ADVANCING A **NEXUS APPROACH** TO THE SUSTAINABLE MANAGEMENT OF **WATER, SOIL** AND **WASTE**

DRAFT WHITE BOOK

In the occasion of the international Kick-off Workshop
on 11-12 November 2013

UNITED NATIONS UNIVERSITY
UNU-FLORES
Institute for Integrated Management
of Material Fluxes and of Resources

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Advancing a nexus approach to the sustainable management of water, soil and waste

Introduction

When preparing for the kick-off workshop on advancing a nexus approach to the sustainable management of water, soil and waste, from the very beginning it was discussed that one of the outcomes should be a white book on the topic of the workshop (see concept note in the workshop booklet). The workshop, intended as a kick-off for regular Nexus conferences (see below) should address research and issues of capacity development in a broad sense, including education and training as well as institutional capacity development related to implementation of the nexus approach to environmental resources´ management. Examples and case studies on research projects, best-practicesand curriculum requirements should be introduced and discussed to provide an up-to-date overview on the issue.

Reflecting the main topics of the workshop, the white book follows the same basic structure and thus deals with

1. Opportunities for adopting a nexus approach to the management of environmental resources and its relevance to the envisaged sustainable development goals and the post-2015 development agenda;
2. Challenges for the nexus approach in managing water, soil and waste under conditions of global change;
3. Capacity Development for research and education programmes addressing the nexus;
4. Institutional arrangements and governance structures that advance a nexus approach to sustainable management of water, soil and waste.

It was envisaged that the issues worked out in this White Book may represent a reference for future developments by identifying "hot" topics related to the nexus approach and defining research and teaching programmes in collaboration with partners. The white book may also provide a roadmap for research and action with respect to the nexus approach and a conceptual reference to define the specific scope of the next Nexus conference(s).

The first of these bi-annual Dresden Nexus Conferences is scheduled for March, 25 to 27 2015. The title of the conference is:

The Dresden Nexus Conference

Advancing a Advancing a nexus approach to the sustainable

management of water, soil and waste

(2015: Global Change, SDGs, Nexus)

Contributors to the white book have been asked to provide their views on one of the four topics mentioned above, considering also the question how to define the nexus in the context of water, soil and waste management. The first chapter on Nexus Approach and Sustainability: Opportunities and Challenges is provided by Dr. Srikantha Herath, UNU-ISP. He works out the relation between the nexus approach, which provides a platform to overcome the traditional compartmentalized scientific approaches and sustainability and the linkage to the development goals: MDGs and SDGs.

The second chapter on the nexus approach to managing water, soil and waste under changing climate and growing demands on natural resources by Prof. Rattan Lal, Ohio State University, numerous inter-connected issues with regard to soil, water, energy, climate and food are identified which can and should be addressed through a nexus approach. He argues that one of the major challenges of humankind, the growing demand for food while water and soil resources are declining can be met by exploring other options including aquaponics, aeroponics and skyfarming, in each case following principles of the nexus approach.

Capacity Development for research and education – Teaching and training programmes addressing the nexus is the topic of chapter three by Prof. Christian Bernhofer and Marco Leidel, TU Dresden. They argue that the need for well-trained environmental engineers is high and that capacity development activities addressing the nexus are urgently needed – proposing various tools and approaches for nexus education.

The last chapter provided by Mathew Kurian and Reza Ardakanian deals with Institutional arrangements and governance structures. They identified some major divides of environmental governance and key overarching questions that can guide rethinking of governance structures that may advance the nexus approach. The paper concludes by presenting preliminary hypotheses with the objective of addressing the goals of session 4 of the workshop that is focused on institutional arrangements and governance structures.

The draft white book shall be distributed among participants of the international kick-off workshop, asking for **feed-back and comments by the end of December 2013** (if not provided directly during the workshop). These will be considered while preparing the final version of the white book.

Reza Ardakanian

Director, UNU-FLORES

Nexus Approach and Sustainability: Opportunities and Challenges

Srikantha Herath
Institute for Sustainability and Peace, United Nations University, Tokyo, Japan

Abstract

Global problems have become increasingly complex and interwoven, across disciplines, geographic regions and sectors. Traditional compartmentalized approaches to knowledge generation by dissecting a problem to smaller components that can be managed by different disciplines do not work well in this context. It is necessary to find ways to address problems in an inter-disciplinary manner that promotes taking a holistic viewpoint. While the traditional discipline based knowledge generation has been very effective in advancing knowledge and technology, we need new platforms to put the pieces back together to solve these interwoven complex problems. Nexus approach is such a platform where one can address interlinked problems in an efficient and effective manner. The solutions we seek need to be targeted towards development that is equitable and sustainable. Hence it is important to link the approaches, solutions and linkages within a Nexus platform with global development agenda and concrete actions required to achieve them. This paper describes the approaches to sustainability, sustainable development, global development agenda and how they may link with a particular nexus platform. Importance of capacity development customized to local conditions to achieve these global targets cannot be overstated, and challenges and opportunities in integrated approach to research and education is discussed with experiences from the postgraduate program of UNU-ISP.

Environment and the Earth System

Global environmental concerns grew since late 1960's with the realization of the difficulties associated in trying to meet needs of rapidly growing population with ever increasing demands from earth's limited resources. The space travel made it possible to view earth from outside that highlighted 'spaceship earth' as a total living system with interconnected environmental processes and finite resources. The UN Earth Summit in Stockholm in 1972 was instrumental in channeling these concerns towards a global movement that that demanded attention to effects of human development on nature. The UN report on development issued by World Commission on Environment and Development report, Our Common Future (1987) also known as "Brundtland Report," provided a common platform for different stakeholders and sectors to discuss ways to address this common goal within each discipline. Its definition of sustainable development as the "development, which meets the needs of the present without compromising the ability of future generations to meet their own needs" has linked the carrying capacity of earth environment across generations. While the definition of sustainable development does not provide a precise mechanism for quantifying sustainability, the flexibility it provided allowed different disciplines to explore its meaning and to communicate across disciplines (Daly, 1990). The report was followed by the United Nations Conference on Environment and Development (UNCED) in 1992 in Rio de Janeiro that produced a detailed action agenda, the agenda 21, and UN conventions on Climate Change and Bio Diversity. In 2002 the World Summit on Sustainable Development held in Johannesburg, South Africa reiterated the commitment to address the relationship between the human society and natural environment. The summit came up with an agenda of five priorities, water and sanitation, biodiversity and ecosystems management, energy, agricultural productivity, and health for promoting both development and sustainability (Annan K., 2002). These conferences and activities in-between them has greatly facilitated in generating global interest and follow up on the human development activities and their linkages and dependence to earth environment.

Addressing Sustainability

The recent manifestations of adverse impacts of global environmental change such as climate change, biodiversity loss, global water scarcity has renewed global interest on the need to address sustainability systematically. The discussions within each discipline have been converging towards inter-disciplinary approaches on the basis of 'sustainable development' objectives. For example, as a discipline, economics is usually concerned with allocation of limited resources across all needs in an efficient manner. The primary focus of economics as a discipline on sustainability is the trade off of current consumption for future consumption (Elliot, S. R, 2005). However, the traditional measure of success of economy as the growth of GDP in a given time does not address the issue of resource depletion or use of non-renewables in generating this wealth. The capital used to produce goods needs to be viewed from sustainability viewpoint to clarify the relation between nature and human needs. The total stock of capital may be considered as the sum of natural capital (Kn), i.e, the resources that come from nature, the human capital (Kh), i.e. the knowledge and technology people bring to the production and the capital created (Kc) such as infrastructure and machines. According to Elliot (2005) a group of economists argue for a weaker form of sustainability, where, as long as the total capital remains unchanged the current generation can use a larger share of Kn and leave future generation with increased Kc (better and efficient machines and technology) and Kh (improved knowledge). On the other hand there is an opposing group of economists who do not consider that these different forms of capitals as substitutes. This second group belongs to the discipline 'Ecological Economics' that has been established more than 20 years ago to discuss the relationship between economics and ecosystems. They subscribe to a 'strong sustainability' view that requires maintaining both man made and natural capital intact separately (Dally, 1990). This approach requires addressing the issue of non-renewables essential to maintain human economic and development activities today. Dally (1990) suggested a way of overcoming this difficulty by proposing to invest in renewable substitutes for non-renewables, so that when the non renewable resources are depleted there will be renewable substitutes to take their place. In a recent article in BioScience, Raudsepp-Hearns and colleagues (2010) challenged this notion that ecological damage will eventually lead to decline in human well being by pointing out, in spite of the declining ecosystems services as identified by Millennium Ecosystems Assessment (MA, 2005), the human well-being has been steadily increasing as captured by the continuous increase in human development index (HDI). However, the sustainability approach should not be viewed from a reductive stock-flow framework where natural capital is only producing eco-system services, but holistically considering the complexity, irreversibility, uncertainty and ethical predicaments intrinsic to the natural environment and its connections to humanity (Ang and Passel, 2012).

According to Baumgärtner and Quaas (2010), ethical considerations of sustainability economics need to go beyond the economics-environment relation and aim at justice (a) between human generations (b) within a human generation and (c) between nature and humans. The objectives of economics and social sciences go beyond the domain of justice between humans and nature. It targets the aspiration of every human to address the needs and wants in an equitable manner. Based on the above they argue that sustainability economics should be based on efficiency of resource allocation to achieve two normative goals of (i) achieving needs and wants individual humans and (ii) promoting justice as given from (a) to (c) above. The aspect of justice towards nature in (c) is important not only as a justice towards intrinsic value of nature and consideration for other species who share the earth with humans, but also for the importance of preserving the interconnectedness among earth system processes needed for the regeneration of renewable resources and ecosystems services that are essential for the survival and well being of humans.

From environmental viewpoint, natural resources base also has ecological functions that keep the earth system as a living organism. This implies maintenance of cyclicity or equilibrium status of major biogeochemical cycles such as carbon cycle, nitrogen cycle and water cycle as well as energy balance of the earth system. Disruptions to these cycles or balances may lead to environmental conditions that are significantly different from the present environment in which the current society has developed. Such manifestations can be seen at small scale as increases of flood frequencies and temperatures in dense urban areas due to changes to water cycle and energy balance, or in large scale as climate change due to disruption to earth energy balance.

A sustainable ecology requires that our needs for environmental services can be met without damaging the sustaining natural system. This also requires consideration of environment to absorb waste. Ecological security is defined as the status reflecting the threat to human living, health, basic rights, guarantee of secure life, necessary resources, social order and the ability to adapt to environmental change. This covers environment, economy and society and relates to environment and human security concept. The definition also is close to the ecological economists description of sustainability discussed earlier. The major achievement of sustainable development concept is to bring close natural and social sciences (Daly, 1980) and its ability to serve as a grand compromise between those who are principally concerned with nature and environment, those who value economic development and those who are dedicated to improving the human condition (Kates et. al, 2005).

