasonable prices. Further, ineffective research and extension, lack of planned crop production, insufficient attention to under-utilized crop varieties such as kurakkan, green gram, pigeon pea etc., which have a potential in the local/overseas markets, ineffective utilization of agricultural by-products, have also contributed to the deterioration of the agriculture sector. A concerted effort is therefore necessary by all stakeholders to make the agriculture sector achieve sustainable development.

The use of agrochemicals in Sri Lanka began in the early 1950s, and since then the amounts used have shown a steady increase, by almost 110 fold between 1970 and 1995 (Wilson, 1998). Agrochemicals have become vitally important in modern agriculture in most countries in order to attain sustainable crop and animal production. At present, most countries in the world rely on increased crop yields, with agrochemicals, the so-called 'green revolution', to access affordable food. As an agriculture based country, Sri Lanka has not been able to avoid the use of agrochemicals. Although the use of these products is unavoidable, sustainability of the practices associated with the use of agrochemicals and fertilizers is questionable. Most of these products are derived from the petrochemical industry, which is currently in crisis. Inefficient use of these substances in agriculture leads to pollution of ground water and then water bodies, expansion of dead zones in coastal waters caused by eutrophication, and some by-products eventually entering the atmosphere as greenhouse gases. This has given rise to health impacts in different parts of the world, which are also of great concern. Several important issues are highlighted by the different sectors related to agriculture, on the many problems created by the use of agrochemicals in Sri Lanka. These include negative externality and deleterious effects on the environment as well as to human health. CKDu is one of the major health impacts with unknown etiology. However, though there is no direct evidence, debates highlight the misuse or over usage of agrochemicals as the factor for development of CKDu. Additionally, a considerable number of pesticide related accidents occur each year in Sri Lanka

resulting in asthma, eye, skin, and respiratory infections. Therefore, the possibility of modernizing or altering the existing agriculture framework to address these health and social issues needs to be considered. In this context, I would like to address the possibility of using safe agricultural practices in Sri Lanka, mainly by avoiding or minimizing agrochemical use.

The way towards modern agriculture from traditional agriculture in Sri Lanka

Chena cultivation, also known as shifting cultivation, is the most primitive type of agriculture known to man since the dawn of civilization. Indigenous agriculture can be divided into two sectors as Chena and paddy cultivation (Bulumulla, 1998). In the ancient period, people gave more priority to Chena cultivation than to paddy farming (Bandara, 2005).

Chena cultivation, which is mainly done in the *Maha* season, was sufficient to meet the livelihood requirements of the ancient people of Sri Lanka. Ancient Chena cultivation had many empirical attributes that were environmentally friendly; such as, the people living there shifting from place to place, crop rotation, use of only existing soil fertilizer, no addition of agrochemicals, use of primary methods of cultivation which do not use water supply methods. In general, products generated from Chena cultivation were used mainly to supplement the food requirements of their families. This concept of the Chena was disturbed due to several factors. Increased demand in the local market for Chena products, lack of family labour to carry out Chena cultivation as a traditional system, availability of machinery, government policy decision to allow the fertilizer subsidy and to buy the Chena products at a high price in the market were some of these factors.

This conversion made the Chena farmers cultivate several crops especially for the market, as well as to meet their family requirements. In the past five decades, Chena farmers had tried to change the Chena cultivation to become a profitable enterprise given the market oriented economy. To meet these objectives, the farmers paid more attention to the use of new technical methodology to increase the yield of the Chena. As a result, the present Chena cultivation in Sri Lanka is vastly different to the traditional Chena cultivation.

Most farmers use machines to cut the forest. Tractors are used for land preparation. Imported seeds and chemical fertilizers are also used. After preparation of the land, only one or two crops such as maize and ground nuts are cultivated as commercial crops. In addition, paddy is also cultivated in the Chena.

This conversion benefited the farmers as well as the environment in several ways. The farmer gained a higher income from the one or two crops cultivated and farmers did not have to shift from their Chena plot annually. However, at the same time, there were adverse effects on the environment, such as reduction in natural soil fertility because over 95% of Chena farmers cultivated the same Chena plot year after year without allowing for a fallow period. In addition, water bodies and soil were polluted due to the use of chemical fertilizers, herbicides, and insecticides. Above all, these agrochemicals badly affected the beneficial fauna in the environment, changing the natural biodiversity.

These changes were motivated and improved by the 'Green Revolution' which was started in Mexico in the mid 1940's where emphasis shifted from crop nutrition to crop breeding – the synthesis of high yielding, short- statured, fertilizer- responsive cereals, without which the world food demand could not have been met today. In Sri Lanka too rice breeding and other research took great strides, increasing yields by over seven fold and production by fourteen fold from the 1940s to date. In addition, the increase in land extent under rice, especially from the Mahaweli project also contributed to production and eventual attainment of self-sufficiency (Table 1).

Table 1: Population and rice statistics of Sri Lanka

Year	Population (millions)	Production (million MT)	Yield (Kg/ha)	Rice Imports (% Requirement)
1940	6	0.3	0.6	60
1960	11	1.1	2.1	40
1980	17	2.4	3.3	25
2000	20	3.4	4.2	<0.1
2010	20	4.3	4.3	Nil

Source: Department of Agriculture, 2013; Department of Census and Statistics 1940-2010

Current Situation of Agrochemical use in Sri Lanka

After the green revolution, agrochemicals and other advanced inputs as well as motorized farm machinery doubled, sometimes tripled the crop yield, achieving the highest targets expected by countries in terms of food security. However, the high intensity high input techniques have come udner serious scrutiny due to concerns over adverse health issues and environmental pollution.

Agrochemical related issues have become of foremost concern in Sri Lanka, especially among vegetable farmers in the recent past. A survey conducted in the Intermediate and Dry zones in Sri Lanka in 2014 revealed that more than 60% of farmers did not follow instructions given in agrochemical labels when applying the agrochemical in the field (Unpublished data, 2014). Farmers opt to follow improper practices such as over dosage, increased frequency of applications and use of improper protection during field application (Chandrasekera *et al*., 1985). Over dosing and increased frequencies of applications were used to obtain high yields and thereby larger profits.

Excessive reliance on synthetic pesticides has posed threats to the environment and the health of farmers; even leading to death of farmers (Wilson and Tisdell, 2001). Athukorala *et al*., 2010 reported that 4% – 7% of agricultural workers suffer ill-health from pesticides each year in Sri Lanka, Costa Rica and Nicaragua. Lack of labour and the intention to complete the application of the pesticide within the day, has led to the long hours of application by farmers (Bandara and Jayathilaka, 1989; Gnanachandran, 1991). It was revealed that nearly 10% of the farmers applied pesticides for more than eight hours continuously. When considering the health hazards, farmers had mild symptoms of poisoning such as feeling faint, headaches, dizziness, and skin and eye irritations during the application of pesticides. This significantly increased with the duration of application. Farmers believed that it was normal to feel such discomfort during pesticide application (Gnachandran and Sivayoganathan, 1989).

Nonetheless, it is difficult to overcome the fears that farmers have; often these have been encouraged by the pesticide industry. Farmers need to overcome fears such as, insects always cause harm, insect pests will transfer from sprayed to unsprayed fields and farms, and fears of crop loss (Palis, 2006). In some cases, farmers have experienced anxiety about maintaining good social relations, spraying their crops secretly at night.

Importantly, environmental impacts should be given prominence when addressing impacts of agrochemicals. Plants can absorb only limited amounts of these macronutrients from the added chemical or composed fertilizer. With rain, the excess fertilizer in the soil leaches into streams and ends up in distant locations, such as ground water and water bodies including reservoirs. Therefore, the recommendations for fertilizer applications and their use should be based on actual crop-soil requirements. However, such soil testing or information is not readily available in farming areas in most developing countries. Consequently, farmers use fertilizers blindly and excessively, wasting resources and polluting the environment, with the expectation that more is better, which is not the case (Wimalawansa and Wimalawansa, 2014). Is organic agriculture alone sufficient to feed the country?

The world population is estimated to be almost 10 billion by the year 2050. The challenge of sustainable feeding such a multitude of people without destroying the environment is one of the most important current topics under serious discussion. Some experts argue that shifting to organic farming would feed the world as well as protect the environment and human health by restoring the decayed parts of the Earth and environment due to heavy use of agrochemicals. Another group of experts is of the view that organic farming alone would not be sufficient to cater to the increasing food demand of the world. They argue that synthetic agrochemicals, genetically engineered crops or any other unnatural additives could feed the 10 billion people (Norman, 2002). For the third group of experts this is a serious issue that needs to be addressed carefully. Many experts believe that a combination of high technology and organic agriculture could provide a better combination for an effective and sustainable solution (Klaus, 2009).

The group of experts who advocate using organic agriculture (OA) produce only the most defensive facts to justify their claim. However, this group of experts face a challenge on rejecting the existing conventional agricultural (CA) system as this system has been used to cater to hunger in the world. Badgley *et al*., in 2006 conducted an experiment using CA as well as OA in developed as well as in developing areas in the world that resulted in a fairly high yield in developing countries for OA but lower in developed countries with high inputs. Thus, researchers in Sri Lanka may need to study the performance of CA and OA to find the more suitable method for our climate.

In this context to determine the suitability of OA for Sri Lanka global utilization should be taken into account. The total world extent under organic farming remains less than 1%; 0.9% in 2012 of the total farm lands. From the said land extent, two thirds are grasslands, 19% arable crops and 8% horticultural crops. This indicates that though Sri Lanka as a country is interested in organic farming, and the issue has been addressed to some extent with an increase in organic production over the past years, there is still a long way to go in this regard.

Conclusion

In conclusion, one can assume that the existing agricultural practices in Sri Lanka have many adverse health and environmental impacts. Organic agriculture also is not totally free of pollution. Further, even though it can be argued that the global food needs can be supplemented by organic technologies it is evident that far more research input is needed to develop technologies that are both practically feasible and economically viable for different as well as specific farming situations. Until such time, feeding the world through organic farming would be a dream; A dream that can be realized in the future. Until such time the immediate need is to ensure judicious and safe use of agricultural inputs into the existing agriculture system in the country. This requires comprehensive identification of lack of knowledge in the farmer community and educating farmers on the safe use of agrochemicals with regular monitoring of the environment for pollution, for immediate remedial action.

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Section C

An Overview of Steel Bridge Construction in Sri Lanka

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Introduction

The world's first cast iron bridge was built at Coalbrookdale, Telford, UK in 1779 which is still in use today carrying occasional light transport and pedestrians. Until 1840, the construction material used for bridges was either cast iron or wrought iron or a combination of both. Instead of wrought iron, steel makers worldwide produced carbon steel, a much more reliable construction material. The Kymijoke railway bridge, which was built in 1870, was the first 3 span steel truss bridge in Finland.

Although railways and railroad bridges existed before the invention of the steam locomotive, discovery of the ability to harness the pressure of the water was the signal event that made railroads one of the great modern marvels. Since the steam locomotive, many types of railroad trains have been put to use, including those that are electric and gasoline powered. Railroad bridges constitute one of the greatest feats of engineering, joining vast distances over chasms, rough terrain and bodies of water.

Classification of steel bridges

Steel bridges may be classified in many ways according to flexibility of superstructure, as fixed span bridges or movable bridges. In the fixed span superstructure the superstructure remains in a fixed position and most of the bridges are of this category. In movable span bridges, the superstructure is lifted or moved with the help of some suitable arrangement.

Based on inter-span relations, bridges are categorized as simple, continuous or cantilever bridges. In simple supported bridges, the width of the bridge is generally divided into a number of individual spans. For each span, the load carrying member is simply supported at both ends. Plate girders and truss girders are used for this type of bridge. They are suitable at places where uneven settlements of foundations are likely to take place.

In continuous bridges, spans are continuous over two or more supports. They are statically indeterminate structures. They are useful when uneven settlement of supports does not take place. In continuous bridges, the bending moment anywhere in the span is considerably less than that in simple supported span bridges. Such reduction of bending moment ultimately results in economic saving on the bridge. In continuous bridges, the stress is reduced due to negative moments developed at the pier from supports. Thus, construction of continuous span bridges is a considerable saving compared to construction of simply supported bridges.

A cantilever bridge is formed where cantilevers project from supporting piers. The ends of a cantilever bridge are treated as fixed. A cantilever bridge combines the advantages of a simply supported span and a continuous span. For long spans and deep valleys and at places where it will not be practicable to use centering, cantilever bridges are more suitable. They are suitable in the case of an uneven foundation. The construction of a cantilever bridge may either be of simple type or of balanced type. In the case of a cantilever bridge with a balanced type of construction, hinges

are provided at the points of contra flexure of a continuous span and an intermediate simply supported span is suspended between the two hinges.

According to the position of the bridge floor relative to the formation level and the highest flood discharge, bridges are categorized as deck bridges, through bridges or semi through bridges.

Deck bridges

Deck-type bridges refer to those in which the road deck is carried on the top flange or on top of the supporting girders. The deck slab or sleeper may cantilever out to some extent beyond the extreme longitudinal girder.

Through bridges

In the through type bridges, the decking is supported by the bottom flange of the main supporting girders provided on either side.

Semi through bridges

The semi-through bridge has its deck midway and the deck load is transmitted to the girder through the web of the girder. In this also, the main girders are on either side of the deck.

Advantages of steel bridges

- High Strength-to-Weight Ratio

The high strength-to-weight ratio of steel minimizes substructure costs, which is particularly beneficial in poor ground conditions. Minimum self-weight is also an important factor in transporting and handling components. In addition, very shallow construction depths are possible with low self-weight. This overcomes problems of headroom and flood clearance, and minimizes the length of approach ramps.

- High Quality Material

Steel is a high quality material, which is readily available worldwide in various certified grades, shapes and sizes. The testing regime carried out at the steel mills should give confidence to all clients and engineers who specify steel for their projects. Prefabrication in controlled shop conditions leads to high quality work at minimum cost. The quality control extends from the material itself and follows on through the processes of cutting, drilling, welding, fit up and painting.

- Speed of Construction

The prefabrication of components means that construction time on site in hostile environments is minimized. The speed of steel bridge construction reduces the duration of rail possessions and road closures, which minimizes disruption to the public using those networks. The nature of steel permits the erection of large components, and in special circumstances complete bridges may be installed overnight.

- Versatility

Steel suits a range of construction methods and sequences. Installation may be by cranes, slide-in techniques or transporters. Steel gives the contractor flexibility in terms of erection sequence and the programme. Components can be sized to suit access restrictions at the site, and once erected the steel girders provide a platform for subsequent operations.

- Modification & Repair

Steel bridges are adaptable and can be readily altered for a change in use. They can be widened to accommodate extra lanes of traffic, and strengthened to carry heavier traffic loads. Steel bridges can be readily repaired after accidental damage. Damaged sections may be cut out and new sections welded in, or alternatively, girders can be repaired by heat treatment to straighten damaged beams, a technique pioneered in the US.

- Durability

Steel bridges now have a proven life span extending to well over 100 years. It has a predictable life span, as the structural elements are visible and accessible. Any signs of deterioration are readily apparent, without the need for extensive investigations. Corrosion is a surface effect, which rarely compromises the structural integrity of a bridge, and any problems may be swiftly addressed by repainting the affected areas. Modern steel bridges do not require frequent repainting. Corrosion protection systems have developed to give a life of 20 – 30 years, and the latest paint systems are expected to offer 40 year lives in the near future.

- Aesthetics

Steel has broad architectural possibilities. Steel bridges can be made to look light or heavy, and can be sculptured to any shape or form. The high surface quality of steel creates clean sharp lines and allows attention to detail. Modern fabrication methods have removed restrictions on curvature in both plan and elevation. The painting of steelwork introduces colour and contrast, and repainting can change or refresh the appearance of the bridge to appear as new.