Development Targets: MDGs and SDGs

While there is general agreement of the three pillars of sustainability there is no general agreement on the subdivisions of each of these dimensions. Indeed one may argue that these divisions are not static but are dynamic, varying with time and societal needs. Thus, another approach to identify what sustainable development aims to achieve is to discuss its objectives in concrete measures. In September 2000, building upon a decade of major United Nations conferences and summits, world leaders came together at United Nations Headquarters in New York to adopt the United Nations Millennium Declaration, committing their nations to a new global partnership to reduce extreme poverty and setting out a series of time-bound targets that have become known as the Millennium Development Goals. Eight of the major goals targeted to be achieved by 2015 are monitored by different UN agencies. The 2013 MDG report by UNDP recognizes that MDGs are the most successful anti-poverty global initiative, as they succeeded in advancing global recognition of poverty and establishing partnerships for its reduction. However, more action is needed in hunger, maternal health, sanitation and environmental protection. A major limitation of MDGs was that it is carried out in a donor driven fashion without focusing on local capacity development for its sustenance. MDGs focuses on ends rather than means and the simple form of goals facilitated achieving basic needs of the most marginalized of the world. Beyond 2015, there is a need to redefine global development targets that encompass human aspirations and earth system sustainability.

One of the major outcomes of the Rio+20 Conference was the agreement by member States to launch a process to develop a set of Sustainable Development Goals (SDGs), which will build upon the Millennium Development Goals and converge with the post 2015 development agenda. The UN was asked to setup an *inclusive and transparent intergovernmental process open to all stakeholders, with a view to developing global sustainable development goals to be agreed by the General Assembly.* (source: *http://sustainabledevelopment.un.org*)

Currently 7 worksreams are engaged in the development of SDGs, which is expected to produce an interim report in 2014 and the final report in 2015. The working streams are the

- Open working group which is a 30 member government representatives
- High level panel of eminent persons chaired by presidents of Indonesia, Liberia and the British prime minister.
- UN System Task Team (UNSTT) co-chaired by UNDESA and UNDP and produced the report, the future we want.
- National, global and thematic consultations
- Regional consultations
- Sustainable Development Solutions Network led by Jeffrey Sachs with memberships from universities, research institutions, civil organizations, etc.
- UN Global Compact

According to the UN system task team (UNSTT) document the following three principles (a) respect for human rights (b) equality and (c) sustainability are proposed as the three principles on which the Sustainable Development Goals are to be built.

Unlike the MDGs, SDGs are expected to encompass not only the basic needs but also the human aspirations considering the sustained planetary wellbeing. Thus, the SDGs will have an *Ecological Ceiling* based on the criteria for planetary well-being and a *Social Floor* considering the basic human well being. The ecological ceiling will address topics such as biodiversity, chemical pollution, climate change, desertification, fresh water, landuse change, oceans, soil degradation, sustainable human development and waste management. It is interesting to note that water-soil-waste nexus is contained in the topics for SDGs currently under discussion. The social floor will be considering topics such as education, energy, food, gender, equality, health, jobs, poverty, resilience, social equity, voice and water. The implementation aspects of SDGs are also expected to differ from MDGs. While the global goals will be a normative framework that is aspirational, universal, time bound and will have means to measure, the implementation of this normative frameworks will depend on specific national targets compatible with own development goals and capacity building activities.

Sustainability Science

What type of education is needed to achieve these development objectives? The traditional form of knowledge production has been organized in academic disciplines where the interest is primarily to produce knowledge on the interaction of physical and human components of nature. For this purpose universities have been organized in faculties and departments. The reward system, career system and quality control by peer review are contained within the disciplinary boundaries. On the other hand, as modern society increasingly demands application-oriented knowledge and the usability of scientific knowledge, integration of knowledge from various disciplines is becoming of vital significance. The 2001 World Congress "Challenges of a Changing Earth 2001" in Amsterdam organized by the International Council for Science (ICSU), the International Geosphere-Biosphere Program (IGBP), the International Human Dimensions Program on Global Environmental Change (IHDP) and the World Climate Research Program (WCRP) proclaimed the birth of a new academic field, namely sustainability science, with strong roots in the environmental aspects of the sustainability concept (Kates et. al, 2001).

Sustainability science has been proposed as a new discipline to integrate approaches and knowledge from different disciplines to solve interconnected global problems. Sustainability science differs from normal science in that it seeks a complimentary truth to traditional form of knowledge generation. Its objective is to ensure the sustainability of earth system. This means we need to have not only the knowledge related to earth system and its processes but also the competency to assess the consequences of knowledge application on the sustainability of earth system. Search of sustainable solutions to global problems requires new methodologies that bring together the three pillars of sustainability; environment, society and economy. Sustainability calls for integration and is well served by the nexus approach. Conversely, we may set up the objectives of nexus approach as to support earth system sustainability and address and resolve opportunities and conflicts in implementing nexus approach on the basis of sustainability principles.

Sustainable Nexus Approaches

Nexus approach is a platform that brings together related disciplines and sectors based on the recognition of the importance of the interconnectedness of resources and their sustainable use. A number of important initiatives emerged recently to advance nexus approach in the context of resource management, notably in the water and energy, and water-energy-food, dimensions. An effective and common approach to identify inter-dependencies and areas for improvement of resource use among nexus focus areas has been the full life cycle analysis of products and activities among the sectors in a nexus group. In addition to potential benefits, such analysis would also invariably identify conflict situations among them, especially in resource scarce situations. Resolving conflicts as well as optimizing resource use among different disciplines then calls for a framework for assessing effectiveness and evaluating trade-offs on common as well as independent activities and resource uses among the nexus focus areas.

In carrying out such analysis and addressing trade-offs among sectors, we should also make attempts not to confine nexus approach only to improve efficiency of resource use among the nexus sectors, but also take a broader viewpoint on the impact of resource use on the overall environment and societal well being. The figure (1a) shows the aim of sustainability approaches. We may consider that each of the circles represent a set of feasible solution in a given dimension to a particular problem. The objective is then to search for solutions depicted in the gray middle area that are acceptable environmentally, economically and socially. A similar approach can be adopted in the search for solutions agreeable to water, soil and waste domains as shown in (1b). However, unlike the sustainability approach where a particular problem is viewed from different perspectives, there could be occasions in a nexus setting where it is difficult to find solutions that are easily resolvable, such as, waste management and water scarcity, or soil salinity intrusion and ground water use. In such cases it become necessary to look for solutions consistent with a higher dimension than the dimension where the conflicts arise. Sustainability provides a framework to address such concerns, where the acceptance of activities being considered in a nexus grouping can be assessed from all three sustainability dimensions. This mapping could be either one to one, or one to many as shown in the figure (2). It would be possible to seek a sustainable solution from environmental, societal and economic perspectives by addressing each from different nexus elements of an activity a community is engaged in as in the relation A of figure (2). The activity could be one that engages all three elements of soil, water waste nexus such as use of partially treated urban waste water in plantations to complete waste treatment and promote growth of trees. The economic benefit may come from the waster treatment component, the environmental benefits from CO_2 sequestration, water recharge, and social acceptance from greenery and amenity. The figure 2 A, is for illustrative purposes only and the linkages could be from any element of the nexus to any dimension of sustainability. If the project under consideration is large and complex, and has the potential to be split back to different compartments in the future it may be worthwhile to see that each nexus elemental component is sustainable on its own as shown by relation B of the figure (2), when trade-offs are considered. The main objetive of a sustainability framework would be to prioritize among a number of feasible projects working towards the production of similar goods or services.

Research to Implementation and Capacity Development Needs

To support the societal demand for application-oriented knowledge, a new mode of application-oriented research is emerging on top of traditional academic research employing a wider set of organizations and types of researchers working in specific contexts on specific problems. Research is not exclusively based in universities but profit from the participation of implementation agencies, user communities and professional bodies. This development is especially useful for the developing countries where the major challenges lie in the difficulty of translating research to practice. This difficulty stems from lack of investment for research in industry and business (Schaaper, 2011), which in the developed countries plays the vital role of converting research, conducted in universities and specialized research institutions to practice . Therefore, bringing research and practitioner communities together in developing countries to form partnerships for conducting and implementing research is extremely important to advance locally relevant sustainable development practices adopting advances in science and technology.

Another major challenge faced by the global community today is the difficulty in adjusting to rapid rate of global changes and the uncertainty of the future status of environment they bring about. Developing countries face these burdens more as they try to overcome the challenges of meeting growing resource needs and managing environment changes, including climate change impacts. To be sustainable, societies need to adapt to global changes according to local conditions. For example, it is well known that although climate projections provides us with general trends of change, the information required at local scale for designing adaptation measures is not easily available due to various associated uncertainties. Not only the future climate conditions would vary with the selection of future forcing parameters, even for a given future scenario different climate models provide a widely varying range of future projections. In addition, methodologies adopted in downscaling from global to local scale as well as correcting the projected data to match with past observations by bias correction approaches introduce further uncertainties to projections. Thus, adaptation has to be a continuous process aided by improved observations and projections at the local scale. Therefore, to be sustainable under global changes, societies need to be adaptive and measures for adaptation have to evolve and be managed locally. From the above, capacity development at both national and subnational levels to assess impacts of global change and design adaptation strategies emerge as one of the most important requirements for sustainability.

Nexus Approach: Challenges and Opportunities

Integration across disciplines: Research

As described above the need to integrate across disciplines is accepted broadly as a requisite for sustainability. The increase of efficiency and search for synergies is expected in the new programs to be undertaken at UNU-FLORES in addressing Water-Soil-Waste nexus. In operationalizing such concepts it will become necessary to adopt research methodology models that will ensure this integration.

The Institute for Sustainability and Peace of the United Nations University (UNU-ISP) was established in 2009 to address the pressing global problems from a Sustainability Science perspective, taking a holistic view of the problems that cut across individual disciplines. In implementing the programme, UNU-ISP encourages research that seeks solutions based on different models that link environment, society and economy. One such approach is shown in figure (3b). Here at first a set of feasible solutions for a given problem, such as urban flood reduction with different types of structural and distributed measures, is obtained through environmental analyses. Then a subset of those solutions is identified which also satisfy economic constraints and finally solutions that pass the test of social acceptance are selected for implementation. A similar approach can also be taken in the water-soil-waste nexus, where the models for acceptance could be efficiency, minimizing resource utilization, etc.

Integration across disciplines: Education

Similar to research across disciplines, developing educational programs across disciplines is a challenging task. Providing a broader understanding across disciplines is desirable, but will produce graduates who understand issues, but not experts to carry out research and program implementation. To make a balance between broad overview education and the specialization required, the UNU-ISP M.Sc. program consists of three components that provide;

- A broad holistic view point, through overview courses
- A deep understanding of a particular field through specialized courses
- A set of courses to provide skills needed to implement research, through competency courses

The outline of the program is shown in the figure (3c).