History of development of steel railway bridges in Sri Lanka

In Sri Lanka, railway bridges which span less than 3 metres are considered as culverts. At the very beginning, the rolled I sections were not available for construction work of bridges. Hence, Rolled Steel Joists (RSJ) were used to construct culverts and bridges. The maximum available depth of these joists was 16". RSJs have been used in railway bridges of spans from 6.0– 7.6 metres. When the span is more than 7.6 metres and up to 18.25 metres built up plate girders were used. In this period girders have not been produced. Hence, built up girders have been used to construct the main girders and other components. For these spans, the depth of the girder used was around 1.624 – 2.133 metres. In plate girder bridges, when the girder depth is more, local buckling of the plate might occur. For a deck type bridge, when the depth of the plate girder is more, it may disturb navigation under the bridge. It also disturbs the water flow at flood levels. Deck type bridges are more suitable when approaches are at higher altitude than the average flow level of the river or stream. The other factor that needs to be considered in selecting different types of structures for bridges is the wind force. Most bridges in the up-country area are deck type bridges. To overcome the effect of the wind force "semi through" type or "half through" type bridges are employed.

Semi through type bridges are designed mainly to increase the space between the bottom frame and flood level of the river and to make the river navigable. Both truss and plate girder bridges are considered as semi through type bridges. When the span is more than 20metres, the use of plate girders become uneconomical. Therefore, when the span is more than 20 metres suspended type bridges or truss girders have to be used.

Section D

Exploring marine biodiversity values through genomic approaches

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Life originated in the oceans and has been estimated to be evolving for 2.8 billion years. Therefore, biological diversity is much greater in the oceans than on land. Nearly three quarters of the planet is covered by oceans. Oceans contain 95% of the world's biomass and they contribute to the functioning of the planet, yielding 60% of the total economic value of the biosphere (Volckaert *et al.*, 2008).

The ocean harbors a number of ecological niches and has proven to be home to more microorganisms than any other environment. It is not surprising that marine ecosystems harbor much higher biological and chemical diversity. Biological diversity in oceans encompasses a scale of variation from genes to ecosystems. To understand the biological diversity of the marine ecosystem, it is important to analyse its types of habitats ranging from highly productive coastal regions to lightless, high-pressure, and low-temperature deep-sea environments. The benthic (bottom-living) species that reside within the sediments in these habitats form one of the richest species pools in the oceans and on Earth. The environment is further diverse with the moving and sedentary life forms and their adaptations for successful lives in diverse habitats.

The diverse nature of marine life

The biological diversity differs according to the vertical and horizontal zonation in the marine environment (Figure 1).

Vertically, or in depth, the marine biomes are subdivided into two main zones:

Photic Environment: Also known as Epipelagic environment: It extends from the surface of the sea to approximately 100 metres depth.

Aphotic Environment: It is determined by the amount of penetration of light. In natural conditions the darkness is absolute. It is subdivided into three environments:

1. Mesopelagic Environment**:** This ambient includes the water volume between 200 metres to 1000 metres depth. The upper limit is determined by the edge of the continental shelf, on condition that the edge of the continental shelf is immersed into a depth where the light cannot penetrate.

2. Bathypelagic Environment: It is situated between the plane at 1000 metres and the plane at 4000 metres in depth.

3. Abyssal pelagic Environment**:** It extends from 4000 metres down to the marine floor, including the bottom of the marine trenches.

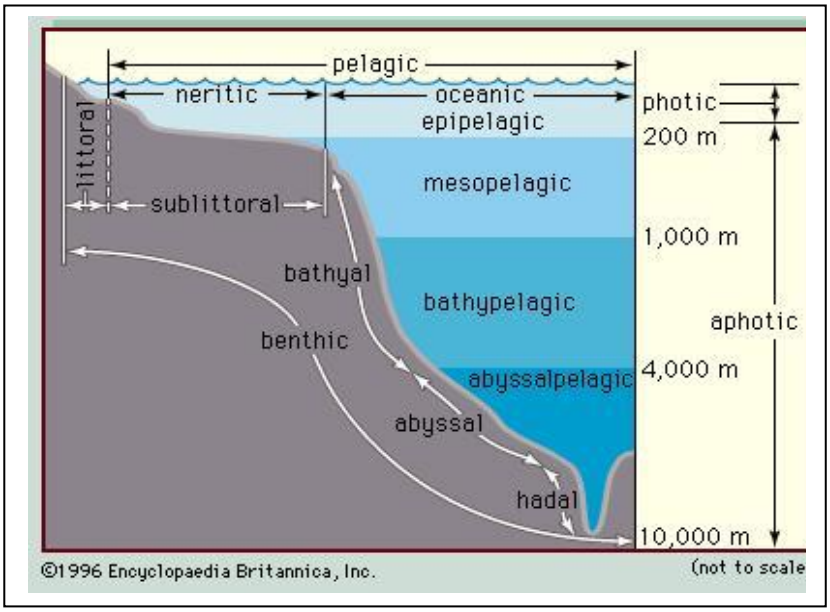

Figure 1: Zonation of the marine environment

Zonation of sea bottom has been classified as follows:

1**. Benthic Littoral Zone**: Like the littoral environment corresponding to the surface, the littoral benthonic zone extends from the line of the high tide to the line of the low tide.
2. Benthic Sublittoral Zone or Shelf: It extends from the line of the low tide to the edge of the continental shelf. It corresponds to the neritic biome of the pelagic zone.
3. Benthic Bathyal Zone: It extends from the limit of the continental shelf and descends in declivity to 4000 metres depth.
4. Benthic Abyssal Zone: It is the marine continuation of the marine bottom from 4000 metres in depth to the bottom of the depressions or trenches.
5. Benthic Hadal Zone: It extends from the edge to the floor of marine trenches.
Vertical zonation occurs due to the amount of light penetration through the marine water column. There are two main zones:

1. The Littoral Zone - It may also be referred to as the coastal zone or intertidal zone.

The littoral zone includes the area between high tide and low tide. During high tide, this zone is covered in ocean water for many hours. It is then exposed to the air for many hours during low tide. The organisms that live in the littoral zone have adapted to both extremes. The littoral zone encompasses a wide variety of habitats, including tide pools, beaches, and inlets.

2. The Pelagic Zone - This includes any area from the low tide mark into the open ocean. In other words, it is the area that remains covered in water. The pelagic zone is divided into two subzones: the neretic zone and the oceanic zone. The neretic zone lies over the continental shelf, is penetrated by sunlight, and only reaches a depth of about 600 feet where coral reefs and other costal habitats can be seen.

Biodiversity in the marine environment

Living organisms could be found in all vertical and horizontal biomes of the oceans; in warm, cold, and even in frozen waters. Living beings can also be found in abyssal and hadal zones. There are animals living on the sea floor (epifauna) and others living within the sea floor (infauna) in all the zones of the oceanic floor (benthonic fauna). Two percent of the marine species that live in the open sea are in the pelagic zone, 98% of the marine living beings inhabit the benthonic environment and 1% live in depths of more than 2000 metres (Titilade and Olalekan, 2015). The recently completed Census of Marine Life estimates that there are approximately 240,000 marine species known to science, while current estimates of the total number of living marine eukaryotic species range from 0.7 to 2.2 million, indicating that at least 70% of marine eukaryotic species are yet to be described (Heip and McDonough, 2012). Except the above eukaryotic species, millions of different types of planktonic and microbes such as bacteria, archaea, viruses, fungi and protists, including microalgae, comprise up to 90% of the living biomass in the oceans (Glöckner *et al.,* 2012).

The importance of marine biodiversity

The biodiversity of the marine environment has important direct and indirect values. Marine organisms, including both microorganisms and higher taxa, provide beneficial goods and services which include food and genetic resources, primary production, oxygen production, nutrient cycling, climate regulation, waste treatment and a range of cultural benefits (aesthetic, educational, recreational), all of which are very difficult to quantify, either in monetary or non-monetary terms. The marine environment acts as a reservoir for dissolved carbon dioxide, helping to maintain a constant atmospheric carbon dioxide concentration. A significant amount of photosynthetic activities are carried out by marine organisms.

Genomic approaches to explore marine biodiversity

Genomics is a scientific discipline that studies the structure, function and diversity of genes and gene products in the genome of a species with the aim of understanding the relationship between an organism and its biotic and abiotic environment. Marine genomics is the application of genomic sciences which attempts to understand the structure and function of marine organisms and thereby, explore the biodiversity values of the marine environment (Huete-Pérez and Fernando, 2013). Unlike other methods, genomic approaches could be used to analyses different biological levels of the environment:

(1) At the level of DNA (genomics)
(2) At the level of gene expression (transcriptomics)
(3) At the level of protein (proteomics)
(4) At the metabolic level

(1) At the level of DNA (genomics)

Model organisms

Genomic approaches have been used to reveal the full genome of marine organisms which could be used as 'model organisms'. Some marine forms in which the whole genome has been revealed are purple sea urchin (*Strongylocentrotus purpuratus*), diatom (*Thalassiosira pseudonana*), the surf clam (*Spisula solidissima*), the sea squirts (*Ciona intestinalis* and *Ciona savignyi*), the tunicate (*Oikopleuradioica*), the little skate (*Leucoraja erinacea*), and the mollusk parasite (*Perkinsus marinus*) (Johnson and Browman, 2007).

Salmon (*Salmo salar*) is one of the most extensively studied fish as a model organism. Since 2010, the organization, Genomic data produced by the International Collaboration to Sequence the Atlantic Salmon Genome (ICSASG) serves as a reference sequence to study other relevant fish species (salmon, whitefish, trout and char). These reference genomes could be used to identify genome wide molecular markers that could be applied in various studies including distinguishing and monitoring various geographic populations (Davidson *et al.,* 2010).

Species identification

Species identification is the critical starting point of any approach in marine biology. The DNA molecule makes it an extremely useful tool for identification of organisms because conventional identification approaches based on phenotypic characters have limited efficiency, such as cryptic species, inherently difficult taxonomic groups, or taxonomically ambiguous eggs and larvae (Huete-Pérez and Fernando, 2013).

Species identification through different molecular markers has been carried out for a vast diversity of marine species including marine microorganism, phyto planktons, algae, sea grass, mangroves, invertebrates, lower chordates, fishes, reptiles and mammals (Trivedi *et al.,* 2015 and references therein). DNA barcoding provides a standardized tool for describing and monitoring species diversity of marine resources at different levels. The Marine Barcode of Life (MarBOL), is an international campaign established for barcoding of marine species.

DNA barcoding is a very effective tool in assessment of cryptic species and the threat of invasive species to marine biodiversity. The technique generates more rigorous and extensive data on recruitment, ecology and geographic ranges of fisheries resources and improves the knowledge of nursery areas and spawning grounds of economically and ecologically important species. DNA barcoding of deep sea organisms has gained global attention due to extraordinary pharmaceutical properties that deep sea organisms possess. Census of the Diversity of Abyssal Marine Life (CeDAMar) is devoted to the barcoding of deep sea organisms (Trivedi *et al*., 2015).

(2) At the level of gene expression (transcriptomics)

This involves sequencing mRNA (Messenger Ribonucleic acid) isolated from the organism and synthesizing cDNA (Complementary Deoxyribonucleic acid). The cDNA can then be sequenced to indicate how the transcription profile of species differs and respond to the environmental changes. The development of bioinformatics resources (DNA or cDNA sequences) and molecular tools enable the gene expression analyses that help in identifying functionally important genes, genes under selection, recent gene family expansions and contractions, or other significant changes like horizontal gene transfer in marine organisms.

Transcriptome analysis has been conducted for Atlantic herring (*Clupea harengus*) an abundant fish found in the pelagic zone of marine waters in temperate areas, and greatly helped in understanding the temperature and salinity tolerance capacities and in genetic differentiation between geographically distant and morphologically distinct forms (Huete-Pérez and Fernando 2013). Transcriptomic approaches are especially useful in the future for investigating the effect of temperature and water acidification (or pH) on the development of different fish species according to global climate change (Keeling *et al.*, 2014).

The Marine Microbial Eukaryotic Transcriptome Sequencing Project, or MMETSP, initiated and provided over 650 assembled functionally annotated, transcriptomes that come from more abundant and ecologically significant microbial eukaryotes in the oceans and are publicly available (Keeling *et al*., 2014).

(3) At the level of protein (proteomics)

Proteomics include the determination of protein expression levels and protein-protein interaction studies. These studies help in the determination of post translational modifications of proteins as well as the organization of proteins in multiprotein complexes and their localization in tissues. With the recent advanced technological applications such as Mass Spectrometry and Nuclear Magnetic Resonance (NMR), proteomic analyses gives a better understanding of organic molecules present in tissues (Minor *et al.*, 2003, Aluwihare *et al*., 2005).

Proteomic studies help to understand which proteins are expressed in the cell, released into the environment, and passed between trophic levels (Nunn and Timperman, 2007). Marine microbial organisms have been identified as the blueprints for diverse suites of organic and inorganic nitrogen and carbon transporters in the marine ecosystem. Through proteomic studies, the extent to which various pathways are utilized, which environmental triggers act on the system, and relative protein-level response to it can be clarified (Palenik *et al.*, 2003, Armbrust *et al.*, 2004).

(4) At the metabolic level

Metabolomics is the study of variations in the abundance of proteins and their subsequent post-translational modifications in a living biological systems. Metabolomic applications show great potential for identifying physiological responses of marine species to their changing biotic and abiotic environments and the first to respond to anthropogenic stressors (e.g. pollutant exposure) and natural daily events (e.g. feeding) (Viant, 2007). The study of all the metabolites present within cells, tissues and organs, as well as at the population level, has become an essential tool for cataloguing bioactive compounds. Both nuclear magnetic resonance (NMR) and mass spectrometry (MS)-based or a combination of the two are increasingly more widely used to perform high throughput profiling of metabolites and to investigate interactions of marine organisms with their environment (Huete-Pérez and Fernando, 2013).

Metabolomics have been used to study biological, chemical and temperature stress of Chinook salmon (*Oncorhynchus tshawytscha*) (Viant *et al*., 2003). This approach was also used as a tool to investigate the production of antibiotics and other secondary metabolites in the obligate marine actinobacterial species (*Salinispora arenicola*), isolated from Great Barrier Reef (GBR) sponges (Bose *et al.,* 2015).

Now there are publicly accessible databases that provide comprehensive information of metabolomic compounds. The Seaweed Metabolite Database (SWMD) is one such which is designed to provide information about known compounds and their biological activity described in the literature. Geographical origin of seaweed, extraction methods and the chemical descriptors of each of the compound are recorded to enable effective chemo-informatics analysis (Davis and Vasanthi, 2011).

'Meta' approaches for exploring marine biodiversity values

The techniques 'metagenomics', metatranscriptomics and 'metaproteomics' provide a unique opportunity to gain an insight into the diversity and ecology of marine natural communities especially microbial communities. Oceanic microorganisms have to face extreme environmental conditions such as low temperature, high salinity, and extreme pressures and they have evolved special metabolites to survive during evolution. Experiments are mainly focused on gene clusters or genes encoding enzymes and on the discovery of biocatalysts for synthesis and production of secondary metabolites like bioactive compounds in microbes (Wong, 2010). Three categories of environments are often considered: (1) highly diverse environments (e.g., seawater), (2) naturally enriched environments for the target gene/biocatalyst, or (3) extreme environments. The 'meta' approach is very effective in the discovery of novel extremozymes, isolated from extreme marine environments and some examples are given in Tables 1 and 2.