Integrating capacity development, education and research

In order to be effective, capacity development should target a range of stakeholders and actors who are involved in development processes and whose cooperative actions are essential for the sustainability of the development efforts. To be effective UNU-ISP, capacity development programs cover the following three major target groups;

- Researchers and Postgraduate sector: This sector is the most important segment of a country that has the capacity and the resources to absorb new knowledge and customize it to local conditions. Educational programs should endeavor to strengthen and engage the research/postgraduate sector in contemporary problems.
- Professionals/Practitioners: Professionals and practitioners need to be introduced to new methodologies and tools as well as emerging and modified design standards. In order to be effective, it is necessary to design programs that can be conducted in a short time and can reach a wide audience.
- Administrative / Local governments: The final target group is the administrators and decision makers including local government officials, who need to have an over view of the technology and science as well as its use. Key messages should be developed for this target group.

It is important to ensure that the above target groups do not work in isolation. This is a major challenge, especially for developing countries as discussed above. Capacity development programs can be designed to address this issue by enabling collaboration among stake holders by conducting group oriented training where groups consist of participants from each stakeholder group who would continue to work together after the training programs providing the long term commitment required for sustainable solutions. One of the approaches adopted at UNU-ISP is to develop pilot demonstration projects, which also act as field stations that promote such collaboration among the postgraduate, government and policy-making communities through applied research work. These demonstration projects provide the venue to customize knowledge and methodologies from the global scale to local scale. This concept is demonstrated in figure (4).

Regional Integration

Resource sharing through various networks and institutional arrangements can make a great impact and difference in the effectiveness of efforts to integrate knowledge across disciplines. It is encouraged that UNU-FLORES develop networks of researchers engaged in soil-water-waste disciplines. UNU-ISP has benefitted greatly in establishing a University Network for Climate and Ecosystems Change Adaptation Research (UN-CECAR). Research and education are the main focus of the UN-CECAR and the network brings together available resources and expertise across disciplinary lines to work collaboratively to enhance understanding on climate change impacts and advance adaptation research for the design of appropriate policy and development strategies. A sample of activities is shown in Figure 5. This approach not only helps to share expertise across educational institutions, but also helps develop research teams and researcher networks of both students and faculty to engage on sustainability issues.

Conclusions

Rapid global changes and growing population demands bring unprecedented challenges in meeting the resource needs challenges of present and future generations within the carrying capacity of earth so that not only the present generation but also the future generations can meet their needs. The solution to these problems converges in integration of disciplines at different levels under the broad umbrella of sustainability. Integration of different disciplines and methodologies brings in new challenges as well as opportunities. New educational and research programs based on sustainability science, where integration of different disciplinary approaches provides pragmatic solutions need to be developed and promoted. In adapting to rapidly changing environmental and social context of these problems, it is necessary to recognize localism, that is incorporating local characteristics in the solutions, is vital to make them sustainable. Postgraduate sector can be the ideal platform for disciplinary integration for sustainability and rapid dissemination and customization of useful global knowledge to local conditions, especially in the developing countries.

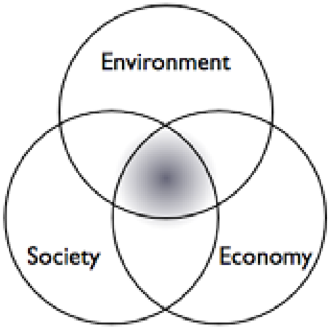


Fig. 1a Sustainability

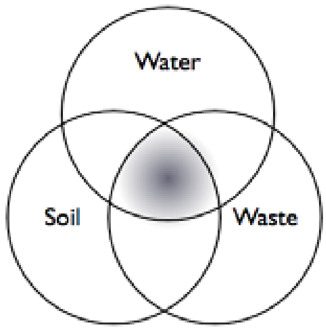


Fig. 1b Water-Soil-Waste

Fig. 1 Integrating Disciplines

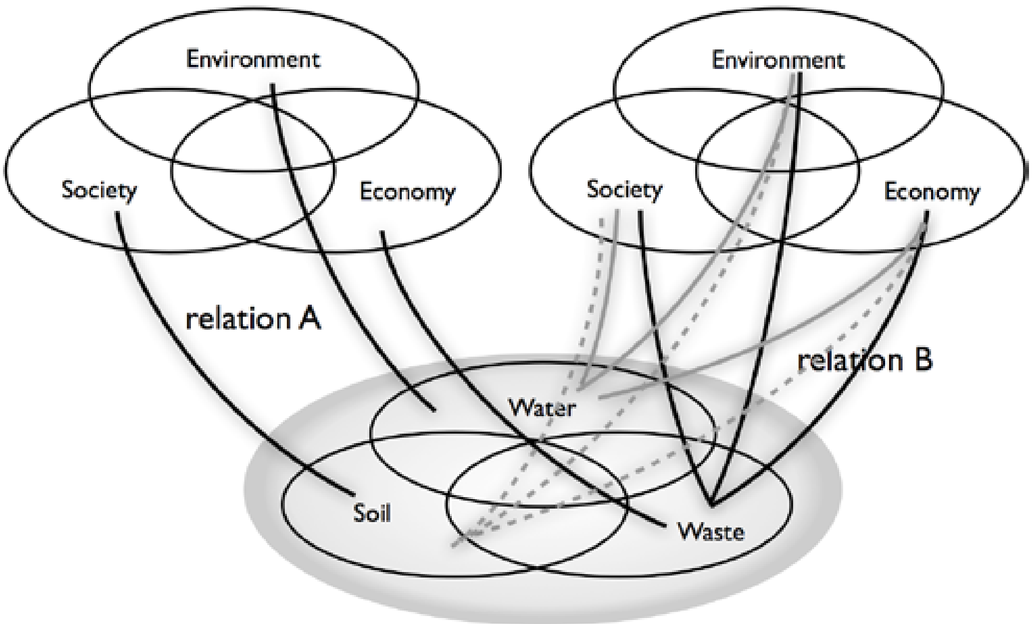
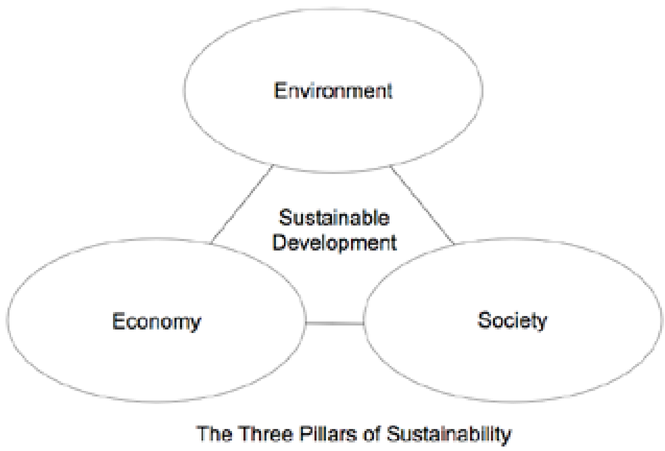
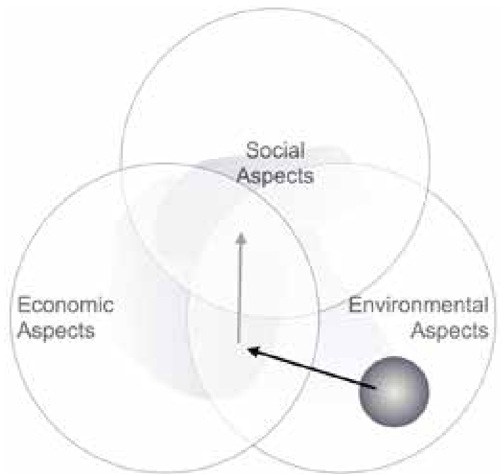


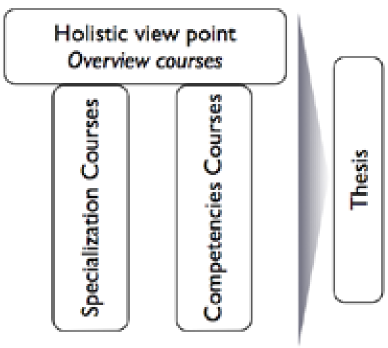
Fig. 2 Mapping water-soil-waste nexus with sustainability approach



a. Sustainability Focus

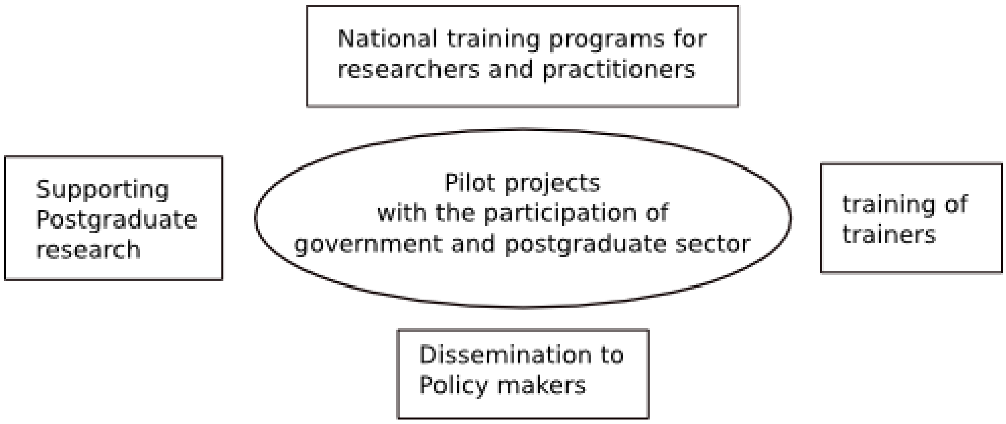


b. Research Methodology



c. Educational Program Components

Fig. 3 Research and Education in addressing sustainability



c. Educational Program Components

Fig. 5 Activities of University Network for Climate and Ecosystems Change Adaptation Research

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The nexus approach to managing water, soil and waste under changing climate and growing demands on natural resources

Rattan Lal

Carbon Management and Sequestration Center
The Ohio State University
2021 Coffey Rd
210 Kottman Hall
Columbus OH 43210 USA
lal.1@osu.edu

Abstract

The increase in human population by ~1000 times since the beginning of settled agriculture, from a few million to 7.2 billion in 2013 and projected to be 9.6 billion by 2050 and ~11 billion by 2100, has severely stressed the fragile and scarce soil, water and other natural resources. Rather than bringing new land under agriculture, which must be protected for nature conservancy, the strategy is to pursue sustainable intensification of existing land for narrowing the yield gap by enhancing the use efficiency and minimizing losses. Because of the strong inter-connectivity among natural resources, it is pertinent to adopt the nexus approach. The latter is specifically important towards reducing, reusing, and recycling the waste from anthropogenic uses. Pertinent examples of the nexus approach in maximizing the resource use efficiency include the inter-connectivity in energy-water, poverty-environment, soil-waste, water-soil, soil-climate, and food security-natural resources. The nexus approach is also pertinent to innovative and emerging approaches to increasing food production and improving the environment within urban centers by adopting skyfarming or vertical farming through aeroponics, hydroponics, aquaponics and other soil-less cultures. The goal is to protect the meager soil resources for numerous ecosystem services and nature conservancy. The nexus approach is also relevant to developing bioregenerative agricultural systems for extraterrestrial and planetary exploration. Researchable priorities for space agriculture include understanding of pedological, hydrological, physiological, and microbiological processes using Martian and Lunar regoliths. The goal is to produce food while generating oxygen, purifying water and decomposing waste in bioregenerative modules for human habitation on the moon and Mars.

Keywords

Bioregenerative Agriculture, Food – Energy –Water – Waste Nexus, Skyfarming, Space Agriculture, Extraterrestrial Farming, Poverty – Environment Nexus, Soil–Climate Nexus, Sustainable Intensification, Nanowaste.

Introduction

The human population has increased more than a thousand times from 2-20 million at the dawn of settled agriculture about 10-12 millennia ago to 7.2 billion in 2013. It is projected to reach 9.6 billion by 2050 and ~11 billion by 2100 (U.N., 2012). The unprecedented growth, not only in the number, but also in the affluence life style, is impacting Earth's biogeochemical processes, and some even beyond the planetary boundaries (Rockstrom et al., 2009). The agroecosystems and related activities are already covering 38% of the Earth's terrestrial surface, emitting 30-35% of the global greenhouse gases (GHGs) and using 71% of the global freshwater withdrawal (Foley et al., 2011). With the focus on agricultural intensification since the 1960s, the irrigated land area has increased by a factor of 2, fertilizer use by 5, and nitrogen use by 8. The present water use by agriculture of 3100 km^3/yr is expected to increase to 4500 km^3/yr by 2030 (McKinsey & Co., 2009). Consequently, global food production must be increased by 50% by 2030 and 100% by 2050 (OECD, 2010). Above all, 24% of the terrestrial ecosystems are degraded and more are prone to anthropogenic perturbations (Bai et al., 2008), and land, water and air quality are at risks (Tilman et al., 2011). Estimates of food-insecure population in 2012 vary from 868 million (FAO, 2012) to 1.33 billion (Small Planet Initiative, 2013). Despite large appropriation of global net primary productivity (NPP) by humans, more than 1 out of 7 persons is food-insecure (Small Planet Initiative, 2013), 2 out of 7 are prone to deficiency of Fe and other micronutrients (WHO, 2013), and almost all of the food-insecure people live in the developing countries where natural resources are already under great stress (FAO, 2012). Faced with these challenges, and the concern that the current increase in crop yields may not feed the human world, what is next for agriculture (Beddington et al., 2012)? Thus, there is a strong need to explore innovative options towards sustainable intensification of agroecosystems. The strategy is to understand the linkages among resources and the underlying processes governing critical processes, which are determinants of principal functions and ecosystem services.

A) Natural Resources and Human Wellbeing

Food security remains to be a major among global issues of the 21st Century. Principal determinants of food security are the availability and quality of soil resources, and their interactions with water resources and vegetation (crop species) through energy-based inputs using managerial skills for optimizing the net primary productivity or NPP (Fig. 1). The latter is specifically affected by critical linkages which govern specific functions of nexuses between: (i) soil and water for the plant available water capacity by influencing water retention and transmission, conversion of blue and grey into green water, and moderating the effects of pedologic and agronomic droughts, (ii) soil and vegetation for biogeochemical cycling which determines elemental budgets (C, N, P, S), nutrient use efficiency, root distribution and turnover and soil/root respiration, (iii) vegetation and energy for energy/mass transformation and influencing energy productivity, ecosystem C budget, and biomass feedstocks for biofuel production, and (iv) energy and water affecting the hydrological cycle with specific impacts on water and energy balance on a landscape, energy use in irrigated systems, and moderation of the hydrological/meteorological droughts (Fig. 1). These nexuses affect and are affected by the climate change and variability on the one hand and the anthropogenic perturbations (human demands) on the other (Fig. 1).

The importance of nexuses and inter-connectivity is also documented by a close relationship between soil security, climate security, water security, energy security, economic security, and political security (Fig. 2). Indeed, an important ramification of the strong nexuses among natural resources is the human wellbeing based on specific needs, which are increasing because of the growing population and affluent lifestyle. For example, the food security (availability, access, nutritional quality, retention) strongly depends on soil security (quality, resilience), water security (renewability, availability, quality), energy security (supply, price, dependability), climate security (optimal temperature and moisture regimes, and low frequency of extreme events), economic security (income and access to resources), and political stability (peace and harmony) (Fig. 2).

Indeed, both economic and political security are closely linked with food security on the one hand and security of natural resources on the other (Fig. 2). Therefore, the co-productivity generated by the anthropogenic use of primary resources (soil, water, climate) and secondary inputs (fertilizers, amendments, irrigation, tillage) must be optimized. Understanding and judiciously managing the food-soil-water-waste nexus is important to achieving the sustainable use of natural resources, enhancing human wellbeing, improving the environment, and sustaining ecosystem functions and services.

B) The Nexus Approach

Nature does not recognize waste, from every death emerges a new life through a meticulous recycling of essential elements contained in the so-called "waste". There are strong inter-linkages and inter-dependences among factors and processes impacting food security and resource use (Fig. 2). Rather than perceiving it as a great risk (World Economic Forum, 2011), the soil-water-energy-waste-food nexus provides an opportunity to enhance the use-efficiency of natural resources, recycle the waste (co-products), and close the cycles of C, plant nutrients (N, P, S, K) and H2O.

Therefore, the objective of this article is to deliberate opportunities and challenges of the nexus (linkages) approach to sustainable intensification of the natural resource so that the resource use efficiency is enhanced, losses (water, nutrient, energy) are minimized, and the flow of environmental/ecosystem services is increased. Also discussed is the relevance of the nexus approach to skyfarming or vertical farming and to explore the significance of soil-less agriculture using aeroponics and hydroponics. The need and prioritization of the nexus approaches to understanding processes governing extraterrestrial farming, using Lunar and Martian regoliths, are also deliberated. This article builds upon the #1 in UNU-FLORES Lecture Series (Lal, 2013).

Materials and methods

This article is based on collation, assessment and synthesis of some relevant literature on the nexus approach. The literature was collated with a focus on integrated and holistic approach to sustainable intensification of some managed ecosystems. The literature review presented herein in specifically focused on application of the nexus approach to: energy–water, poverty–environment, soil–waste, water–soil, soil-climate and food security nexuses.

The review also explores applications of the nexus approach to skyfarming or vertical farming for addressing issues of food security and environment in urban ecosystems. With the growing need and interests in the planetary exploration, the review provides some examples and outlines research needs for extraterrestrial agriculture on the moon and Mars under hypogravity conditions.

Results

Results of the literature-based review of the nexus approach are presented below on the basis of thematic issues listed above.

(a) Energy-Water Nexus

Water and energy, two basic necessities of any civilization, are closely intertwined (Gentleman, 2011; Schnoor, 2011). Most ancient civilizations were based on access to water and its energy (the hydric civilization). The water-energy nexus involves bi-direction consequences originating from coupled processes and factors governing use efficiency of resources involved. There are three types of water: blue, green and grey. Plants can utilize only the green water (transpiration). Thus, conversion of blue (runoff, stream flow, groundwater) and grey (human waste) into green water requires energy. It is needed for transformation of blue (uplift) and grey (purification) water for increasing plant uptake and improving the NPP. Thus, increase in global material consumption also increases the water demand and the vice versa. About 20 gallons per megawatt-hour are consumed by evaporation of the hot water from the surface of the receiving body, and power plant with cooling towers requires 400-500 gallons per megawatt-hour for evaporation (Hightower, 2011). Indeed, water use is expected to grow globally by 30 to 100% for energy sector, 20-40% for agriculture, and 20-40% for domestic water supply. Yet, the supply of blue water may decrease by 25% because of reduction in surface water flows in the mid-latitude region because of the projected climate change (Hightower, 2011). Thus, enhancing the use efficiency of water and energy for diverse uses and conversion of grey into green water are critical strategies. Indeed, sewage, flowing (blue) water and warm wastewater are potentially important energy sources (Venkatesh and Dhakal, 2012).

In the context of fossil fuel consumption, C footprint must be assessed through life cycle analyses (LCA) at all stages of the production chain, and the baseline or system boundaries must be carefully defined. Because of the increasing urbanization, with more than 50% of the world's population already living in urban centers and 80% projected to be urbanized by 2050, the water-energy nexus is more important than ever before for the cities of the future. Thus, there is a strong need of achieving net zero C and pollution through reuse and recycling of water and recovering the plant nutrients and other resources. Production of biofuel feedstocks, through establishment of energy plantations is also water–intensive. Both C and H2O footprints are sub-components of the overall environmental footprint (Table 1). There are large differences in water required per unit quantity of biofuel (ethanol) produced from different biofuel feedstocks, and for different management systems. Thus, problems must be addressed rather than shifted, because the water-energy nexus is a high priority at regional (CEC, 2005), national (Hardy et al., 2012) and the internationals level (Venkatesh and Dhakal, 2012). In terms of the policy interventions, localized challenges are diminished when approached in the context of broader perspectives. Similarly, regionally important challenges cannot be prioritized locally (Scott et al., 2011).

The water-energy nexus is also linked with the virtual water and the water footprint in relation to the production-consumption patterns. The virtual water is defined as the amount of water needed to produce the goods and services to be consumed by a country or individual. It is the amount of water that is needed to generate a product such as a 1 kg of wheat or 1 kg of beef meat (Allan, 1993; 1994). Thus, the virtual water can be traded, exported and imported (Veláquez et al., 2011). In comparison, water footprint refers to "the volume of water necessary to produce the goods and services consumed by the inhabitants of a country" (Hoekstra and Chapagain, 2007). The water footprint of different food products are given in Table 2.