Genomics approaches used to explore marine resources in Sri Lanka

Sri Lanka, an island in the Indian Ocean is a biodiversity hotspot in the world. Sri Lanka possesses a territorial sea of 21, 500 km^2 and an Exclusive Economic Zone (EEZ) of 517, 000 km^2. The EEZ is more than seven times larger than the geological extent of the country. The marine environment is blessed with a rich biological diversity including plants, animals and microbes and some of these may be extremely rich in products or potential products to be developed as drugs or for other applications. Only a few studies have been reported on application of biotechnology for exploring marine resources. Most reported studies are based on genomic research for analyses of population structure of marine fishes (Senevirathna *et al*., 2016; Munasinghe, 2015; De Silva and Munasinghe, 2016; Nanayakkara *et al.*, 2014, Croos and Palsson, 2010; Dhammannagoda *et al.*, 2008) and a few others have been reported on proteomic approaches (Wanasinghe *et al*., 2015 a;b). Knowledge gaps still exist on marine biodiversity values. Thus, it is extremely important to enhance research activities and investigations to fulfil the gaps. With the development of novel technologies, it is now high time to utilize molecular tools to explore marine biodiversity values for the betterment of society as well as to protect and conserve the biodiversity values in nature.

Table 1 Extremozymes through metagenomic approach

Enzymes	Source
Esterase	Seashore sediments
Lipase	Deep-sea
Esterase	Inter tidal zone
Alkaline Phospholipase	Tidal flat sediments
Glycoside Hydrolase	Baltic sea
Phospholipase	Hot spring
Esterase	Deep-sea
Glycoside Hydrolases	Hydrothermal field Hydrothermal vent
Fumarase	Marine water
β-glucosidase	Hydrothermal spring
Laccase	Marine water
Esterase (salt tolerant)	Tidal flat sediment
Esterase	Red sea brine pool
Mercuric	Red sea brine pool

(Source Barone *et al.*, 2014)

Table 2| Natural products discovered through metagenomic approach

Compound	Source
Onnamide A	*Theonella winhoei*, bacterial symbiont
Bryostatin	*Bugula neritina*, bacterial symbiont
Minimide	*Didemnum molle*, microbiome
Apratoxin A	*Lyngbya bouillonii*
Patellamides	*Lissoclinum patella*
Zn-coproporphyrin III	*Discodermia calyx*

(Source Barone *et al.,* 2014)

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Section E1

Conceptual burden for Mathematics to be interdisciplinary

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Anything we learn or engage in is accomplished by conceptual, theoretical and practical motivations. A conceptual aspect caters to fundamental, but sound ideas along with an abstraction of experience as well. In that sense, Mathematics is renowned since abstraction sometimes continues to occur even without real world experience. However, that characteristic at the extreme limits may restrict the opportunities in collaborative involvement in learning, teaching and research with other disciplines. Thus, it limits interdisciplinary engagement. What is this conceptual burden? is the question to be discussed here. It is important to see how to overcome it too.

Pure Maths and Applied Maths

In the book 'Philosophy of Mind', a question raised right at the beginning is very interesting. That is "*Does a tree falling in the forest make a sound when no one is around to hear it*?" [1]. It was given that the answer depends on the way we define "sound", physical sound or experienced sound. The physical sound relates with waves and detecting them by an instrument. However, the experienced sound wants the presence of someone to receive the sound. One can say the same for "Mathematics" mimicking "sound". Physical sound seems to be aligned with Pure Mathematics, which caters to the abstract aspect of Mathematics, while experienced sound tallies with Applied Mathematics. Now the question, is it possible to develop Mathematics without applications?

History has been biased towards the answer as "No" to the above question. This means that no application suggests no development. In searching for a mathematical method in the internet or in any other source, it is evident that the origins of many methods correspond to real world applications, an "experienced sound". What is the need of abstraction in Mathematics then, the "physical sound"? We cannot show "one", but we are comfortable in showing "one man", "one book", "one world" etc. Then why do we need "one"? A simple answer is that because we tend to communicate our experience beyond our context. Thus, there should be a better medium probably everyone can understand. In that way, Pure Mathematics is a medium to communicate our experience of solving real world problems. Then, what is Mathematics? Is it about "developing the medium" or "using the medium"? One who prefers to be interdisciplinary opts for the latter aspect, "using the medium". On the other hand, a conceptual burden may occur when someone says it is only about "developing the medium". Pure Mathematics can be developed without relating to a clear application every time, even though the origins may be application-driven. However, what is interesting is to keep the hopes of applying such pure mathematical findings once they are required, probably in the future. It seems a canal is being constructed to supply water, but the need of water is yet to appear.

Interdisciplinary and Multidisciplinary

Inter plus disciplines, is a way to understand the word interdisciplinary. But, one may often misunderstand it with the word multidisciplinary, multi plus disciplines. What are the notable differences? A recruitment officer of a health care service who has experienced misunderstandings of interviewees regarding interdisciplinary care teams and multidisciplinary care teams prepared a document regarding this (Jessup, 2007). According to that, an interdisciplinary team approaches a patient with a single consultation *via* integrating separate disciplines. In multidisciplinary teams, the task is for individuals in different disciplines to approach a patient with their own perspectives, often not at one time. However, such individuals meet together without the patient to discuss matters. Otherwise, it would have not been a team anyway. In general, if there is a problem to be solved with the involvement of individuals in many disciplines, are mathematicians ready to be a part of it? What would be their preference, interdisciplinary teams or multidisciplinary teams? In the context of definitions, axiomatic systems, mathematical logics, proving techniques etc, mathematicians tend to involve with multidisciplinary work. Thus, interdisciplinary approaches would be a struggle which could be transferred to a challenge amidst those burdens. In a multidisciplinary approach, what matters finally is how the whole process is to be benefited from that. Instead, being interdisciplinary would get mathematicians on track.

Model Parsimony and Model Adequacy

Mathematicians' involvement in research teams can be improved through a principle in Mathematical Modelling, called ‘principle of model parsimony’. This tactic is more associated with attitudinal change, a harder one because changing attitudes is much harder than changing the levels of knowledge and skills. The ‘principle of model parsimony’ says that the simplest possible model should be selected (McLeod, 1993). In contrast, the ‘principle of model adequacy’ aims at incorporating all relevant information *via* the model. Thus, the best possibility of improving interdisciplinary involvement is to drag mathematicians into applied research where the ‘principle of model parsimony’ has a dominant role to play. Individuals who have a slight knowledge in statistics may see a good potential here.

If someone outside of the field of statistics asks for advice on analysing data already obtained, a statistician would see what can be carried out in the most parsimonious way. But, sometimes such involvement would not be favourable if the statistician aims at model adequacy, asking for more data. It should not be limited to statistical work. More contributions can be made merely by using the ability for logical thinking, which is the dominant feature of any mathematician compared to a non-mathematician. Albert Einstein opted to continue his investigations in Physics irrespective of his expertise in Mathematics. Probably that happened because of the application oriented nature of Physics in contrast to the tendency of abstracting in Mathematics. He once said, "As far as the laws of Mathematics refer to reality, they are not certain, and as far as they are certain, they do not refer to reality", which reveals his intentions to go with Physics. It is worthy to note one famous quote on mathematicians; "A mathematician is a blind man in a dark room, looking for a black cat which is not there". Who is the culprit? Is it the blind man? black cat? dark box? or the person who said this?

Science-push and Need-pull

It is noteworthy here to see two concepts, namely, science-push and need-pull, compiled by Steve Conway and Fred Steward (2013), in their book 'Managing and Shaping Innovation'. Both are relevant to innovation of a product or a technique, in which two different flow models are adopted. In science-push the flow is started from basic science, followed by development, then manufacture and finally marketing. Briefly, it indicates that if we invent a product using basic science, finally we should market it. On the other hand, the second concept need-pull, emphasises a flow starting from market need, followed by development and manufacture again, but finally ending with sales. Pure mathematical developments are more like science-push, finally marketing is required. However, Applied Mathematics resembles the need-pull scenario where the market is already there. Therefore, mathematicians have to do either a science-push or a need-pull to achieve the so called development of the subject Mathematics. In both ways, an interdisciplinary context can be reached although the latter need-pull has more potential. For instance, simply think of developing a new method of solving a certain class of equations. Then one can market that method tailoring it to be used in an interdisciplinary research. Thus, it is a science-push approach. The need-pull counterpart of the above case is evident once the requirement arises to solve a certain equation, where the available methods fail, then mathematician can develop a method.

Interpretations of Mathematics

By bringing the philosophical context of Mathematics into discussion, we would elaborate more on our main concern, the conceptual burden. John D. Barrow in his article 'What is Mathematics?' mentions four interpretations of Mathematics; Platonism, Conceptualism, Formalism and Intuitionism (Ferris,1991). Platonism agrees with the view that mathematicians discover Mathematics rather than invent it. Conceptualism addresses the total opposite of Platonism with the view of inventing Mathematics, not discovering it. That means, people create mathematical structures and force the world into those structures in conceptualism. Thus, it seems Platonism expects ready-made packages to interpret something existing, while conceptualism deals with constructing something called mathematical. If someone focuses only on one aspect of the above two interpretations, that would be a barrier to be interdisciplinary. Mathematicians should discover hidden features while creating a mathematical theory for it. It will be beneficial in developing further theories as well as seeing further applications.

Next, formalism brings the core idea of manipulating infinite matters using common tactics used in finite matters. Thus, formalists believe that mathematics is not more than manipulation of symbols according to a given set of rules. Therefore, what occurs in nature is irrelevant to what occurs in mathematical structures. It is evident that formalism may restrict an interdisciplinary way of engagement. Intuitionism also addresses matters outside our experience, in which a way of constructing them through intuitive steps must exist. In classical logic, a statement is either true or false. However, in intuitionism, there is a state of ‘undecided’ in addition to the states of true and false. In an interdisciplinary context, keeping this undecided category is useful since a chance factor of a certain event occurring can be defined. Fuzzy logic is one of the fields that emerged in this area during the last few decades (Buckley and Jowers, 2006).

Interdisciplinary avenues for Mathematics

There is a high potential for mathematicians to become involved in other fields such as Biology, Economics, Sociology etc. other than the direct involvements in Statistics, Physics and Computer Science. It is a duty of mathematicians to do a science-push. They should investigate the applicability of mathematical tools and techniques in other fields. Differential equations and numerical methods have gained a good reputation in that respect, where further developments are still required. The field Mathematical Modelling which replaced the classical way of naming it 'Mathematical theory/formulation of...' has emerged to facilitate it (Ferris,1991). Partial Differential Equations and Finite Element Methods are two specific areas to work at, where rapid growth in computational software always provides potential improvements. From a theoretical perspective, numerical analysis in solving differential equations, partial differential equations, integral equations and integro-differential equations is in great demand in graduate courses and research (Atkinson and Han, 2009).

However, a considerable effort is still necessary to make use of Abstract Algebra in interdisciplinary research. Is Abstract Algebra too much abstract? What is the burden of being involved with something outside? Abstract Algebra is mainly about formulating structures such as Groups, Rings, Fields and working with a set of axioms involved in each structure. If it is all about creating structures and expecting the world to fit with them, then it is a total conceptualism. In an interdisciplinary context, no one may involve with Abstract Algebra until people believe these structures exist in the real world. Sometimes rigorous definitions in mathematics hinder the possible involvement with practitioners in other fields. In Mathematics, a definition means a collection of symbols arranged in a meaningful order that connects unknown thing with known things. It seems formalism takes the dominant hand. What is the requirement of definitions? How do they contribute to our knowledge? According to the book 'Buddhist Logic', if we know about something, then we do not want definitions for that thing and if we do not know, then we cannot define (Stcherbatsky,1996). Further, it claims that what a thing is in itself, we only know its relations. This is in accordance with earlier claims on Abstract Algebra. If we do not know a way to relate the real world with abstract structures, then there is nothing that definitions can do in an interdisciplinary context. On the other hand, if someone knows to identify a structure and work with it, then there is no need of definitions. It is more like identifying and working with colour red without bothering about defining red. Thus, definitions and the way someone absorbs them need refinement in minimizing conceptual burdens associated with abstract structures.

Gaining knowledge as a process is similar to scaffolding. Always we move from known to unknown. That process comprises different levels according to Bloom's taxonomy: Knowledge, Comprehension, Application, Analysis, Synthesis, and Evaluation (Huitt, 2011). To enhance the applicability of mathematical tools in such a learning or knowledge gaining process, it is useful to see resembling scenarios in the real world. For instance, Lotka-Volterra model which contains a system of differential equations is not confined to explaining predator-prey dynamics. For instance, it can be applied to explain parasite-mosquito dynamics regarding filarial parasites and vector mosquitoes (Ganegoda, 2009; Ganegoda and Perera, 2011). However, the parasite-mosquito scenario is different from a predator-prey, though the resembling dynamics exist. The task of mathematician is to recognize such hidden patterns in applications. As a further addition to applications of Lotka-

Volterra model, some economic behaviour may also be analysed using it. If researchers in mathematics are able to study at least a preliminary level of another subject, they can overcome many of the burdens in interdisciplinary engagements. Then they have a grip to capitalize on by providing mathematical formulations. For instance, the field of Mathematical Biology will be strengthened if mathematics researchers would study Biology.

Another useful scope of connecting Business, Finance and Economics with Mathematics is 'optimization', where the objectives of maximizing and minimizing are achieved subject to constraints. This field has many inward and outward flows *via* Operational Research, Actuarial Science, Financial Engineering, Business Economics etc. (Blischke and Murthy, 2000). For mathematicians, much of the content comes with finding out critical points of functions and determining whether they are maximizers or minimizers (Peressini *et al*., 1988). Finance related sectors always expand with new research findings aiming at market growth. As an outcome of this, concerns on data mining and techniques of optimal selections have achieved an enormous growth (Goebel and Gruenwald, 1999; Huysmans *et al*., 2005). This emerging potential would be a good hunting ground for mathematics researchers. Industrial internships/trainings and industry-based projects in undergraduate programs have already shown this potential and special attention should be rendered to design more and more applied mathematical courses at university level to cater to that demand. Experts who engage in Mathematics teaching and research should recognize the future potential of interdisciplinary research as every subject field seems to be merged together. The finance sector would have a considerable share in that regard. If Mathematics is to be benefited, there will not be a separate avenue, but to march forward with all other fields.

Final remarks

Advancement of science cannot be experienced by using only scientific research. Mathematics is also no exception. It should be a collective effort of two aspects: science and philosophy (Hart, 1996). If we all agree with some finding and methodology used, then it is more in science. However, if so many opinions are there regarding a problem or a finding in a broader perspective, then it belongs to philosophy. Deciding whether Mathematics is a science or an art is itself a philosophical problem. It hints at the impossibility of developing Mathematics only by a scientific routine. Instead, challenging opinions should be expected and entertained preferably in an interdisciplinary context. There is no other way of overcoming conceptual burdens in that task except "engaging with other disciplines". Ultimately there will be no "other" all are "together".

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Section E2

Engineered Nanomaterials from Mineral Resources: Applications in Industry & Environment

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Introduction

Nanotechnology has attracted considerable scientific interest due to the new potential uses of particles in 1-100 nanometer scale (Stone *et al*., 2010). At the nanoscale, physical, chemical, and biological properties differ from the properties of individual atoms and molecules of bulk matter. Therefore, it provides an opportunity to develop new classes of advanced materials which meet the demands of high-tech applications (Kharisov *et al*., 2010). Thus, industries may be able to re-engineer many existing products that function at unprecedented levels. Globally, nanotechnology is projected to be an all pervasive technology. Nanotechnology is estimated to make a great impact on the global economy. The world market for nanotechnological products by 2015 was around US$ 3 trillion. A quickly growing range of applications of nanomaterials in many fields has been observed in recent years. Among them, nano titanium dioxide (nano-TiO_2), nano carbon, nanographite, graphene, carbon nanotube, nanoclay and nanosilica are widely used nanomaterials with a wide spectrum of industrial and environmental applications.

Nano titanium dioxide (nano-TiO_2) from ilmenite

As a new material, nano-sized TiO_2 has been of great interest to many scientists in the recent years. Its small size and large specific surface area allow for certain unique unusual physicochemical properties. Nano-TiO_2 has the tightly controlled particle size that increases both the refractive index and light scattering properties as a result of the uniform particle size distribution and additional surface area. Due to the higher photocatalytic activity, nano-TiO_2 can be used in anti-fogging coatings, where nano-TiO_2 incorporated into outdoor building materials can substantially reduce concentrations of airborne pollutants such as volatile organic compounds and nitrogen oxides and as photocatalyst coating which assist in deactivation of bio-contaminants. Recently, a large number of studies were reported, based on the photocatalytic activity of TiO_2 for oxidation of organic chemicals, obviously the most potential environmental friendly process. In general, two methods of application of TiO_2 in photocatalysis have emerged, one as highly dispersed fine particles on porous support materials and suspended fluids in liquid medium, and another as their films (Sonawa *et al*., 2002).

Sri Lanka has vast deposits of ilmenite ($FeTiO_3$) which is the major raw material for titanium dioxide (TiO_2) pigment production. Major concentrated deposits are located along the 72 km North-East coastal stretch of Sri Lanka. It has been estimated that the North-East coast contains 8-9 million tons of ilmenite and 1.0 million tons of rutile. The beach sand deposits in the North- East coast at Pulmoddai are very high grade, with a heavy mineral content of 80% and a composition of 70-72% ilmenite ($FeTiO_3$), 8% rutile (TiO_2) and 8-10% zircon ($ZrSiO_4$). The present plant has a capacity of

150,000 tons of ilmenite ($FeTiO_3$), 10,000 tons of rutile (TiO_2) and 6,000 tons of zircon ($ZrSiO_4$). The current annual production of ilmenite is about 80,000 metric tons (Premaratne *et al*., 2003 & 2004).

Currently, Sri Lanka does not produce any type of value added TiO_2 pigments. The country imports its entire requirement of titanium dioxide pigment (TiO_2). More than 90% of the titanium ore is processed into titanium dioxide pigment, known as titanium white, a brilliant white, non-toxic pigment. Titanium dioxide pigment is used as a whitening, pacifying, self-cleaning or UV-radiation protecting agent in paint, printing, rubber, paper, textile, electronic, detergent, cosmetic, food and pharmaceutical industries. Approximately 60% of titanium dioxide pigment produced globally goes into the paint and coating industry, 20% into plastics, 13% into paper products and the remaining 7% into other industrial applications (Premaratne *et al*., 2014). For its use as a white pigment, titanium dioxide competes with ground calcium carbonate, precipitated calcium carbonate, kaolin, and talc. Global demand for feedstock amounts to over 5 million tons annually. According to industry estimates, total annual sales for the titanium dioxide pigment industry and titanium metal markets are over US$ 20 billion.

The production of titanium dioxide pigment is extremely relevant to Sri Lanka. The setting up of a titanium dioxide pigment and nano-titanium dioxide manufacturing plant of global standard would be a very desirable venture to develop the country's economy using its natural mineral resources. Microwave heating is a potentially beneficial technology for the titanium metallurgical industry especially for the manufacture of high quality titanium dioxide pigments and nano-TiO_2 effectively, efficiently and economically (Premaratne *et al*., 2014). It is important that Sri Lankan policy makers realize the potential of our resources and consider creative pathways for development.

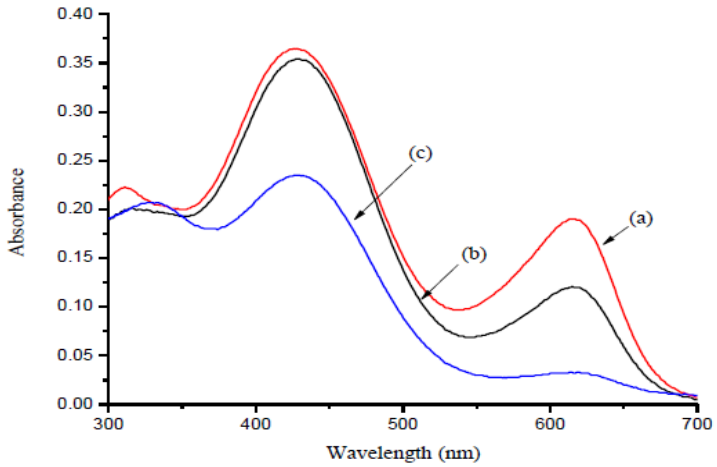

Figure 1: UV-Vis spectra of reaction product of bromothymol blue solution: (a) with uncoated glass (control), (b) with the TiO_2 coated on glass, (c) with nano-TiO_2 powder after exposing to diffused light for 48 hrs. (Fernando *et al*., 2010)

In one of our investigations, nano-TiO_2 and pigmentary TiO_2 were synthesized using Sri Lankan ilmenite through the sulfate process and sol-gel method using sulfuric acid. Synthesized nano-TiO_2 showed a morphological homogeneity with grain size falling mostly in the range of 20 nm. The photocatalytic activity of nano-TiO_2 was assessed by the degradation of bromothymol blue in aqueous solution. Figure 1 (b) shows that the reduction of absorbance at 614 nm in bromothymol

blue solution was mainly due to the photocatalytic capabilities of TiO_2 thin film coated on glass. Figure 1 (c) shows the significant decrease in absorbance both at 428 nm and 614 nm indicating that most of the bromothymol blue has been photo-oxidized by nano-TiO_2 with diffused light. The maximum percentage of photo-oxidation of bromothymol blue by nano-TiO_2 under diffused light, was 82.6% at 614 nm. Nano-TiO_2 coated on glass showed a high photocatalytic activity and self-cleaning effect that can be effectively used in building envelopes. This method can be implemented in a wide range of applications, involving the deposition of photocatalytic TiO_2 films on low thermally resistant materials, such as plastics. Therefore, value added nano-TiO_2 can be easily produced from Sri Lankan ilmenite ($FeTiO_3$). Nano-TiO_2 coated glass has the potential to be an effective and efficient photocatalyst and self-cleaning agent and in a commercial context, may provide savings with respect to both time and energy (Fernando *et al*., 2010).

Nano-carbon, nanographite, graphene and carbon nanotube from graphite mineral

Graphite is extracted around the world by both open pit and underground mining. While flake graphite and amorphous graphite are both mined open pit and underground, lump (vein) graphite is only mined underground in Sri Lanka. Graphite is one of the most important minerals in Sri Lanka. Its purity is extremely high (over 99%). Among these, the vein graphite is the most important type. The reserves of graphite are known to be large and the deposits are confined to the high grade metasedimentary rocks of the Precambrian complex. A more detailed survey has been carried out of the Bogala Graphite Mine which is one of the chief operating graphite mines of Sri Lanka (Herath, 2008).

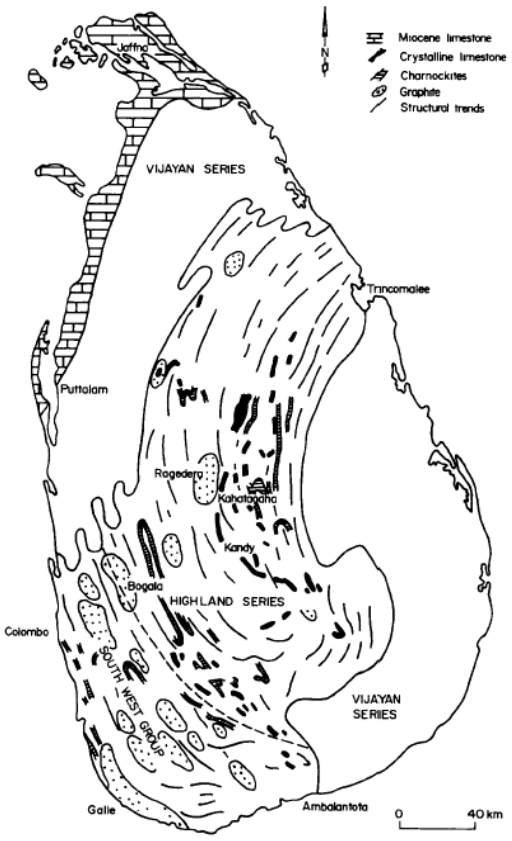

Figure 2: The distribution of graphite occurrences in Sri Lanka (Dissanayake, 1981)

It has been concluded that the vein-type graphite of Sri Lanka was formed from the surrounding carbon-rich sediments and transported in the solid phase as the slippery graphite grains moved along grain boundaries down a pressure gradient. Research had shown that the mineralization of graphite is tectonically controlled and that graphite veins are localized in well-defined regions within anticlinal structures (Dissanayake, 1981). Inferred reserves of graphite in Sri Lanka have been estimated at around 4000,000 to 500,000 metric tons. The vein type graphite is mainly confined to fracture or joint systems in the folded metasedimentary rocks. Figure 2 shows the distribution of graphite occurrences in Sri Lanka and the two large operating mines, at Bogala and Kahatagaha (Herath, 2008).

Graphite based nano-structures are the most talked about nanomaterials in the world. Since graphene won the Nobel Prize for Physics in 2010, the electronic industry has invested considerable amounts of money and time in graphite based nanomaterials (nanocarbons). Nanocarbon products include single-walled carbon nanotubes (SWNT) and multi-walled carbon nanotubes (MWNT), fullerenes, graphene, carbon nanofiber and nanodiamonds. Properties of graphite nanoplatelets (GNPs) are given in Table 1, and Table 2 shows the properties of carbon nanotubes.

Table 1: Properties of Graphite Nanoplatelets (XG-Sciences, 2016)

Properties	Values
Thickness	~ 5 nm (1 nm-15nm)
Particle diameters	sub-micron to 100 microns
Density	~2.0 g/cm ^{3}
Electrical Resistivity	~ 50 x 10^{-6} Ω cm
Thermal Conductivity	3000 W/m K
Tensile Modulus	~1.0 Tap
Tensile Strength	~10-20 GPa

Applications of nanographite and graphenes

- **Fuel tank and fuel line coatings:** the unique shape imparts high barrier properties that, when coupled with its electrical conductivity, make this an ideal additive to Nylon for fuel tank linings.
- **Electronic enclosures:** adds electrical conductivity to polymers at low densities of 3 to 5 wt%. These materials can also be used to provide EMI or RFI shielding to a variety of polymers.
- **Automotive parts:** a composite made with graphite nanoplatelets can be painted electrostatically, thereby saving cost.
- **Aerospace:** graphite has long been used in aerospace composites. Graphite nanoplatelets can be combined with other additives to reinforce stiffness, add electrical conductivity, add RFI shielding, etc.

- **Appliances:** fortified polymers provide superior thermal and electrical conductivity, thereby saving the costs of separate heat dissipation mechanisms.
- **Sporting goods:** graphite-based composites are stronger and stiffer and lighter than comparable materials.
- **Coatings and paints:** graphene platelets can be dispersed in a wide variety of materials to add electrical conductivity and surface durability.
- **Batteries:** graphene nanoplatelets increase the effectiveness of Lithium-ion batteries when used to formulate electrodes.
- **Fuel cells:** both bi-polar plate and electrode efficiencies can be improved.Table 2: Properties of Carbon nanotubes

Table 2: Properties of Carbon nanotubes

Property	Item	Data
Geometrical	Layers	Single/Multiple
	Aspect Ratio	10-1000
	Diameter	~0.4nm to >3nm (SWNTs) ~1.4 to >100nm (MWNTs)
	Length	Several μm (Rope up to cm)
Mechanical	Young's Modulus	~1 TPa (steel: 0.2TPa)
	Tensile Strength	45GPa (steel: 2GPa)
	Density	1.33~1.4g/cm^3 (Al: 2.7 g/cm^3)
Electronic	Conductivity	Metallic/Semi-conductivity
	Current Carrying Capacity	~1TA/cm^3 (Cu: 1GA/cm^3)
	Field Emission	Activate Phosphorus at 1~3V
Thermal	Heat Transmission	>3kW/mK (Diamond: 2kW/mK)

(Wong *et al*., 1997)

With application segments demanding commercial access to reasonably priced materials, carbon nanotube (CNT) companies are realizing the importance of expanding their manufacturing capacity to enjoy the benefits of greater demand through reduced prices. Assessment of the future of carbon nanotubes revealed that revenue in this industry totaled US$ 30 million in 2005 and US$ 700 million in 2010 and is projected to reach US$ 10 billion by 2020 (Nanozar, 2016). The price and performance advantages of graphene ultra-thin sheets of carbon atoms over incumbent carbon-based nanomaterials, such as carbon nanotubes, have made the material a hot topic in nanotech circles.

Mass production faces the challenges of complexity and costs, the impact of which is felt more in the single walled carbon nanotubes (SWCNT) market than in multi walled carbon nanotubes (MWCNT) market. Despite its higher price margins, SWCNT are gaining prominence in applications that demand high purity and faster response times. Thus, commercial producers of CNT are propelled toward improving different synthetic procedures such as, chemical vapor deposition, arc discharge, and catalytic methods for efficient manufacturing. Some companies have even developed proprietary manufacturing processes and have licensed their technology to others. Additionally, as

the application sectors for CNT demand high quality, CNT companies are taking active steps to monitor quality and ensure reproducibility.

Though mass production, reduced costs, and greater demand are critical to complete CNT's transition from the laboratory to the open market, the true success of the lab-to-fab transition lies in the commercial success of the products that incorporate the CNT material. In Sri Lanka, currently 99% pure graphite, which is very likely to be the key raw material of local CNT production, costs about $2000 per 1000 kg. Hence it will be a very profitable industry, if the mass ratio of CNT produced / mass of raw graphite consumed can be made to reach 30-50%.

CNT manufacturers that collaborate with the application developers are likely to have an edge over those restricting their roles to being mere material suppliers. Such partnerships enable CNT suppliers to leverage their expertise in gaining partial control over product development and commercialization, thereby influencing CNT's increased penetration into varied application markets.

Nanoclay from montmorillonite clay mineral

Nanoclays which consist of stacks of layers which occur in the nanometer scale in thickness with interlayer charge balancing ions are interesting due to their potential applications in catalysis, environmental remediation, controlled delivery and in the synthesis of nanocomposites with organic and inorganic materials. Depending on chemical composition and nanoparticle morphology, nanoclays are categorized into several classes. Montmorillonite (MMT) clay is one of the smectite groups, composed of silica tetrahedral sheets layered between alumina octahedral sheets. Although MMT is a little known smectite group clay mineral in Sri Lanka, it is recorded in dry zone soils and is believed to be formed as a result of weathering of micaceous minerals. After mapping the boundary, clay samples were collected from Murunkan area in the vicinity of the Giant tank from different depths. The dried and powdered samples were analyzed for their mineralogical composition by using physical and chemical characterization methods. X-ray diffraction (XRD), scanning electron microscopy (SEM), and energy dispersive X-ray spectroscopy (EDX), Fourier transform infrared spectroscopy (FTIR) and thermal gravimetric analysis (TGA) methods were used. Wet sieving method was used to study the particle size distribution of Murunkan clay deposit and each fraction was characterized. Experimental results revealed that the Murunkan clay deposit contains more than 40% of montmorillonite of high purity. Marketable montmorillonite (nanoclay) of high whiteness and high purity was produced from the Murunkan clay deposit by chemical processing using H_2O_2 and hydrochloric acid (Latta *et al*., 2016).