(b) Poverty-Environment Nexus

There exists a strong poverty-environment nexus (Dasgupta et al., 2001). Indeed, when people are poverty stricken and miserable, they pass on their sufferings to the land (Lal, 2008). The poverty is strongly linked with the access to basic resources (e.g., water, energy, soil). Thus, poor households exacerbate environmental and resource degradation. Agricultural, industrial and economic development are closely interlinked with the environment and climate. Therefore, any developmental strategies must address the environment (climate change), food and energy (biofuel) security, and land restoration. Therefore, development and climate (environment) nexus is an important consideration (Davidson et al., 2013). In addition to agriculture, the urban ecosystems (refer the section on skyfarming) are also affected by the water-energy-environment nexus. The global climate change may exacerbate these challenges (Novotny, 2011; Smit and Parnell, 2012). Thus, there is a need to improve resilience of urban and agricultural ecosystems.

(c) Soil-Water-Food Nexus

Two important determinants of global food security are soil and water resources. These resources are finite, unequally distributed over the landscape, and prone to degradation and pollution by misuse and mismanagement. Rapid depletion of ground water and salinization are examples of misuse and mismanagement of soil and water resources (Khan et al., 2009). The low productivity of smallholder agriculture in drier areas of developing world may be attributed to the limited availability of the good quality soil and water resources (Twomlow et al., 2008). It is the water movement in and through the soil regolith which impacts salinity and numerous other pedogenic processes (Schoenberger and Wysocki, 2005). The annual per capita water availability is decreasing in the Indo-Gangetic Plains, North China Plains, southcentral parts of the U.S. Great Plains, etc. Thus, producing more crops and livestock products per unit of agricultural water invested within the soilscape is a key strategy of achieving food security.

(d) Soil-Waste Nexus

Conversion of organic waste to compost for use as a soil amendment has beneficial impacts on soil quality. Rather than taking biosolids to landfills, composting biosolids and using as soil amendment has numerous ancillary benefits. Soil applications of waste from plant and animal residues can alleviate some constraints and enhance soil quality. For example, application of manure can improve aggregation, nutrient retention and availability, microbial biomass C, water retention and transmission, earthworm activity, etc. Organic waste can also be converted into vermicompost. Soil application of vermicompost can enhance plant available water holding capacity and help in sustaining favorable components of the hydrologic cycle (Munnoli and Bhosle, 2011). Long-term improvements in soil quality have been reported through application of olive mill pomace compost in Andalucia, Spain (Garcia-Ruiz et al., 2012). Using biomass urban waste (lawn clippings) can improve quality of urban soil, and strengthen its ecosystem services (Washbourne et al., 2012), conversion of organic waste to compost can reduce emissions of GHGs (Kong et al., 2012), thus linking mitigation and adaptation through composting (Ayers and Hug, 2009). In Santa Catarina, Brazil, Palhares et al. (2012) observed that managing the use of animal manure with optimum chemical fertilizer use and installing riparian fencing may also be a mitigation option for protecting the water quality.

Production of cellulosic or the 2nd generation biofuels can also provide effluent/waste which can be used as a soil amendment. Long-term ecological benefits of a bioethanol system can be realized through a system approach to biogas recovery and adoption of agricultural practices to enhance agronomic productivity without input of chemical fertilizers (Silalertruksa and Gheewala, 2011). Conversion of municipal solid waste into biofuel is another benefit of the nexus approach. Shi et al. (2009) reported that globally up to 82.9 billion liters of waste paper-derived cellulosic ethanol can be produced replacing 5.36% of the gasoline consumption. It is important, however, to reduce the risks of N2O emissions to enhance the environmental sustainability of biofuels (Carter et al., 2012). With a high global warming potential (GWP) of N2O (298) and of CH4 (21), any benefits of biofuels can be negated by the emissions of these gases. Composting from food waste at the community center is another option to avail the benefits of soil-waste nexus (Schwalb et al., 2011).

Rather than composting for improving soil quality, some biowaste can also be used/converted into animal feed and their dung used as manure. On the contrary, animal manure can also be used for algae production as a biofuel feedstock. Bai et al. (2012) reported that pig sludge can be used to produce algae (e.g., Chlorella spp., Scenedesmus spp., Arthrospora spp.) with 141-152 Mg/ha of annual dry yield on a 12-day long rotation period in an outdoor experiment. The biomass can be used as a biofuel feedstock.

(e) Water-Soil Nexus

Being essential for life, soil-water management is crucial to agricultural productivity, and ecosystem sustainability (Loucks and Jia, 2012). With increasing scarcity of freshwater, the wastewater can be used to enhance soil quality and improve productivity. Thus, waste water systems have been considered to assess gaseous emissions both from reservoirs and wastewater treatment plants (Hall et al., 2011). When used for irrigation, wastewater application can reduce C footprint, earn C credits and enhance crop yields (Hanjra et al., 2012). Thus, wastewater is a valuable resource of irrigation water in arid and semi-arid regions (Babayan et al., 2012). However, risks of environmental and health hazards must be minimized. Continuous application of wastewater may lead to accumulation of heavy metals in soils. Thus, rate of application must be assessed in relation to soil type, crop species, etc.

The runoff water generated from a mixed-farm landscale unit may be enriched in plant nutrients. There exists a strong relationship between the sources of pollution (e.g., cows, pigs, poultries) and quality of water runoff (Palhares et al., 2012). Under such conditions, installing a riparian buffer may be useful to mitigate non-point source pollution. Similar to the municipal wastewater, the winery wastewater can also be used for irrigation. However, the high salt loading of winery wastewater is an issue that must be addressed (Laurenson et al., 2012). Emission of NH3 from slurry emits bad odor. Thus, separate management of solid and liquid fractions, covered manure storage and band spread slurry application may be some mitigation options (Dinuccio et al., 2012).

Another ramification of water-soil nexus is the transport of soluble nutrients in surface runoff from cropland and grazing lands receiving manure. Technological options to minimize nutrient losses include (Harmel et al., 2009): (i) combining application of organic and inorganic fertilizers, (ii) providing alternate fertilizer sources, and (iii) enhancing understanding of the farming communities. There also exists a water markets and soil salinity nexus which is an important issue with regards to secondary salinization risks (Khan et al., 2009).

(f) Food Security – Natural Resources

Food security depends on an adequate availability of good quality soil, water and nutrients. The nexus between integrated natural resources management and integrated water resources management is important to improving productivity of smallholder agriculture (Twomlow et al., 2008). Being in short supply, sustainable intensification (Pretty et al., 2011) of these limited resources is critical. Sustainable intensification, producing more from less by reducing losses, is relevant to resource scarcity. Further, simultaneous management of water and energy is also essential to addressing the climate change (Beal et al., 2013), and developing climate-resilient agriculture. In this context, virtual water and the water footprint are also inter-related (Velázquez, et al. 2011), and constitute important issues of global significance. Water mismanagement and lack of provisions for adequate drainage can also exacerbate the soil-water-salinity nexus (Khan et al., 2009), which is a major problem in irrigated agriculture in arid and semi-arid biomes. The strategy is to avoid deforestation and conversion of natural to agroecosystems and effectively use resources already allocated to agroecosystems. It is thus important to protect arable land, biodiversity, and ecosystem resilience (Jacobsen et al., 2013), functions and services. In terms of water, the strategy is to look beyond the watershed, minimize hydro-centricity (Allan, 2006) and carefully evaluate the importance of hydropedology (Schoeneberger and Wysocki, 2005). Soil hydrology is relevant to understanding transport of water and nutrients over and through the soilscape. The soil-water-climate-food nexus must be carefully managed, especially in arid and semi-arid regions. Thus, the importance of integrated management of natural resources, and especially integrated water resource management cannot be over-emphasized (Twomlow et al., 2008).

The water–food security nexus is more important now than ever before because of the growing water scarcity caused by the increasing population pressure. Water available for agriculture is a major factor for food security in arid and semi-arid regions of the word (Rosegrant and Cai, 2001). The strong nexus between agriculture, which depends on water availability and economic development, cannot be overlooked (Rahman et al., 1999). The changing and highly variable climate is especially important in rapidly developing economies such as China (Mu et al., 2009). Further, 60% of the global population may suffer from water scarcity by 2025 (Qadir et al., 2006). Thus, identification of non-conventional water resources (e.g., grey water, desalination of sea water) is crucial to the wellbeing of population in arid regions. The importance of water saving techniques and increasing water productivity cannot be over emphasized (Hamdy et al., 2003). In this context, there is an urgent need for rethinking of the virtual water with regards to global food trade and policy perspective (Kumar and Singh, 2005). Thus, the nexus approach is critical to advancing food security in he water-scarce world.

Skyfarming: the urban waste and food nexus

Most of the land suitable for crop production is already being cultivated. The unused land exists in regions that are either too dry, too wet, too cold, too hot or otherwise inaccessible. Further, some of the potentially available land exists in ecologically-sensitive ecoregions (e.g., tropical rainforests). Yet, the per capita arable land area has decreased to about 2500m2 (0.25 ha). Whereas sustainable intensification to narrow the yield gap in developing countries (e.g., Sub-Saharan African, South Asia, the Caribbeans, Andean region) is needed and must be pursued, there are ecological limits to what can be achieved. The soil-less agriculture is not a new concept, and it has been used in research for decades throughout the 20th Century. The soil-less culture refers to "an artificial means of providing plants with support and a reservoir of nutrients and water" (Johnson Jr., 1985). There are several types of soil-less culture. Floating gardens, a form of hydroponics, has been used in South Asia (Haq and Nawaz, 2009; Irfanullah et al., 2011; Wikipedia, 2013) and Central America (Squier, 1851). The "Chinampas", small floating islands constructed from mud and plants, were used by Aztecs to grow crops. Aztecs expanded the city's land surface to cover over five square miles (http://www.instructables.com/id/Build-an-Aztec-Water-Garden/). Nonetheless, floating gardens now constitute modern technology (Sweat et al., 2013).