Iron-containing clay minerals (nanoclays) are ubiquitous in soils, sediments, and water and provide a significant source of redox-active Fe is known to influence metal sorption, contaminant fate, and nutrient cycling (Handler *et al*., 2014). While biological reduction of clay minerals has been known for some time, it has only recently been shown that Fe(II) can abiotically reduce Fe(III) in clay minerals. In one of our research studies, we used Mössbauer spectroscopy to show that Fe(II) reduces an extensive amount of Fe(III) in a low Fe clay mineral (Wyoming montmorillonite SWy-2, 2.3 wt% Fe) which is also known as nanoclay. The extent of reduction ranges from 12 to 78% over a pH range of 4.0 to 7.5 and Fe(II) concentration from 0.4 to 2.2 mM, and increases as the amount of sorbed Fe(II) increases until about half of the mineral is reduced (Figure 3). Our work demonstrates

that Fe(II) reduction of clay minerals can occur across a range of geochemically relevant conditions and that extensive reduction can occur in low Fe clay minerals *via* electron transfer through the basal plane (Latta *et al*., 2016).

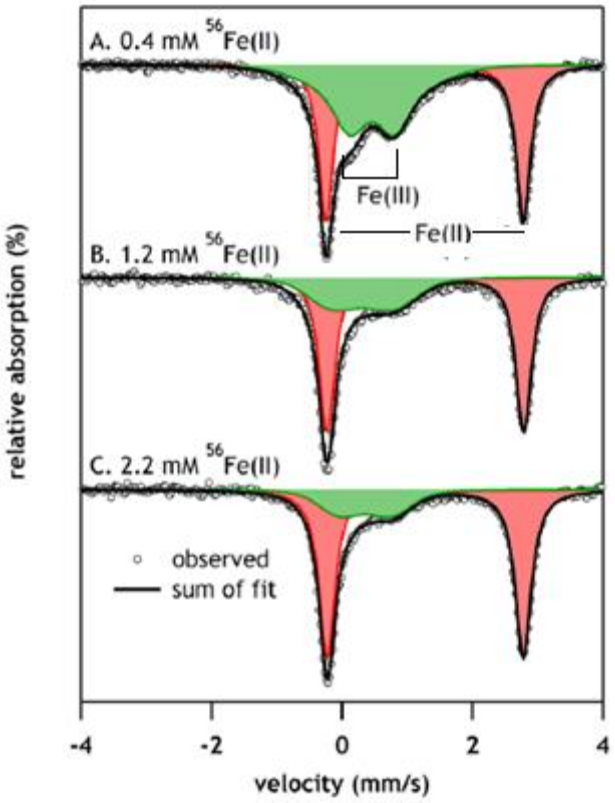

Figure 3: Mössbauer spectra of 2 g/L SWy-2 after reaction with (A) 0.4 mM ^{56}Fe(II), (B) 1.2 mM ^{56}Fe(II), and (C) 2.2 mM ^{56}Fe(II) in 25 mM MOPS (pH 7.5) and 50 mM NaCl. Spectra are modeled with Fe(II) (sharp) and Fe(III) (diffused) doublets (Latta *et al*., 2016)

Nanosilica from quartz mineral

Vein quartz is one of the most abundant minerals in Sri Lanka and it is mined mainly for porcelain and materials industries. Vein quartz is an economically viable earth resource for the production of nanosilica through chemical methods as a value added product. Nanosilica is one of the widely used nanomaterials in adhesives, sealants, paints & coatings, cement-based building materials and rubber composites as a reinforcing, thickening and flattening agent (Premaratne *et al*., 2013).

In our research work, pure nanosilica was synthesized by a simple chemical precipitation method from Sri Lankan vein quartz and characterized by various analytical techniques. X-ray diffraction (XRD) data indicated that the natural Sri Lankan vein quartz is highly crystalline and pure. Energy dispersive X-ray spectroscopy (EDX) data confirmed that vein quartz comprises pure silicon oxide with fewer impurities. Scanning electron micrograph (SEM) data showed that synthesized nanosilica particles from vein quartz were in the agglomerate form with average particle size of 50 nm. XRD

data showed a strong broad peak around 22.14° (2θ) indicating that the synthesized nanosilica was in an amorphous form.

The absence of a sharp peak at 695 cm^{-1} in the FTIR spectrum of nanosilica indicated the structural change from crystalline silica (in vein quartz) to amorphous silica. Silica nanoparticles were subjected to surface modification by oleic acid ($C_{18}H_{34}O_2$). Thermo gravimetric analysis (TGA) indicated the thermal decomposition of oleic acid in functionalized nanosilica with a significant weight loss between 350 ºC - 400 ºC. FTIR data showed that nanosilica modified with oleic acid contained the carbonyl stretching peak of an ester bond at 1711 cm^{-1}. This confirmed the ester bonding between the silinol group and the carboxylic group of the oleic acid. Surface modification of nanosilica particles is carried out with oleic acid to improve the compatibility between inorganic silica nanoparticles and the organic matrix for applications in polymer engineered materials and compounds (Premaratne *et al*., 2013).

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Section E3

Role of ICT in multidisciplinary approach for sustainable development

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According to NASA, nine of the ten warmest years have occurred since the year 2000. In 2012, the Arctic summer sea ice recorded the lowest level and during the last 100 years, the global sea level has risen by 178 mm. Greenhouse gases are the main contributors to these climate changes. Even if emission of greenhouse gases is stopped today, global warming and climate change will affect future generations (Figure 1). Ecosystems and agriculture will be affected by these climate changes. Therefore, achieving the sustainable development goals 'Climate action', 'Life below water', 'Life on land', 'No poverty', 'Zero hunger', and 'Good health and well-being' will not be a reality, if the global warming is not monitored and controlled. Collection of data from the environment, processing using computers, storing in storage devices and sharing data and information among engineers, scientists, social scientists, healthcare professional, farmers, managers, academic community, policy makers and general public through networks is essential to reduce climate change (mitigation) and to adjust to living in a changing climate (adaptation). This shows that the fight to eradicate global warming is clearly a multi-disciplinary effort. NASA collects climate data and makes the data available to the public, policy makers, decision makers, and scientific community around the world using Internet. ICT has reduced the cost and effort of sharing data around the globe while increasing the availability of accurate data and information, efficiency of storing and maintenance in a central location.

Figure 1: Potential future effects of global climate change
Source: http://climate.nasa.gov/effects/, accessed on 10/10 2016

Quality education is one of the important sustainable development goals. The idea is to promote quality education and lifelong learning opportunities for all. A couple of decades ago these goals were not achieved due to the 'rich' and 'poor' division of society. Quality education was not available to poor people in the society while the rich enjoyed the luxury of education. A bestselling

book 'A letter to a teacher by the School of Barbiana' written in 1967 by eight students from the School of Barbiana, in the Tuscany region of Italy, tells how the low quality education for poor people affected their lives. This heartbreaking story will open the eyes of decision makers and policy

makers to learn a lesson from the past. '*ADARANEEYA GURUBHAWATHUNI*' is a similar kind of a book written by Prof. Sarath Wijesooriya of the University of Colombo. I personally recommend these books to all teachers and lecturers. A critical analysis is not required to show that most children of poor people in our society either end up with no proper education or education in the Arts stream just because their parents are poor. It is a well- known fact that most of the unemployable graduates are from the Arts stream. They wait for the government to provide job opportunities for them. Lack of infrastructure, reading materials, and good teachers are also reasons for not providing a quality education for poor people. However, the advancement of ICT could solve most of these problems.

Internet has become a part of our lives and the information need of today's society is mainly satisfied by the Internet. Even the television has become a good teaching tool. BBC in UK and NHK in Japan are good examples. Their education channels are the best among the education channels worldwide. Before the Internet, television was a means of providing a good education to all. However, the Internet has become the main tool now. This creates another division in our society. This is the 'digital divide'. Society is now divided into two groups: those who have access to information through digital media such as Internet and those who do not. Access to information strongly depends on the socio-economic status of people. Therefore, the solution to the digital divide is multi-disciplinary. ICT plays a major role in education in many countries. Online courses/ degree programs, online books, quality education materials, good web sites, and distance learning are examples of applications of ICT in education. Experience in teacher training shows that lack of quality reading materials are still a problem in our education system. Depth of subject knowledge and experience are not the same among teachers. The delivery system is still the traditional teacher based education. Stressful tuition classes are the result of this traditional teaching. Problem based, student based and/or blended teaching can help students learn more while enjoying their learning. ICT has been successfully used in converting traditional teacher based education to a more successful student based learning system. If our traditional teacher based school education can be transformed to a student based learning system, stressful tuition classes will play a diminished role in education. Figure 2 shows the different teaching methods in a digitally divided society.

Figure 2: Education in digitally divided societies
source:https://www.thoughtworks.com/insights/blog/bridging-digital-divide-underprivileged-communities, accessed on 10/10/2016

Mobile communication/computing can reduce this digital divide significantly. Wired networks are not always feasible. However, mobile networks are available and provide services to every corner in the country. A majority of people use mobile devices for communication because of their affordable prices, and sometimes, they are the only solution.

Year	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016 June
Subscribers	2,644	14,687	29,182	51,316	71,029	114,888	174,202	256,655	430,202	667,662	931,403	1,393,403	2,211,158	3,361,775	5,412,496	7,983,489	11,082,454	14,264,442	17,267,407	18,319,447	20,324,070	20,447,508	22,123,000	24,384,544	24,695,535

Figure 3: Cellular Mobile Telephone Subscriptions (1992 – 2016 June)
Source: http://www.trc.gov.lk/2014-05-13-03-56-46/statistics.html, accessed on 08/10/ 2016

According to Figure 3, the number of mobile phone users in Sri Lanka by June 2016 reached 24 million. However our population is around 21 million people! Therefore, mobile computing/communication can bridge the gap of the digital divide in Sri Lanka.

Figure 4 shows the changing digital divide, originally because of access and cost but now due to knowledge and use. It is no longer a socio-economic problem but is directly related to awareness and readiness. A proper education in ICT and its applications in different domains are required.

Figure 4: The changing digital divide
Source: http://denovati.com/2014/01/new-digital-divide, accessed on 10/10/2016

About 500,000 students sit for the GCE O/L every year. Only about 300,000 students get an opportunity to follow the GCE A/L. About 30,000 students secure a place in government universities, leaving at least 270,000 students without a proper education. On the other hand, the Sri Lanka Association for Software and Service Companies (SLASSCOM) needs 200,000 IT-BPM experts for the 1000 start ups projected by the year 2022. It is difficult to generate such a large number with the current supply of IT-BPM related graduates of around 8000 per year.

English and ICT are widely required skills for any job in Sri Lanka. Providing a quality education in ICT and English has become a national priority now. However, it is not feasible to accommodate nearly 270,000 students into a few academic institutes for training. A virtual school created using online programs will be the best solution. However, there is concern over unsupervised learning. Fortunately there are more than 2000 school teachers trained in ICT jointly by the National Institute of Education (NIE) and the Ministry of Education (MOE) with the help of university academics. There are over 100 Computer Resource Centers (CRCs) governed by the MOE around the country. These CRCs and trained teachers can be used for this purpose with low investment. A national e-learning policy should be prepared and a governing authority should be established by the government. Malaysia has successfully used e-learning for better education. The program content, web page accessibility, learners' participation and involvement, web site security and support, institution commitment, interactive learning environment, instructor competency, and presentation and design are already identified as success factors. These success factors clearly show that if e-learning is to be successful, a multi-disciplinary approach is needed. Experts from humanities, social sciences, ICT, and other domains should be members of an e-learning group. A reliable method of identifying needs, e-learning content design and creation, delivery, validation and verification with accreditation should be established. If e-learning can be used effectively as an additional learning approach in our education system, providing quality education to all will become a reality. A highly educated and skilled population will provide the necessary human resources to achieve the sustainable development goals of our country.

Table 1: Evolution of Distance Learning Past and Present

	Past Distance Learning	Present e-Learning
Definition	• Any approaches to education delivery that replace the same-time, same-place, and face-to-face environment of a traditional classroom (i.e., correspondence teaching; multimedia distance teaching)	• The most recent evolution of distance learning that creates, fosters, delivers, and facilitates learning, anytime and anywhere, with the use of interactive network technologies (i.e., E-learning)
Paradigm in education	• Focus on teaching: lesson based Objectivist model of learning in which learners are passive • A series of lectures for efficient transfer of knowledge from instructor to learner	• Focus on learning: learner based • Constructive, collaborative, and cognitive information processing of learning • Individual differences in the learning process; learning as a social process
Interaction	• Lack of direct interaction between the teacher and the learner • Asynchronous interaction	• Interactions between instructor and learner, and among learners • Asynchronous/synchronous or real-time (e.g., chat forum, instant messaging, video conferencing) interaction
Technology	• Written or printed materials, broadcast media, audio/ videotapes, telephone, and CAI/ CBT with stand-alone computers	• All electronic media, especially, network technologies such as the Internet, intranets, and extranets

Source: Goi and Ng, 2009

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Table 1 shows how ICT converted the traditional distance learning into e-learning. The Malaysian experience shows that e-learning provides more learning opportunities for adults and improves the quality of education. Sri Lanka has not yet utilized the power of e-learning in its education system for a better tomorrow.

The practice of obtaining needed services, ideas, or content by soliciting contributions from a large group of people, and especially from the online community than from traditional employees or suppliers is defined as 'Crowd sourcing' in the Merriam-Webster dictionary. This term was introduced by Jeff Howe in 2006. Crowd creation, crowd voting, crowd wisdom and crowd funding are four types of crowd sourcing. Crowd sourcing with mobile users will be useful in monitoring and control of natural disasters (e.g. Tsunami). In such situations, all other forms of communication will fail, leaving mobile communication as the only mode of reaching the affected areas. Data verification is also a good application for crowd sourcing. Crowd sourcing reduces the cost of data collection while getting a large crowd involved with the process within a shorter period of time.

The initial capital required for ICT infrastructure development is fairly high. This high cost prevents a majority of SMEs using ICT in their businesses. This inability negatively affects their marketing and promotions. This is another form of digital divide. In this case, the SMEs in developed countries will use ICT in their businesses while those in developing countries will not be able to adopt ICT due to the high investments. The result of this digital divide is the loss of completion for the SMEs in developing countries. A Cloud based solution does not require such a high capital at the early stages of ICT adoption. Government and policy makers should take necessary action to promote Cloud based solutions in the country. Sectors such as healthcare, education and agriculture will be benefited by Cloud computing.

Internet-of-things (IoT) is another emerging trend in ICT. This is defined as "a system of interrelated computing devices, mechanical and digital machines, objects, animals or people that are provided with unique identifiers and the ability to transfer data over a network without requiring human-to-human or human-to-computer interaction". Wearable devices are part of IoT. Healthcare related wearable devices can monitor the number of steps walked, number of stairs climbed, heart rate etc. The real power of IoT and wearable devices is yet to come.

All these ICT related technologies such as mobile computing, crowd sourcing, cloud computing, IoT and wearable devices play a major role in reducing cost of living, improving healthcare, providing a better education for all, poverty alleviation, environment protection, controlling global warming, disaster monitoring and controlling, and to implement all the sustainable development goals to provide a better tomorrow for the next generation.

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Section F

Ensuring Irrigation Water User Rights in a Market Driven Economy: With Special Reference to the Village Irrigation Systems in Sri Lanka

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Proper understanding of the context of a policy is critical to its success. There are no "one size fits all" policies. The context matters a lot, and thorough studies are the only means to assess the context properly, and to understand how people make decisions regarding usage of water. In this discourse, a mechanism for ensuring irrigation water user rights in the context of a market driven economy with evidence from village irrigation systems in Sri Lanka is discussed, and suggests policy options for these systems to maximize these synergies as a way to fulfill the challenge of producing more food, conserving the environment and enhancing food security in the current market economic background without talking about water pricing. The problem description is presented first, followed by the suggested policy options. The final section provides possible policy recommendations.

Introduction

A reliable and efficient water supply is a fundamental prerequisite for human survival and social development. About 60% of the human body consists of water. Our vital organs – the brain, heart, kidney, lungs, muscles and skin have more water. The need for water depends on our genetic makeup, stages of growth and how we live: as a percentage babies and children have more water than adults, women have less water than men. Water is the most essential limited input in nature for food production though it covers a larger part of the globe. Food is a very basic need for human survival but to whom do the user rights of water belong to? The importance of ensuring water user rights in a market promoted economy is discussed.

Changes in supply and demand are placing increasing pressure on water resources across the globe. Enhancing supply reliability and efficiency of water is a global challenge of huge proportions, and making water available, when and where needed in appropriate quantities and of a reasonable quality to match the purpose is no easy task. Social, environmental, technological and economic realities that vary across space and over time dictate what is achievable in a particular location at a particular time. Random measures that disregard this complexity can only aggravate the nature of the challenge. Therefore, managing water resources is a social priority. This involves developing approaches to prioritise the needs of water users, including the environment.

One of the key challenges of the 21st century is matching supply and demand for water. The question is, can we maintain current standards of water use in a context of:

1. Rising populations
2. Urbanization
3. Declining environmental stocks,
4. Changing social preferences (change of life style) and technological options, and
5. Uncertainties of climate change and pollution of water resources? (Aheeyar *et al.*, 2008)

Do we actually need a more radical shift as to how we use and manage our water resources efficiently, both for consumptive use and for the natural environment? This is really a serious public policy issue as it affects the current and future benefits from the nation's water resources.

Decision making in irrigation

Irrigation systems are common pool resources supplying water for multiple uses. Agricultural production often takes precedence, but their role in supplying water for other uses is often overlooked. The importance of non-farm uses of irrigation water in livelihood strategies has implications for irrigation management and water allocation, especially as increasing scarcity challenges exist in allocation mechanisms (Meinzen-Dick & Bakker, 2001). Often, the activities undertaken by businesses and households are equally important in adding value to society. They collectively increase national wealth – the annual gross domestic production (GDP). This is what all governments aspire to achieve. Such activities will also be profitable in the long-term, sustainable and hence socially desirable.

Irrigation water use (for farming) is a risky and uncertain business. Irrigation was developed initially to supply water for crop cultivation. In a broader sense it mitigates risks of drought, and therefore, makes better use of land. As a farmer, the aim is to fulfill subsistence necessities and to increase the probability of success in producing, harvesting and selling an extra crop that will give maximum benefit. Formally, it was about maximising the expected value of benefits from a farm enterprise taking into account of possible states of nature, such as seasonal conditions and the operating environment, also known as the institutional setting or policy context.

A crucial issue in water resource policy is about how to deal with the uncertainty surrounding the behavioural incentives for adaptation – how do people use water? How can we keep the fields green, rivers flowing and wildlife secure, while keeping enough water for urban and household uses? How is this paid for? The efficiency of utilizing water over time is conditional upon how adaptation takes place in the presence of uncertainty as moderated by public policy.

Irrigation systems of Sri Lanka

As in most other Asian countries, irrigation agriculture is widespread and is an important common economic activity. In low rainfall regions, reservoir water is the main source of water for reservoir-based rice farming, in addition to other uses such as for bathing, household washing, livestock rearing and fisheries (Kularatne *et al*., 2009).

Over a span of two thousand years, a multitude of reservoirs have been constructed in Sri Lanka primarily to irrigate paddy fields. Construction of these reservoirs has enabled rainfall to be widely distributed in low rainfall regions (Figure 1).

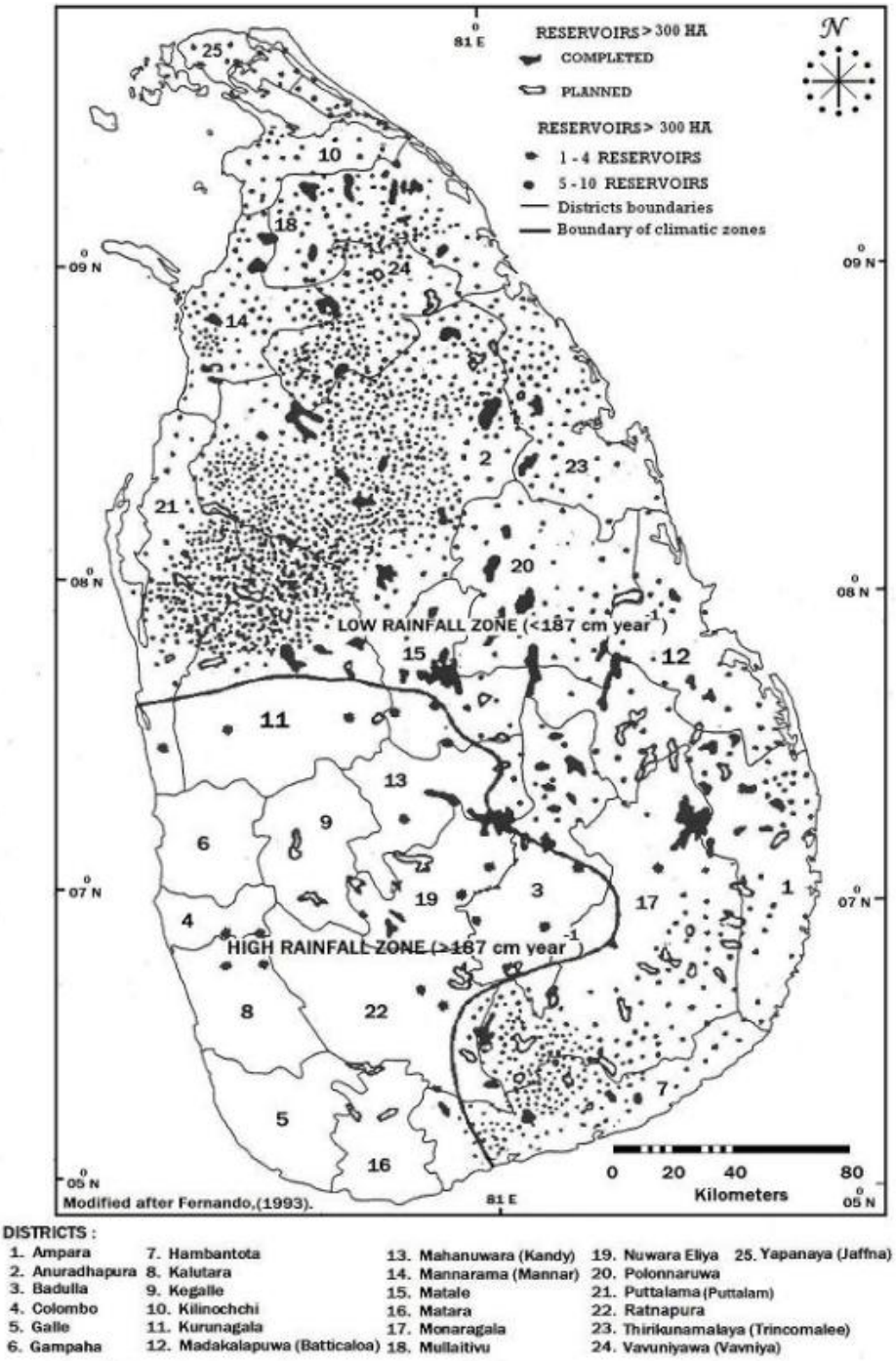

Figure 1. Reservoir distribution in Sri Lanka

Reservoir density in Sri Lanka is about 2.7 ha per km^2 of land area of the country (Fernando, 1993). These reservoirs represent 74.8% of the inland water surface area of the country (NSF, 2000). There are four types of reservoirs, categorised based on their capacity and functions: (i) large reservoirs are used only for hydroelectric power generation; Six large reservoirs were constructed during the last 30 years for hydro power generation under the Mahaweli river water diversion scheme covering 21,747 ha of land area, (ii) 72 ancient medium sized reservoirs covering 70,850 ha of land area provide water for irrigation and power generation, (iii) 160 minor perennial reservoirs, covering 17,001 ha of land area, do not directly discharge water for cultivation, however, they convey irrigation water (Costa & De Silva, 1995), (iv) Approximately 10,000 small-scale water conservation

systems covering 23.1% (39,271 ha) of the total surface of land area have been designed for multiple uses (Fernando, 1993). These small-scale water conservation systems are generally referred to as village agro-ecocomplex: (Ulluwishewa, 1991) or later as village irrigation systems (VISs).

The distribution of VISs is also based on monsoonal patterns (Figure 1). Reservoir density is highest in districts located in low rainfall regions. The low rainfall regions (so called dry zone) of Sri Lanka are located within the lowest peneplain of the island and covers approximately 66% of total land area. This area accounts for 33% of the country's population. Current irrigation withdrawals in these districts account for over 75% of reservoir water (Samad, 2005). Historically, the rural lifestyle in Sri Lanka was based on a "water culture" based on the concept of "one tank - one village" (Siriweera, 1994). According to the Department of Agrarian Development (DAD) 12,005 VISs are recorded in the country (DAD, 2000).

VISs in Sri Lanka depend entirely on direct rainfall and runoff water from their own catchment areas. Therefore, they are positioned where distinct cascades exist either in well-defined small cascades or in meso-catchment basins (Udawattage, 1985; Panabokke, 2001). A cascade can be defined as a "connected series of tanks[1] *organised within the meso-catchments of the dry zone landscape, storing, conveying and utilising water from an ephemeral rivulet*" (Panabokke *et al*., 2001). Drainage from paddy fields in the upper parts of the cascade flows into a downstream reservoir for re-use.

These VISs partly modified ecosystems were considered as village agro-ecocomplexes (Ulluwishewa, 1991). Subsequently, within these agro-ecocomplex systems, six subsystems can be identified. They are crops-livestock, crop-forestry, livestock forestry, crop-fishery and forestry-fishery. Nevertheless, these subsystems in the village agro-ecocomplexes were severely damaged by modern development efforts. Importantly, settlement schemes were established under the large scale irrigation development projects in the 1950s in Sri Lanka (Ulluwishewa, 1991).

Most of these reservoirs were used increasingly for alternative economic activities such as fish production in recent times. Traditionally, fish production from inland reservoirs was based on indigenous species whereas the extent of commercial-scale inland fisheries was limited until a few decades ago. However, with the introduction of government assistance (on a small-scale) for the development of inland fisheries in the 1950s, commercial scale fish production has increased. During the 1980s, introduction of culture based fisheries (CBF) activity, was essentially a farming practice conducted in small water bodies (generally less than 100 ha). They cannot support a subsistence fishery due to inadequate 'natural recruitment' (Amarasinghe & Nauyen, 2009). Since the introduction of CBF, attention has been focussed on the development of CBF in village reservoirs as an alternative economic activity with successive governments supporting this approach to increase fish production in the country. Increased CBF production could maximise water use efficiency and reservoir-based community welfare (De Silva, 2003). However, the economic efficiency (EE) of irrigation water in VISs has changed with agricultural modernisation (Mahendrarajah & Warr, 1991). Therefore, competition for limited inland water resources essentially requires an efficient water allocation system to sustain competing water demands, especially among the multiple users. Therefore, there must be a policy for efficient water use among the multiple users where water is allocated without a market based mechanism: water price. However, there are some key issues in water policy reform when water is supplied free of charge to farmers.

[1] In the early literature reservoirs were referred to as 'Tanks".

Key issues and water policy reform

The total utilizable water resources per unit area calculated across districts ranged from 0.03 to 1.43 metres (m) during the *maha* (high rainfall season) season and from 0.02 to 1.7 m during the *yala* (low rainfall season) in Sri Lanka (Samad, 2005). Therefore, managing through droughts and making water available where it is needed remains a challenge. Therefore, enhancing water productivity in all sectors is becoming critical.

Growing scarcity and climate change vulnerabilities increases the need for sound economic analyses. As supply is finite, water demand management is one of the important areas of water policy reforms. Water having a 'price' will give a clear signal to the users that water is indeed a scarce commodity that should be used efficiently. Price for irrigation water in Sri Lanka is excluded from the water discourse due to its free supply, hence the public raise a voice against pricing of water. However, the task is, how can we value water when it is free, and how can we increase the efficiency of available water use?

Problem description

Attention has to be paid to water transfers between competing sectors in order to have a productive integrated agri-aquaculture system. Therefore, solving inter and intra-sectoral water allocation issues are of utmost importance in policy making. The diversity of water rights agreements between users and the livelihood strategies adopted by the affected communities make these issues even more complicated. A critical issue of involving water use is to ensure that producers consider the consequences of their decisions, and how such decisions could lead to the depletion of water resources. A solution to this issue is to either allow the relevant institutions to allocate resources systematically or to leave the problem of resource allocation to the market to determine the allocation based on the largest benefits (Bostock *et al.*, 2010).

In many Asian countries, water ownership, allocation and water rights are not well established (Dennis & Arriens, 2005). This issue is important because water in small-scale irrigation systems (*i.e.*VISs) can be considered as a common property resource. In such situations it is important to consider the value of water and its alternative uses so that it can facilitate re-allocation decisions (Kadigi *et al*., 2004). Therefore, the development of a water allocation model for reservoir water use is needed to cater to competitive demand (Dudu & Chumi, 2008) especially, where water rights have not yet been established (Dennis & Arriens, 2005). Therefore, an integrated agriculture and aquaculture system (IAAS) is proposed in order to make policy to ensure irrigation water user rights without imposing water pricing to enhance rural employment and food security among the agricultural farming community.

Ongoing decision making process of water sharing

Currently, VISs are managed by Farmer Organizations (FOs). Farmer Organizations have been established under the Agrarian Services Acts of No 58 of 1979, No 4 of 1991 and Agrarian Development Act No 46 of 2000. After establishing FOs, the farmers themselves are able to plan various agricultural activities that enhance their living conditions. Working as a group, preparing agricultural plans, marketing, accessing formal credit facilities and receiving government subsidies to

the organizations, maintaining minor irrigations, savings, generating other sources of income, receiving extension services and solving farmers' conflicts are some of the provisions, powered by the Act. The role of FOs associated with VISs is very strong in improving the living conditions of rural communities. For strengthening of management links from the vilage level to national level, characteristics of farmer communities will most likely have to be organised under the FO umbrella. FOs have been provided with well defined property rights by the Act for use of reservoir resources. However in practice, there is still property rights issues in the context of who the responsible group is, of alternative economic activities (*i.e.* fisheries activities in the reservoirs). Though there are well defined user rights for use of reservoir water for agriculture, studies have revealed that there is a problem of transfering water user rights on CBF production. Therefore, there are no defined formal user groups of reservoir waters for culture-based fisheries.

As a tradition, a community meeting is held at the beginning of each cropping season (which is a major annual decision making event) to discuss reservoir water management and allocation[2]. During this meeting, planning of agricultural activities takes place and collective decisions are made that cannot be changed by a single or a few individuals. Farmers who own a plot of land in the reservoir command area with or without the membership of the FOs[3] have access to water use for rice farming[4] (DAD, 2000). The quantity of water received by an individual farmer (or paddy field) depends on the time it takes to irrigate his plot of cultivated land. This is because water is supplied *via* a single unprotected canal that traverses the block from upper fields to lower fields.