The skyfarming/vertical farming is an innovative option of enhancing food production by utilizing the food–waste nexus in urban ecosystems. The skyfarming involves indoor crop production within purpose-built multistory buildings (Germer et al., 2011; Fischetti, 2008). It minimizes resource use (land, water, nutrients) per unit of crop production, and facilitates soil-less culture where nutrients and water can be supplied through one of the following options: (i) **aeroponics** involves spray of nutrients on roots growing in air, (ii) **hydroponics** involves floating the roots in a pond of water, (iii) **nutrient-film-techniques** involves periodic flooding of roots with nutrients, and (v) **aquaponics** involves combination of raising fish and plants for recycling the nutrients in wastewater. The basic principle is to eliminate runoff from agricultural ecosystems, reduce the adverse impacts on the environment, and include skyfarming as an integral component of urban planning (Despommer, 2009). Nutrients contained in the grey water (urban waste water) and biosolids (e.g., lawn clippings) can be effectively and efficiently recycled through skyfarming. The World's largest indoor vertical farm (FarmedHere, 90,000 ft²) is located in a suburb of Chicago, IL (http://www.mnm.com/your-home/organic-farming-gardening/blogs/ ; http://www.plantchicago.com). Another 2-acre vertical farm is planned for Milwaukee, WI and operated by the Growing Power Vertical Farm Co. (http://www.growingpower.org/verticalfarm.html). Their 5-story utility includes south-facing greenhouses and aquaponics for production of vegetables year-round. A downtown Tokyo office operates a vertical farm (http.//gizmodo.com/this-downtown-tokyo-office-tower-contained-a-vibrant-ver-1140007476). Singapore, a city state with little arable land, operates A-Go-Gro vertical farm, which is 9m high (three stories) for growing leafy vegetables (http://skygreens.appsfly.com/media). Another vertical farm, Jack Ng's City Farm, has a capacity to produce 1 ton of fresh vegetables everyday (http://www.amusingplanet.com/2013108/singapores-vertical-farms.html). Vertical farming is also being used in the Middle Eastern countries where scarcity of water is the principal constraint to traditional farming. Being water and nutrients-conserving because of the closed loop systems, the aeropoinc systems (providing nutrients to plant roots by a mist) are developed by using a reusable cloth medium rather than soil. The so called "AreoFarms: Soil-less Solution" uses artificial lighting in old or vacant warehouse-type buildings in crumbling downtown lots of major cities. The controlled lighting system, operating 24/7, has numerous advantages of rapid growth cycle, no pesticides, complete absence of contamination, and reusable cloth media (http://www.greenprophet.com/2010/05areofarms_vertical-farming/). The innovative concept of skyfarming is also being included in modern art. An example of such an artistic vision is "Farming the Land and Sky: Art Meets Cosmology in a Sustainable Environment" (Bertol, 2000).

Space agriculture and the nexus approach

Recycling and utilizing the waste is integral to space agriculture for providing the life support system through exploitation of the food–waste nexus on extraterrestrial bodies such as the moon and Mars. The space agriculture technology is critical to developing a Lunar Outpost for any space exploration initiative (Hossner et al., 1991). The goal of a nexus approach is to design a bioregenerative life-support system.

The NASA developed a Controlled Ecological Life-Support System or CELSS for long-duration human habitation on the moon or Mars. Salisbury (1992) outlined some challenges and researchable priorities in designing a Lunar or Martian microgravity CELSS. Technological challenges listed by Salisbury included: (i) creation and control of gas composition (CO2), light, and the roosting media, (ii) equipment for waste recycling, (iii) techniques for environmental monitoring and control, and (iv) identifying appropriate species and cultivars, and optimal growing conditions. Several life-support systems have been designed, technologies tested for growing plants in space (Morrow et al., 1994) and manned space mission (Aydogan-Cremashi et al., 2009; Nelson et al., 2008). Simulation modeling have been used to assess mass balance for a biological life support system (Volk and Rummel, 1987), the C balance in bioregenative life support systems (Wheeler, 2003), and equipment for composting on Mars (Finstein et al., 1999a,b), by the use of hyper-thermic aerobic composting bacteria (Kanazewa et al., 2003). The first space vegetables were grown under the CELSS project by means of the controlled environmental conditions (Ivanova et al., 1992).

Principal researchable challenges include understanding of the pedological, microbiological and physiological processes under microgravity conditions (Hoson et al., 2000; Maggi and Pallud, 2010). It is important to understand the biophysical limitations in physiological transport and exchange processes of plants growing in microgravity (Portfield, 2002). There is a need to understand the effects of hypogravity on transpiration of plant leaves (Hirai and Kitaya, 2009), water distribution and flow (Jones and Or, 1959; Heinde et al., 2007) and capillarity in porous soil (Podolsky and Mashinsky, 1994; Jones and Or 1998), water supply and substrate properties in porous root matrix systems (Bingham et al., 2000), and modeling heat and mass transfer for human habitation on Mars (Yamashita et al., 2006).

Since the discovery of water on the moon (Hand, 2009) and Mars (Gortzinger, 2009), there has been a growing interest in space agriculture. Using the principles of bioregenerative strategies for long-term life support in extraterrestrial conditions, soil-based cropping is considered as a more effective approach for waste decomposition, C sequestration, oxygen production, and water bio-filtration than those of hydroponics and aeroponics cropping (Maggi and Pallud, 2010). Silverstone et al. (2003) proposed a soil-based bioregenerative agriculture. The proposed closed system included a wetland wastewater treatment system similar to that of the Biosphere 2.

The nexus approach can be extremely useful in developing bioregenerative life-support systems for planetary exploration.

Discussion

There are numerous inter-connected issues with regard to soil, water, energy, climate and food. These issues, with numerous manifestations and ramifications, can be appropriately addressed through the nexus approach. If not sustainably managed, ignoring these nexuses can be a serious threat to the terrestrial-based human civilization (Diamond, 2005). Improved provisions of food, energy and water necessitate policy interventions (Bazilian et al., 2011) to optimize resources and enhance the use efficiency. Just as managing the energy-water nexus is important (Hussey and Pittuck, 2012), so are soil-water, soil-waste, climate-waste, climate-soil, and soil-water-energy-waste-climate nexuses. The bottom line is integrating waste recycling and reuse at all levels of the production chain. Yet, the safe operating space must be clearly defined (Beddington et al., 2012), because agriculture is a major force affecting the environment even beyond the planetary boundaries (Rockstrom et al., 2009).

Rather than using soil as the medium of agricultural production, the nexus approach is also crucial to developing soil less culture (Fig.4). The growing food demands of 9.6 billion by 2050 and ~11 billion by 2100 (UN, 2012) can be met by exploring other options including aquaponics, aeroponics and skyfarming. In this context, the nutrient-rich grey water can play a significant role, for which there exists a strong need for development of appropriate technology (Li et al., 2008; 2009). Earthworms are useful organisms to enhance and treat high-strength wastewater (Chiarawatchai et al., 2008), and can be critical to minimize the risks of reusing the wastewater (Zaidi, 2007), through appropriate technology (Wendland et al., 2007). The use of bacterial cultures and synthetic biology (Blamer et al., 2013) is relevant to enhance environmental security. Potential and challenges of large-scale water storage in surface reservoirs need to be assessed (Lindstrom et al., 2012) for site/region specific situations. Nanotechnology industry can be used in managing environmental issues, by using the principles of green chemistry and development of biodegradable goods (Vaseashta, 2009). However, the nanotechnology itself is generating a new form of waste stream called nanowaste (Musee, 2010), which may need additional research.

The nexus approach is also crucial in sequestration of atmospheric CO2 either through biological measures (soil, trees, wetland, oceans) or engineering measures (geological sequestration). For example, stable isotropic techniques can be used to assess leakages in geologic sequestration (Lackner and Brennan, 2009), and in determining the old vs. new carbon in the soil (Puget et al., 2005).

There exists a strong link between soil and climate on the one hand, and soil and ecosystems C on the other. World soils have been a major source of atmospheric CO2 since the onset of agriculture, but can be a sink through conversion of degraded and desertified lands to restorative ecosystems, and adoption of recommended management practices. In comparison with the C capture and storage (CCS) technology in geological strata at $600 to $800 per Mg of CO2 (Economist, 2012), the biological technique of C sequestration in soils may have negative cost because of numerous co-benefits such as enhancing soil quality, increasing use efficiency of inputs, and improving agronomic productivity (McKinsy and Co., 2009). However, several CCS Programs in Norway and in the U.S. have been cancelled or put on hold (Wald, 2013) while the U.S. has allocated the U.S. DOE some $6 billion to spend on CCS-R&D since 2008, the CCS technology has not been proved to work at commercial scale neither in the U.S. nor elsewhere. In addition, CCS can add another 30% to the cost of generating electricity (Kintishch, 2013). Thus, biosequestration of C through soil-climate nexus may be a natural fix to reducing the net anthropogenic emissions.

The use of biomass input application of organic wastes, use of green manuring and other amendments to improve quality of soils under sugarcane production (Cheong et al., 2009), which strengthen and validate the importance of the nexus approach in addressing complex issues. The conducted throughout the production chain is also important and useful to perform the greenhouse gas accounting for emission trading (Cowie et al., 2012).

Conclusions

The review presented supports the following conclusions:

- Increase in anthropogenic demands has jeopardized natural resources, and exacerbated soil and environmental degradation.
- The nexus approach, based on inter-connectivity among resources and the underpinning processes, is essential to minimizing losses and maximizing use efficiency.
- Sustainable intensification of agroecosystems involves exploring the connectivity among water–energy, water–waste, soil–waste, soil-climate, and food production–water–energy nexuses.
- Because of numerous functions and ecosystem services provisioned by soil, it is prudent to protect, restore, and enhance soil resources and protect for nature conservancy. Thus, use of soil-less culture is important to protecting soil resources.
- In addition to meeting the food demand of the growing population, the nexus approach is also critical to adaptation and mitigation of the climate change.
- Skyfarming or vertical farming is needed to produce food for urban environments by utilizing and recycling waste through principles underlying the nexus approach.
- Extraterrestrial farming under Lunar and Martial environments is crucial to planetary exploration.
- Bioregenerative systems, based on the nexus approach and utilizing Lunar and Martian regoliths, can be used to develop space farming in support of human habitation.

Tables

Table 1

Water footprint (WF) for renewable energy from biomass (Adapted from Gerben-Leenes et al., 2009)

m³ H2O/GJ					
Crop	**Latin Name**	**Brazil**	**The Netherlands**	**USA**	**Zimbabwe**
Cassava	Manihoe esculenta	30	-	-	205
Coconut	Cocos nucifera	49	-	-	203
Cotton	Gossipium hirsutum	96	-	135	356
Groundnuts	Arachis prostrate	51	-	58	254
Maize	Zee mays	39	9	18	200
Miscanthus	Miscanthus gigantus	49	20	37	64
Palm Oil	Elaies guineensis	75	-	-	-
Poplar	Populus Alba	55	22	42	72
Potatoes	Solanum tuberosum	31	21	32	65
Soybeans	Glycine max	61	-	99	138
Sugarbeets	Beta vulgaris	-	13	23	-
Sugarcane	Saccharum officinarum	25	-	30	31
Sunflower	Helianthus annuus	54	27	61	146
Wheat	Triticum aestivum	83	9	84	69
Rapeseed	Brassica napus	214	67	113	-
Average		**62**	**24**	**57**	**142**

The WF is negligible for wind, 0.3m³/GJ for solar, and 22m³/GJ for hydro.

Table 2

The water footprint of some food products (Adapted from Mekonnen and Hoekstra, 2012)

Food	**Liters of water per kg**	**Relative**
Vegetables	322	1
Starchy roots	387	1-20
Fruits	962	2-99
Cereals	1644	5-11
Puses	4055	12-56
Chicken meat	4325	13-43
Bovine meat	15,415	47-87

Figures

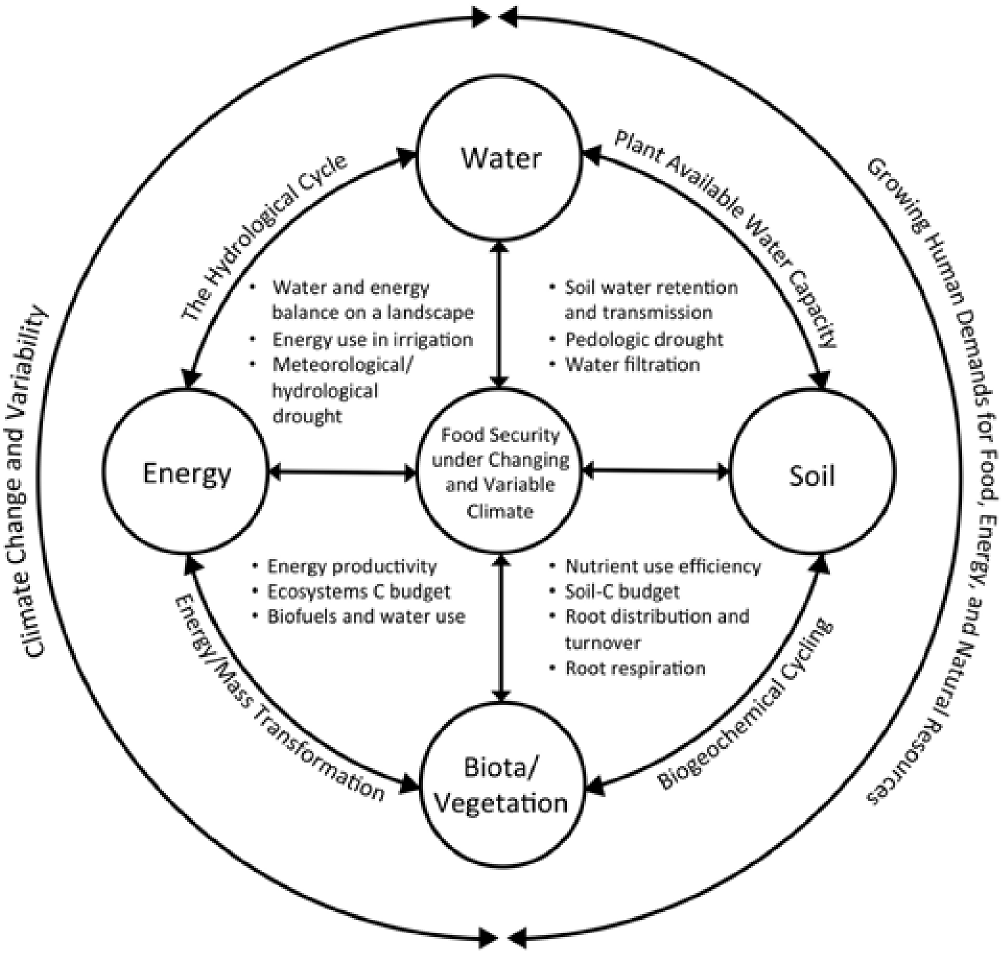

Figure 1. Soil-water-energy-vegetation nexus affecting food security under a changing climate.

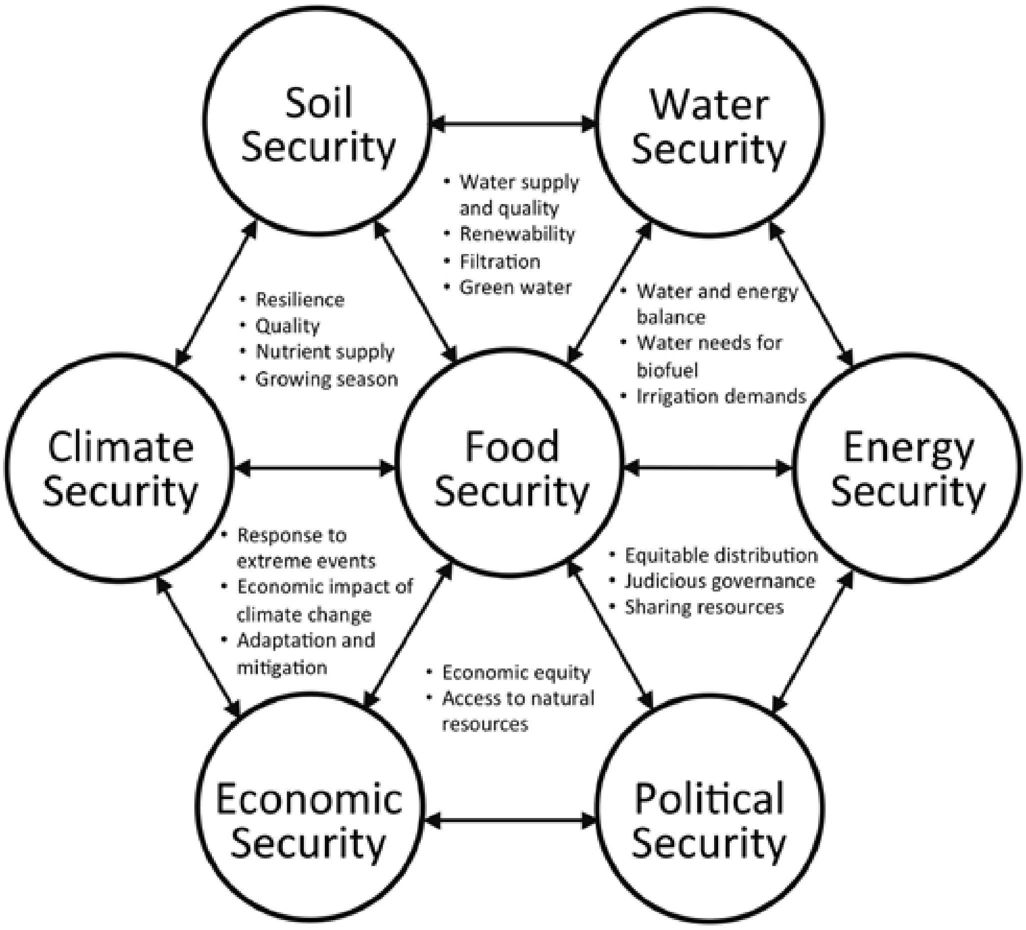

Figure 2. The interdependence of food security on security of natural resources, and economic and political security.

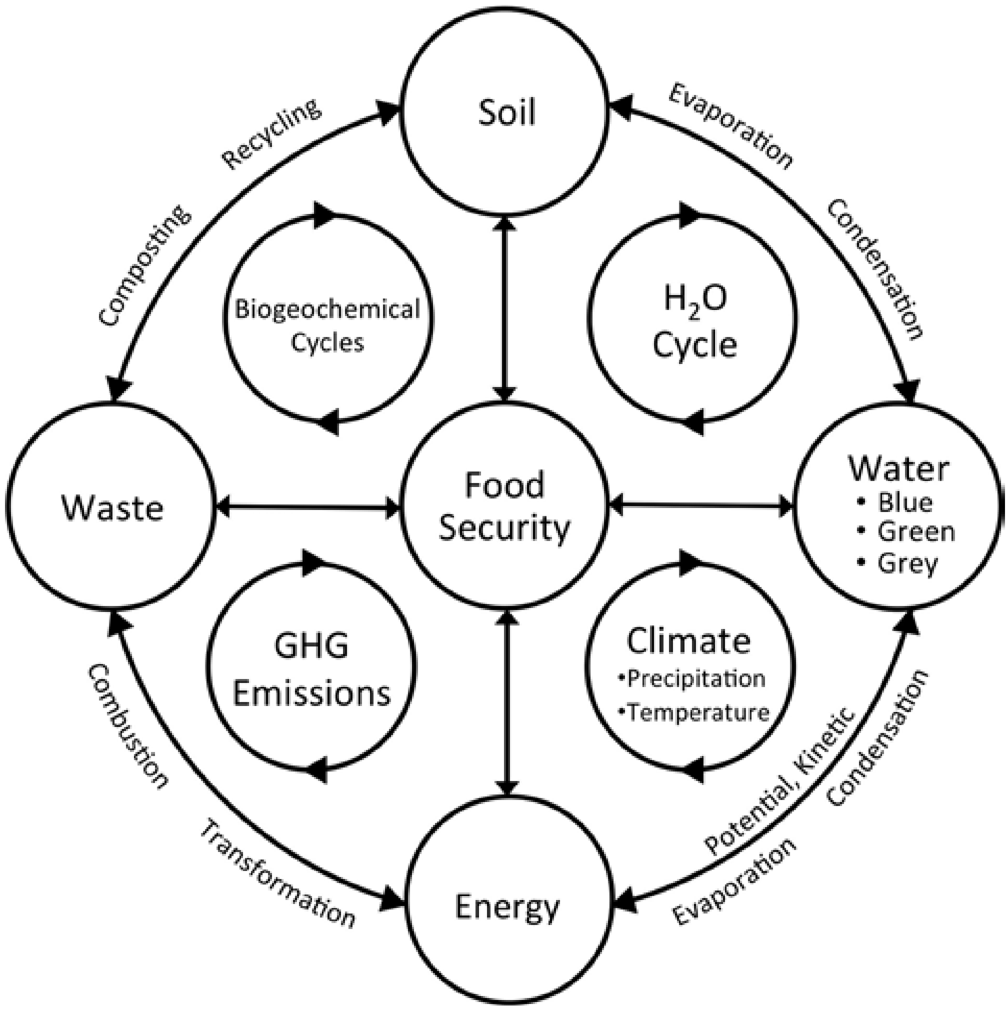

Figure 3. Inter-linkages among natural resources in relation to food security, sustainability, resource use efficiency and resilience.

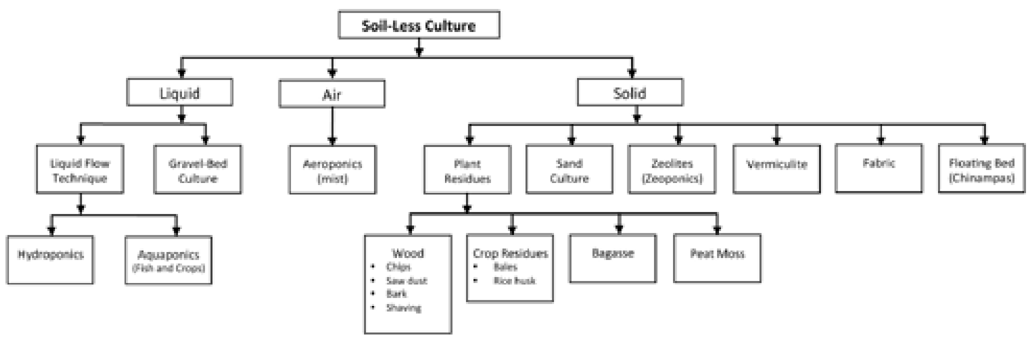

Figure 4. Types of soil-less culture

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Capacity Development for research and education
Teaching and training programmes addressing the nexus

Christian Bernhofer and Marco Leidel

TU Dresden, Faculty of Environmental Sciences, Institute of Hydrology and Meteorology, Chair of Meteorology, 01062 Dresden, Germany

Introduction

One of the key challenges to establish the nexus approach of water, soil and waste is the lack of capacity, as capabilities and knowledge are not sufficient to cope with such a complex task and as appropriate specific teaching & training are not yet sufficiently available. Capacity development is generally a prerequisite for sustainable development (cf. Alaerts and Kaspersma 2009, Leidel et al. 2012a). Thus, innovative concepts for target- and region-specific knowledge transfer as well as appropriate methodologies and approaches for academic and professional education are needed and will be developed within the United Nations University Institute for Integrated Management of Material Fluxes and of Resources, UNU-FLORES (Ardakanian et al. 2011).