In this context, the main problem associated with IAAS in reservoir-based VISs are inter and intra-sectoral water allocation. Therefore, the main issue of allocating water across multiple uses needs to be addressed. The productive integration between agriculture sub-system and the aquaculture sub-system is very important. Then the functions of the other sub-systems are supplementary.

Issues related to the current water allocation

Water in the reservoirs are generally used for cultivation and domestic necessities, livestock farming, fishing and other economic activities such as brick making and cadajan thatching. Ecologically, these

[2] This is called kanna meeting. In addition to the water distribution, there also needs to be agreement on the timing of water issues since once the tank sluice is opened all receive water. Traditionally the most important date is when the water will be first issued since this is when land preparation will begin. There must also be agreement on the date of first sowing, the type of rice to be sown, the date for harvest and for draining the field. Various combinations of government, farmer and hereditary leaders have been involved in these timing decisions. In addition, so called lucky or auspicious days are generally preferred (Leach, 1961).

[3] FOs were established under the Agrarian Services Act (No 58 of 1979, No 4 of 1991) and the Agrarian Development Act of 2000. FOs encourage farmers to undertake various agricultural activities that enhance their members' living conditions. They include, amongst others, preparing agricultural plans, engaging in marketing, accessing formal credit facilities and receiving government subsidies, maintaining minor irrigation systems and intervening in farmers' conflicts. Therefore, FOs play a strong role in the village reservoir-based agricultural system.

[4] The common term used for rice farming in Sri Lanka is paddy cultivation. However, in this writeup these two terms are used interchangeably.

systems serve both as flood moderators in times of heavy rainfall and drought mitigators in times of long dry spells. Therefore, VISs are common resources with multiple uses. Reservoir irrigation systems were constructed and are maintained by an experienced community, with a collective effort (Siriweera, 1994) until a new institutional mechanism is established.

The institutional mechanisms of water allocation in village reservoirs facilitate collective decision-making which is based on shared cultivation. A direct market price for the amount of water used by individual farmers does not exist. Therefore, a market mechanism in reservoir water does not necessarily work. The main factor responsible for the market failure of reservoir water allocation is the inability to identify the target group of reservoir water users (non-excludability). Non-exclusion of water users leads to an overuse of water. This implies that there is less water available for other users. The main weakness of these organisations is that they would be less effective for inter-sectoral and intra-sectoral water allocation because all sectors of users are not included when water allocation decisions are made (Meinzen-Dick, 1996; Dinar *et.al.*, 1997). Therefore, one of the pertinent unsolved problems in reservoir-based agriculture in Sri Lanka is that the total volume of reservoir water is not being allocated efficiently among multiple uses (*i.e.*, irrigation, domestic use, fisheries, livestock and cottage industries) and users (groups of farmers in the head-end, middle and tail end farmers and cattle owners). The use of water for rice farming by an individual farmer can have an impact on the volume of water used by other farmers. If FOs decide to increase the residual volume of water[5] used for other purposes, it implies a reduction in the volume of water for rice farming. The decision to reduce the volume of water made available for rice farming will also reduce the extent of paddy land cultivated during the irrigation season.

Of the competing uses, culture-based fisheries (CBF) is currently being given priority due to the commercial value of fish production. CBF is a form of aquaculture which is practised in inland waters. The country did not have a tradition of aquaculture or an organised freshwater fishery until recently, although a minor subsistence fishery existed from historical times. However, after introduction of *Oreochromis mossambicus* in 1952 into the freshwater bodies the fishery system of inland waters was changed. In the 1990s, the government promotional programme of inland fishery stopped on a religious basis. Nevertheless, subsidies and aid programmes for inland fisheries resumed with the support of consecutive governments in 1994. In situations where CBF has been popular among farmers as an additional source of income, the demand for 'residual' water has increased. Under these circumstances, farmers have to use water for rice farming more efficiently in order to maintain a 'residual' volume of water for other competing demands. In most Asian countries, the fresh water fisheries and aquaculture sector are attractive areas of their fisheries. In Sri Lanka, the importance of freshwater fisheries and the benefits on the low-income groups to enhance their food security has been recognized. However, what is needed is to develop a comprehensive integrated management plan for the multiple use of water in the reservoirs (De Silva, 1991).

[5] Residual volume of water is defined as the 'remaining volume of water in the reservoir after water has been released for rice farming at a given time. It is assumed that loss of water due to evaporation and seepage is minimal.

Legal dimension of water institutions in VISs

There is no village tradition to exclude those who use residual volumes of water for multiple purposes in the reservoirs (Siriweera, 1994). Therefore, any solution for allocation of water efficiently needs to consider the existing legal dimensions.

Farmers have private property rights over individual land holdings. However, farmers cannot transfer their water user rights to any other productive alternative because water allocations are made by FOs based on collective decisions with priority given for rice farming. For this reason, the needs of CBF are not considered by the FOs, and as a result, water is always under- allocated for CBF. Therefore, there is a trade-off between the use of water for rice farming and other competing uses such as CBF because the existing allocation mechanism for residual water fails to achieve the maximum social benefits.

The more important legislation and its key provisions provide an overview of the situation relating to the legal dimension of water institutions in the country. The village council was the earliest known institution that engaged in water allocation rights. In 1815, the British rulers abolished village councils but they were re-established in 1856. The Irrigation Ordinance (No. 32) was first enacted in 1856 by the British colonial administration to both legalise customary irrigation practices and to prescribe the conditions for water extraction, particularly for rice cultivation. Notably, this ordinance does not mandate a planning system nor does it address important issues such as inter-sectoral allocation. Appointment of an irrigation headman by the British administration was the first turning point of collective management into state control in 1856 (Leach, 1961). Following political independence in 1948, cultivation committees were appointed under the Paddy Land Act. However, these committees were abolished and replaced by appointed officers nominated by Members of Parliament in 1977. The Agrarian Services Act of 1979 and subsequent amendments were related to regulations governing the land tenure systems of paddy land and the management of minor irrigation schemes. The latter function was transferred subsequently to Provincial Councils. At present, the Act provides legal recognition to FOs, and stipulates the responsibilities of the FOs including the levying of water fees, and confers the authority on DAD to support the activities of FOs. However, the existing legislation does not adequately address Sri Lanka's current and anticipated water resources management needs. One of the major shortcomings is that the existing laws do not provide a logical basis for inter-sectoral water allocation.

Policy option

Policies can be considered as alternative institutions. Water re-allocation aims to allocate water for enhancement of the total reservoir water productivity. The analysis of marginal value product (MVP) of water shows that the optimal allocation of water between rice and CBF production enables an increase in reservoir water productivity.

Several policy options have been discussed in order for better management of irrigation water. A market based approach such as introducing water markets: sale of exchange in coexistence with subsidies is one discourse. Ensuring tradable water rights: recognizing the current users and establishing the rights is the other end. Service related user charges in operation and management of irrigation systems are currently practiced informally. The other method is volumetric pricing which is widely used in Japanees agriculture (Kobayashi, 2005).

Integrated water resources management approaches are proposed especially for the small-scale irrigation systems such as VISs.

Proposed integrated agriculture - aquaculture system (IAAS)

The traditional strategies for sustainable utilization of VISs, have disappeared recently, mainly due to the macroeconomic policies of the governments, and management systems, recent agricultural modernization and population increases that have changed the biophysical, environmental, and socio-economic setup in the minor irrigation-system. Local institutions have already weakened under the modern centralized administration (Abeyratne and Perera 1984; Ulluwishewa, 1995; Aheeyar, 2001). Nevetheless, reservoirs have the potential to develop CBF together with agriculture which is able to contribute to poverty allevation of the rural poor (Mendis, 1977) with the integration of other sub systems such as livestock and forestry in the upper catchment of the VISs (Figure 2).

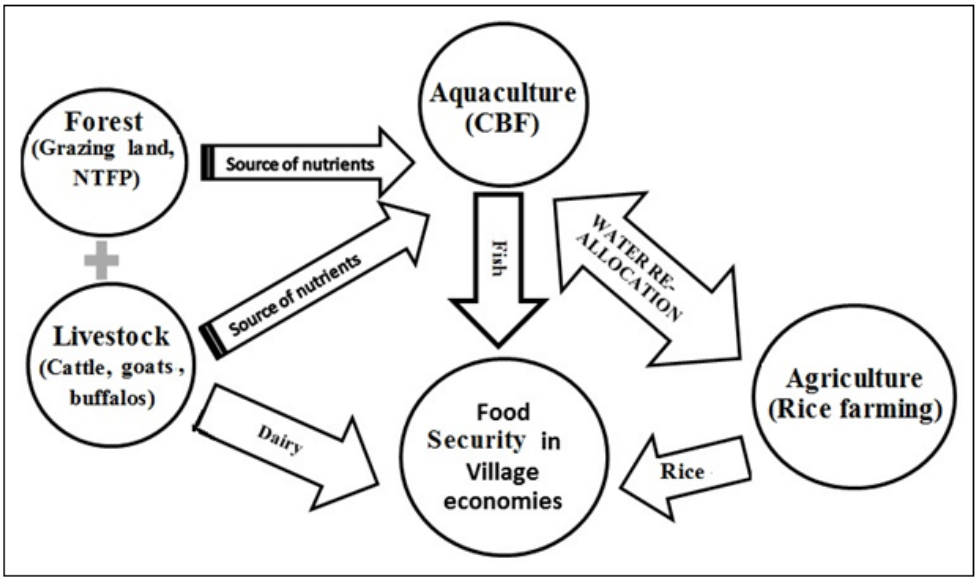

Figure 2. Proposed Integrated Agriculture Aquaculture System (IAAS)

1. The forest sub-system
2. The animal husbandry (cattle and water buffalos)
3. The Aquaculture sub-system (CBF)
4. The agriculture sub-system (rice farming)

In the next section these four sub systems are explained according to the interconnection of the resource flow of the VISs: forest, animal husbandry, fishing and crop cultivation (rice).

Forest sub-system

The forest cover in the catchment areas, perennial trees growing in the irrigation tank and on either side of the irrigation canals of the village agro-ecocomplexes contribute to increased crop and fish productivity. The forest cover in this system enhances the production of organic matter, thus maintaining soil fertility, reducing erosion, conserving water. Water flowing from the forest to the reservoir and then to the paddy fields contain forest – soil runoff that is rich in elements of soil

fertility. The vegetative cover associated with the irrigation system provides dead leaves and soft debris for making fish habitats (Ulluwishewa, 1991).

Animal husbandry (cattle and water buffalos)

Livestock, mainly buffaloes and other cattle were important in the agro-ecocomplex to provide draught power for ploughing and maturing of the paddy fields (Ulluwishewa, 1991). The catchment (peripheral) areas of the VISs become terrestrial habitats during the dry season due to the heavy draw-down effect of the VISs. These areas often serve as grazing for animals (*i.e.* buffaloes, cattle and other domesticated and wild animals). Animal droppings, terrestrial vegetation residues and solar exposed detritus of the bottom sediments and other allochthonous materials are the main nutritional inputs of the VISs. With the monsoon rains, the water level of VISs gradually increases which results in flushing of nutrients into the reservoirs providing favourable conditions for growth of plankton. Chandrasoma (1986) showed that high primary productivity levels in these VISs favour the aquaculture of food fish particularly, the polyculture of carps. Animal grazing in the catchment plays a major role in nutrient dynamics by adding dung in the peripheral areas of VISs. Athula *et al.* (2008) claimed that the VISs in the Hambantota and Monaragala districts were more productive than those in the Anuradhapura and Kurunegala districts in terms of chlorophyll-a content.

Aquaculture sub-system (CBF)

Integration of fishery and rice cultivation in the paddy fields has been a long-standing practice among the farmers of small scale irrigations in Sri Lanka until the heavy usage of fertilizers and pesticides. This integration is also used as an integrated pest management practice. The carnivorous species contributed by controlling harmful insects and worms while herbivorous species consumed algae and weeds (Ulluwishewa, 1991). The ultimate result was increased farm productivity.

Agriculture sub-system (rice farming)

Sustainability of agriculture ensures long-term welfare benefits for small-scale rural farmers (Farshad, 1993). Agriculture in Sri Lanka includes growing of rice and field crops, livestock, bee keeping and inland fisheries (Agrarian Development Act No 46 of 2000). Historically, the rural life style in Sri Lanka was based on a water culture which had a hydraulic civilization of 2.6 ha of reservoirs to every square kilo meter of the island (De Silva *et al.* 2006). Any IAAS involves an agriculture that usually existed before the introduction of the aquaculture. Rice farming in the paddy fields was the main agricultural activity and home gardening and shifting cultivation (Chena) were the complementary agricultural activities in typical agro-ecocomplexs. Successive agricultural systems ensures the food security of the villagers.

Implementation of IAAS

Water supplies for rice production were based mainly on reservoir-based irrigation systems. Therefore, the efficient use of water in the irrigation systems is a necessary condition for any proposed IAAS. Saving more water in the reservoirs facilitates successful CBF production. Grazing animals and growing forests enhance the CBF. Therefore, the proposed IAAS must essentially include these four sub-systems to ensure food security by providing rice, fish, and dairy product to the

villagers. The main four agricultural activities are rice cultivation, CBF, livestock and forestry of the proposed IAAS (Figure 3). The two main actors of the planning stage of IAAS are FOs and the relevant government representatives at village level. Aggregate benefits can be assessed and revised at the first meeting of the cultivation season *(Kanna* meeting).

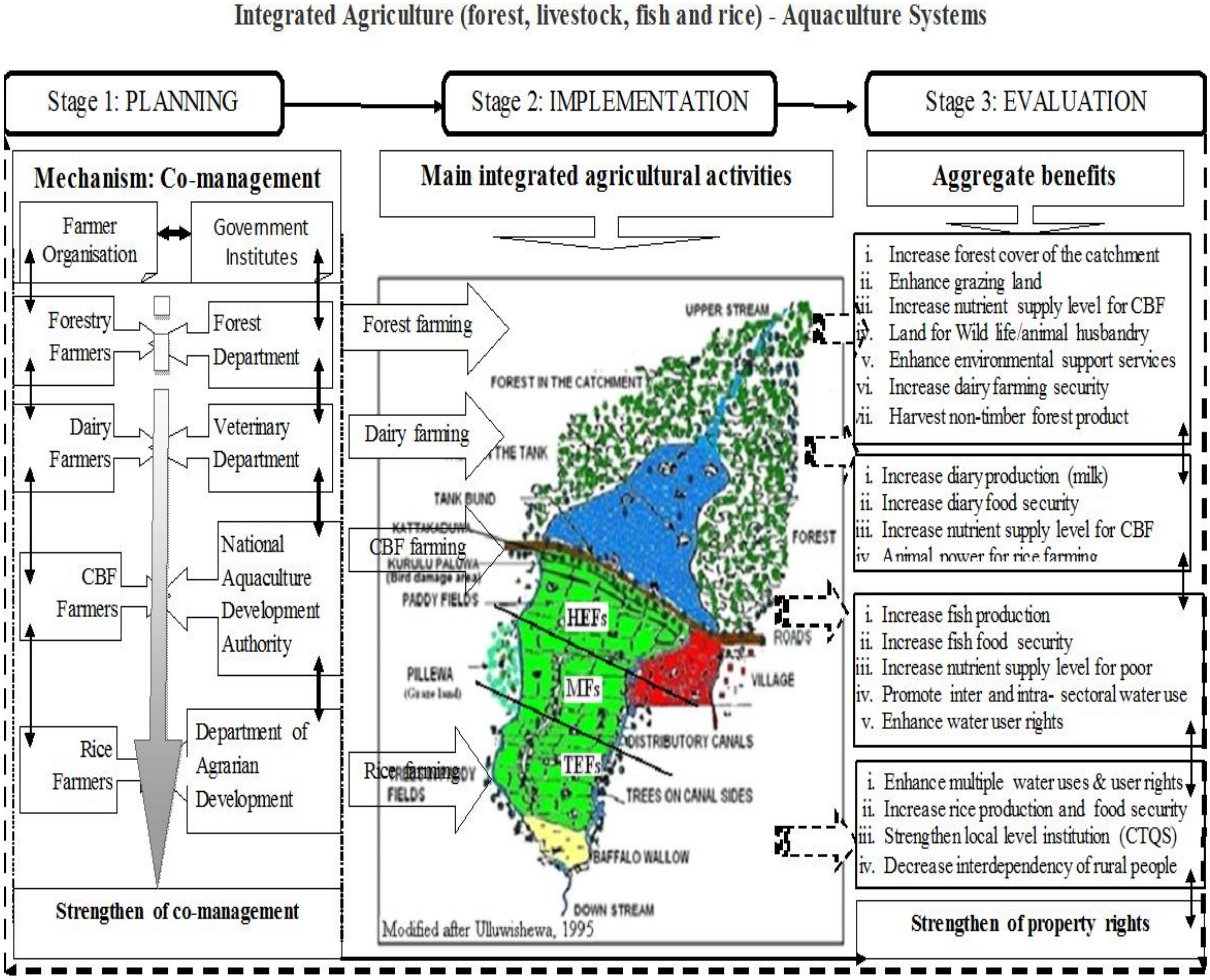

Figure 3. Proposed integrated reservoir-based agricultural activities in VISs

In the proposed IAAS, there is a possibility for encouraging livestock farming in the watershed areas within a framework of integrated agriculture (Prein, 2002) for sustainable CBF. As such, an integrated crop (rice and forest)-animal (fish and livestock) systems should be established as formal institutions under the umbrella of a FOs. This will ensure the conservation of the environment, increase food productivity and ensure the food security.

Successful IASS can be achieved through strengthening of co-management and property rights. It is important for policy makers to know by how much agricultural production can be increased by increasing its TE, without altering the amount of available water, given the technology involved. It has been estimated that for the same quantity of input, it is possible to increase output by up to 28% in rice farming in VISs (Kularatne *et al.* 2012). It also has been found that enhancing the institutional capacity of FOs will further improve technical TE. Furthermore, it has been shown that if it is possible

to put in place a system to transfer land ownership and hence water user rights to solve locational sharing issues, this will improve the institutional capacity of the FOs and will thereby help to reduce technical inefficiency. It has been also found that the total benefits of reservoir water can be increased by improving water use efficiency in rice farming and improving the TE of CBF production.

There are three important areas which need to be addressed in order to achieve a higher level of food productivity of IAAS by strengthening of co-management as an implementing mechanism in order to ensure the irrigation water user rights. These are:

1. Efficient use of irrigation water increases the residual volume of reservoir water, which can be used for multiple purposes.
2. The inter-sectoral water allocation mechanism is made effective by introducing an acceptable transferable water user rights system.
3. Total benefits of irrigation water can be increased by solving water user rights for alternative water uses (*i.e.* CBF production) and ensuring transferability of water among the multiple uses.

1. Efficient use of irrigation water:

Water allocation is a critical issue in an IAAS for maximizing benefits among the sub-systems (*i.e.* rice farming and fishing). Estimates show that the effect of optimal allocation from actual level to the frontier level of production would increase total water productivity three-fold. For this to occur, water would need to be reallocated by reducing 32% of the actual allocation. Such inefficient volumes of water can be reallocated for CBF production by 53%.The estimated shadow value of water (per M/ha) at the given level of TE is LKR 20660 (approximately AU$ 206) per M/ha. This can be increased by approximately five times (up to LKR 71055 per M/ha) by removing the technical inefficiency of rice farming.

Water re-allocation in VISs can be estimated under the policy option of demand shifting. The existing demand for water shifts with re-allocation decisions. Removing inefficient use of water in rice farming is the main factor for the demand shift. Consequently, MVP of water is increased by three times at the optimal allocation of water in the frontier level of production. With the increase of water demand, the volume of water is increased by approximately 32%. This is because the residual volume of water is increased with optimal water allocation (re-allocation) in the reservoirs. Therefore, removing inefficient usage of water in rice farming increases the volume of water which can be used for CBF production. This means that the farmers' total net benefits (TNB) increases by LKR 21553 per M/ha of water used for reservoir based agriculture.

The most influential factors for TE were FOs membership and the participatory rate in FO activities (collective action) while paddy field location, water sharing and landownership issues decreased TE. These results proved that low efficiency among rice farmers is mainly due to inefficient use of water. Therefore, the enhancement of co-operative arrangements (collective action) is effective in increasing the TE of allocating irrigation water for rice farming. In summary, there are two possible ways of improving TE in rice farming. First, by formalising transferability of land ownership and

hence, water user rights. Second, enhancing institutional capacity of FOs in order to solve locational water sharing issues.

The mean TE of CBF in these VISs was only 33%. Furthermore, 54.2% of CBF farmers are beyond the mean TE level. This is lower than the mean TE of 0.57 for existing aquaculture systems in Asia. In the context of CBF production, the residual volume of water used for CBF production was highly significant (at the 1% level). With respect to the 10% increase of residual water, CBF production increased by 4.5%. As such, there is a possibility of increasing CBF production from 2,715 kg to 8827 kg per reservoir by operating at full efficiency. In order to achieve these efficiency gains, attention has to be paid to strengthening group stability, improving accessibility of extension services and promoting a mechanism for maintaining independent investment on CBF without depending on subsidies, and to ensure well defined water user rights. Investigation of current water use patterns and the estimation of intra-sector optimal allocation of water have enabled the researcher to make allocation decisions, which will eventually increase sectoral water productivity.

Established water user rights and transferable water user rights must be initiated at the existing village level institutions (FOs). The Ministry of Agrarian Services and the Ministry of Fisheries and Aquatic Resources should formulate relevant policies for further strengthening relevant institutions. The responsible legal body for solving water allocation issues with FOs is the DAD network. NAQDA should facilitate the technical aspects of CBF production. Collaboration of these two institutions with FOs would considerably improve collective action of farmers and would advance the co-management strategy further. Selection of farmers for CBF production in particular VISs can cope with the re-introduction of community transferable quota systems (CTQs), and as mentioned earlier are already being practised in rice farming[6] systems and can be successfully used for the selection of CBF farmers without introducing new selection criteria as it is inherently practised by village farmers.

2. Strengthening of property rights

The sustainability of IAAS depends on efficiency and the equity of water use. Therefore, strengthening of property rights and community transferable quota systems are suggested for the sustainability of IAAS. Many developing countries have begun to decentralise policies and decision-making related to the development, public services, and the environment (Agarawal, 2001). Nevertheless, central government management of water and aquatic resources (e.g., fisheries) often lacks the capacity to enforce property rights and regulations on resource use. In addition to institutional arrangements, market power for allocation of property rights through transferable

[6] *Thattumaru* is the rotational cultivation of one plot of land by several children within one household. One of the children cultivates the entire plot for one season, the next season another son/daughter will cultivate the entire plot, etc. *Thattumaru* prevents the division of land into smaller and smaller plots. In each village, *Thattumaru* is applied on average by 4 or 5 families with small landholdings. *Thattumaru* is practiced to prevent conflicts among children. *Thattumaru* is subject to creative arrangements, such as selling one's share to one's brother or sister, or in combination with sharecropping or a private lease. *Thattumaru* is most likely to be practiced when further fragmentation of lands within a family is no longer feasible.

property rights is discussed in the literature (Hahn, 1984). Wingard (2000) suggests that transferable quotas to the community rather than transfer to the individuals minimise social impacts and internalise externalities.. Suitable water allocation policy reforms remain poorly understood. Furthermore, because of increasing competition for water use, water allocation has to be treated in an integrated manner, considering all purposes of water uses (Swanson, 2003).

The subject of water rights is receiving increasing attention from policy makers due to the growing understanding that ill-defined water user rights impairs efficient use because it creates high transaction costs (information search costs, negotiation and monitoring) in decision making on water use. The main costs of collective decision-making reviewed in the economic literature are the so-called transaction costs. Transaction costs are those costs of collective agreement decisions or the costs of making decisions. One of the determinants of the transaction cost is the group size involved in decision making

It has been shown in many parts of the world that co-management and community-based management of natural resources could provide effective alternatives for natural resources management (Wade, 1987). Ostrom *et al*. (1990) have summarised and documented some of those key conditions necessary to maintain successful co-management institutions. From their work, co-management is likely to succeed in resource systems where boundaries are clearly defined, membership is clearly defined, the user group is cohesive, the user group has prior experience with the organisation, and the benefits of management exceed costs. Additional criteria are that there will be participation in management by those who are affected, due to the enforcement of management rules under which these co-management approaches are enforced. Further, the user group has legal rights to organise, so that there is co-operation and leadership at the community level. Furthermore, there is decentralisation and delegation of authority, and there is co-ordination between the government and the community.

It has been found that participation rates for collective action (FO activities) are a positive factor for increasing TE in rice and CBF production in the case of reservoir based irrigation in Sri Lanka. However, recent studies on major, medium and minor irrigation systems in the Kurunagala and Anuradhapura districts of Sri Lanka have found that the participation rate for FO activities is 38% because of lack of accountability and transparency of FOs (Thiruchelvam, 2010). As a result, Thiruchelvam (2010) recommended establishing strong linkages between FOs (primary level stakeholders) and water authorities (responsible institutions) for successful irrigation management. According to Khalkheili & Zamani (2009), the establishment of co-operation with water authority operators will enhance farmers' participation in irrigation management. Furthermore, co-management practices should promote active involvement of immediate actors to the resources for their management rather than relying on institutional hierarchy.

3. Transferable water user rights system

The idea of implementing CTQs is not a new phenomenon in reservoir-based agriculture in Sri Lanka. However, the CTQs need to be reinstated and re-established as formal institutions under the umbrella of a FO system, in order to increase total productivity of reservoir-based agriculture.

Selection of farmers for CBF production can be streamlined by re-introducing CTQs. This is already being practiced by rice farmers in Sri Lanka and is known as the *thattumarau*[6] system. This system ensures transferable water user rights for all farmers between the different consecutive cropping years and culture cycles. Furthermore, farmers are likely to be motivated by more efficient intra-sectoral water management due to the increased benefits received from CBF production. This may also solve the problem of inefficient use of water in the middle fields of the command areas. Therefore, establishing both water user rights for CBF production and ensuring the existence of a transferable water user rights structure for rice farming can be achieved by establishing a CTQ system.

The economic gains of re-allocating water was necessary to estimate farmers' welfare in comparison to that of competing water users. The allocation of water in VISs is assumed to be at sub-optimum levels when water usage is inefficient. The total potential expansion of CBF with optimal efficiency in water allocation in rice farming, estimated by measuring the net farmers' welfare, is LKR 21553 in rice and CBF production per M/ha of reservoir water. The total net benefits of CBF production are lower than the total net benefit of rice due to the low levels of given TE. However, it can be concluded that the total net benefit of reservoir water re-allocation can be increased which is mainly attributed to the marginal value of water productivity of CBF production. Therefore, the main constraints to increasing reservoir water productivity by incorporating CBF production are sharing economic benefits of CBF production and the selection of CBF farmers. These two constraints, which arise with water re-allocation, are due to the absence of well-defined water user rights for CBF production and the non-existence of transferability of water user rights in rice farming.

Community Transferable Quota (CTQ) system on CBF production

Community level agricultural management is very common in Asia. The CTQs have many potential advantages for addressing social shortcomings of efficiency and equity. Under a CTQ system, a large number of people would be able to remain in the fishery at least on a culture-cycle basis, as a group of farmers to get involved in CBF activities. This may determine the total number of farmers in the group. Under a CTQ system, there are two factors which may maximise the economic benefits while minimising cost impacts:

If the group of farmers is considerably large (small group favours group stability), they can be given a community quota on the basis of the culture cycle. The total group can be divided into smaller groups. Group one could be given an opportunity in the first culture cycle and the second group could be given an opportunity in the next cycle and so on. This system could be rotated for each consecutive culture-cycle.

Depending on the spatial MVP of rice farming, one group of farmers with higher MVP of rice farming could cultivate rice, while others who have a lower value of MVP could become involved in CBF, especially during the share cropping seasons. The idea of implementing CTQs is not a new phenomenon in reservoir-based agriculture. However, the CTQs need to be reinstated and re-established as formal institutions under the umbrella of a FO system, in order to increase total productivity of reservoir-based agriculture. At present most fish poaching occurs due to villagers having no opportunity to participate in CBF production. CTQ systems facilitate maximum

involvement in both rice and CBF production. Furthermore, farmers are likely to be motivated by more efficient intra-sectoral water management due to the increased benefits received from CBF production. This may also solve the problem of inefficient use of water in the MFs of the command areas. Therefore, establishing both water user rights for CBF production and ensuring the existence of a transferable water user rights structure for rice farming can be achieved by establishing a CTQ system in reservoir-based agriculture in Sri Lanka.

Conclusion and recommendations

Based on the findings of studies it is clear that strengthening of property rights of water users and the CTQ system are ideal for dealing with the water re-allocation issues for sustainability of the IAAS. Therefore, community transferable quota systems (CTQs) are proposed as a possible policy instrument within the framework of the co-management strategy which can be implemented through DAD and NAQDA.

Agricultural use has a low marginal value for water (Junna *et al*., 2006). Re-allocation of water from this sector to others, based on the sectoral marginal values of the resource, has the potential to increase the income of the poorest households. The above sections showed that agriculture's marginal returns from using water in VISs are not as high as in CBF production. Furthermore, re-allocation of water from agriculture to CBF production increases the MVP of reservoir water. Therefore, the results favour the implementation of inter-sectoral water re-allocation based on TE and support the recommendation that the institution of user rights and inter-sectoral transfer of rights could be a workable policy for promoting CBF production. Co-management of the water resources is the most appropriate mechanism that can be recommended where a combination of both farmers and formal institutions would share the management responsibilities in the market environment.

Analysis of the research on water allocation shows that the TE of the existing mode of water allocation can be improved and that water can be optimally re-allocated in VISs in Sri Lanka. The productivity of water can be increased in VISs through a combination of sharing responsibility in water management between responsible institutions and primary level stakeholders based on market demand. In this context, it is clear that existing institutions (*i.e.,* FOs) need to be re-organised, while market forces are used to guide the efficient re-allocation decisions. In such a scenario, farmers would be motivated to manage their water demands, not only through enforcement of rules, but also through the development of an understanding of the importance of efficient water use in rice farming in order to increase reservoir water productivity.

This high level of water productivity can be achieved by the development of CBF in VISs without altering the volume of water used in rice farming. CTQs can be introduced to the CBF production system for the selection of CBF farmers. Co-management of water resources is the best policy for reservoir water management with market guidance from the MVP of water. An increase of farmers' welfare, through reservoir-based agriculture, would remove village dependency on external sources (subsidies and political support). The FOs could act as the main village level institutions for reservoir water management and decision making in collaboration with the relevant formal institutions. This research has demonstrated that instead of allocating water based on farmers' experience (and

haphazardly) they can now base their decisions on efficient water use with a view to increasing water productivity of VISs in order to enhance their incomes and the welfare of the community.

As a whole, the value of reservoir water can be increased by re-allocating water through minimising the inefficient volume of water use in the different sectors. The main problem of the intra-sector water allocation at present is that farmers have no proper motivation to engage effectively in field-level water management. However, results from this study show that intra-sectoral efficient use of water increases the inter-sectoral reservoir water allocation, which ultimately increases the total reservoir water productivity, thereby food productivity and security.

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