Capacity development (CD) can be understood as the ''process through which individuals, organizations and societies obtain, strengthen and maintain the capabilities to set and achieve their own development objectives over time'' (UN Development Programm Capacity Development Group 2008). Thereby, it is often distinguished between different levels of CD measures, namely between the individual level (education and training), the organisational level (development of institutions) and the enabling environment, i.e., the improvement of the societal and political system (cf. van Hofwegen 2004; Alaerts 2009). Within this triad, we examine in this chapter the individual level, often referred to as the basis for capacity development, and focus on teaching and training programmes addressing the nexus.

Successful capacity development at the individual level attempts to address all three aspects of learning, namely knowledge, skills and attitude. This results in well educated participants at master's level as well at PhD level that are prepared to solve nexus-related problems worldwide.

Definition and scope of a nexus oriented teaching and training programmes

A trial to define the nexus according to teaching and training programmes

The Nexus of Water, Soil and Waste has been defined as the central topic of the United Nation University Institute FLORES. It is obvious that nexus research as well as teaching will concentrate on broadening particularly the knowledge on the linkages of the three elements with emphasis of the elements itself as well as on issues of global change with a system approach. These three elements and their linkages are reflected by the five units of the UNU-FLORES Institute in Dresden in 2012: "Water", "Soil and Land Use", "Waste", "Fluxes and Global Change" and "Capacity Development and Governance" (flores.unu.edu). Teaching and training programmes addressing the nexus should reflect this structure and broaden it by (i) general methodological skills, both academic and non-academic, and (ii) by including other topics relevant to the Nexus of Water, Soil and Waste. This embraces alternative views on the nexus as well as additional points to be taken into account when defining future challenges to cope with a world of limited resources and growing demand.

In Fig. 1 this view is symbolised by two triangles: the inner triangle water – soil (and land use) – waste stands for the UNU-FLORES Nexus, the outer triangle energy – food – land stands for central criteria relevant for the UNU-FLORES Nexus and also for the context to the "Water Energy and Food Security Nexus" (Hoff 2011). These central criteria are: Energy efficiency – how much (external) energy is needed for a certain process in water management, in soil use (i.e., agriculture or forestry) or in waste management, land use efficiency - how much area is needed for a certain process in water management, in soil use (i.e., agriculture or forestry) or in waste management and – finally – food production efficiency - how much food can be sustainably produced given the constraints of area, water, nutrients and energy. Especially in the latter aspect, biodiversity plays a major role, as it ensures adaptive capacity to environmental changes, both natural and man-made.

Fluxes form the "exchange currency" between the compartments, energy fluxes (e.g., in W/m²) received by land area for renewable energy production), water fluxes (e.g., in m³/yr of maximum groundwater recharge for drinking water "production") or nutrient fluxes (e.g., phosphorus in urban waste water as a limiting resource for agricultural production, but also as the major cause of eutrophication of inland waters). This exchange is at the heart of the nexus approach and allows creating measures or indicators of sustainability and efficiency. Last, but not least Capacity Development (CD) is included, as the backbone of any implementation. This contribution focuses on individual CD for research and education - teaching and training programmes addressing the nexus. Here, challenges include the link between research (fundamental, applied and implementation research) and the implementation itself being dependent of human, financial and governmental resources.

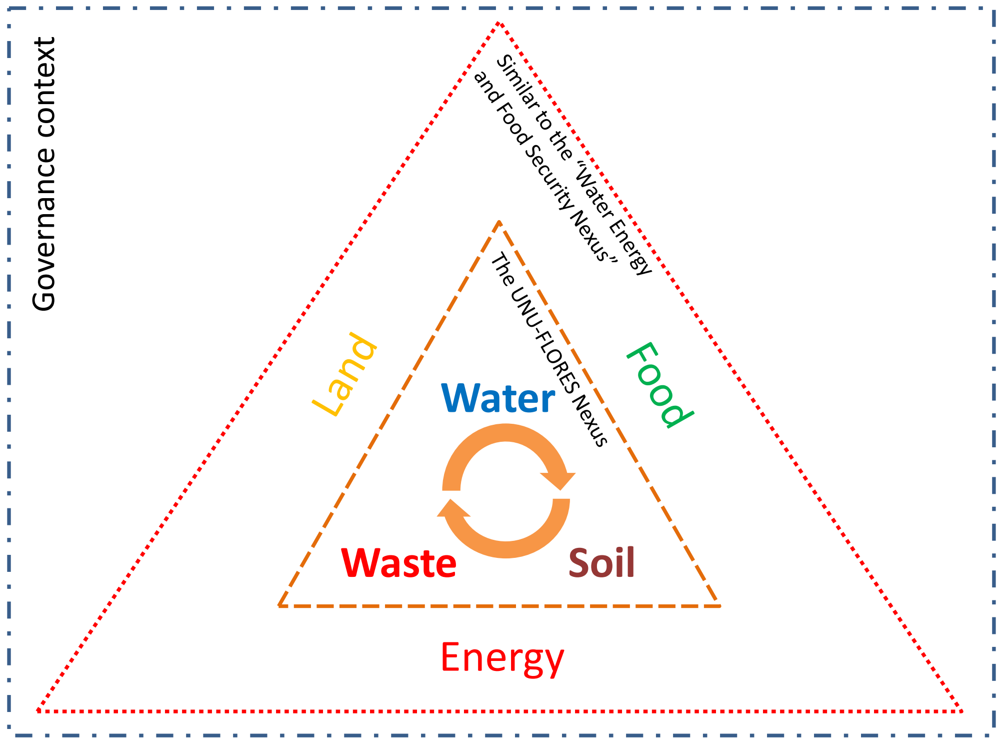

Figure 1: The UNU-FLORES Nexus and its linkage to measures of efficiency and sustainability

Research topics to be addressed in teaching and training programmes addressing the nexus

There is an almost infinite variety of research topics that can be addressed by the nexus. The following research topics in Table 1 are a collection of previous UNU FLORES Workshops as well as consultations with institutes of the Faculty of Environmental Sciences at TU Dresden.

Table 1. Selected research topics related to the nexus and description of associated teaching topics (in part based on collection of previous UNU FLORES Workshops). Important aspects of e.g., population change, land use change or economic change & Poverty are not included for brevity.

Research directions	**Research topics**	**Description of related teaching topics**
Water resources management	Water types	• blue, green, grey water • virtual water
	Sectoral perspectives	agriculture/forestry, industrial, human use etc.
	Water management	• river basin management • groundwater management • protection of water sources/ rivers • ecological issues • wastewater and sanitation • irrigation (partly by use of wastewater) • nutrient recycling • water and energy (e.g., relation btw. hydropower and aquatic ecosystems)
	Sanitation and health	• drinking water supply • waste water treatment
	Flood risk management	• technical measures versus improved natural retention • increasing awareness, resilience and preparedness, decreasing vulnerability

Soil and land use management	Soil degradation	• erosion (+ impacts of CC on erosion) • loss of soil carbon, nutrients and related soil fertility • improper fertilizer management • salinisation and soil water/groundwater regime • soil compaction and sealing
	Soil use and management	• soil ecosystems • ESS (ecosystem services of soils and vegetation including e.g. natural retention) • natural and constructed wetlands
	Food production	• soil as basis for crop production • land and water grabbing • required yields to meet population growth • food versus biofuels
Waste management	Recycle economy	• waste composition & reuse
	Nutrient recovery	• sludge composition & reuse
	Solid waste management	• waste and energy • land-fills • specifics of toxic waste (e.g., electronic waste) • waste transport & recycling
Systems and flux analysis	Nutrient fluxes in general	• recycling of nutrients • fertilizer issues
	Carbon fluxes	• Fate of carbon, erosional processes, sinks, sources, GHG • carbon sequestration • organic amendments, quality and function of soil organic matter
	GHG	• Fate of GHG, sinks, sources, GHG uptake • N fertilizers, humus characteristics
	Pollutants	• sources and sinks
	Water fluxes	• evapotranspiration • link between C flux and transpiration • groundwater recharge • fluxes of polluted water – e.g., from land fills
	"Waste" fluxes	• fluxes of polluted water – e.g., from land fills

Capacity Development and Governance	Science-Policy-Interface; knowledge management	• knowledge management system (platform) for knowledge exchange/ transfer • coordination and cooperation btw. actors • continuous adaptation and improvement of strategies and measures (knowledge platform)
	Capacity issues	• capacity assessments • monitoring and evaluation of CD measures • indicator development for CD
	Governance problems	• taxation issues • corruption and rend-seeking • Equal/adequate importance of NEXUS topics
	Policy frameworks	• How do policy frameworks influence the nexus
	Land and water grabbing	• Land grabbing versus direct investments? • Social and political processes caused by grabbing
	Human rights based approaches to water and sanitation	• water rights • transboundary basin issues
Global Change	Climate change (CC)	• Impact of, and adaptation/mitigation to CC: climate and climate change analysis, adaptation and mitigation measures • Tools and methods to address CC: Global Climate Models, Regional climate downscaling tools, Uncertainty of CC model results • CC politics: International and National organizations dealing with CC, Carbon Certificates and related options
	Population change	• impact of population increase & urbanization on above mentioned topics, like food production etc.
	Land use change	• agriculture and forestry • desertification, deforestation, afforestation • link to soil use, water and carbon (ESS) • wildfires (natural versus human-induced)
	Economic change & poverty	• basics of economy • drivers of economical change • strategies and scenario building

Specific nexus related research and teaching issues have typically to address more than one field of "water, soil and waste" and utilize existing programmes related to the individual components of the nexus. However, "global change and governance" as well as "systems and flux analysis" have to be central research and teaching issues of the nexus related programmes. Examples of such multi-component issues are shown in the "Flower graph" of Fig. 2.

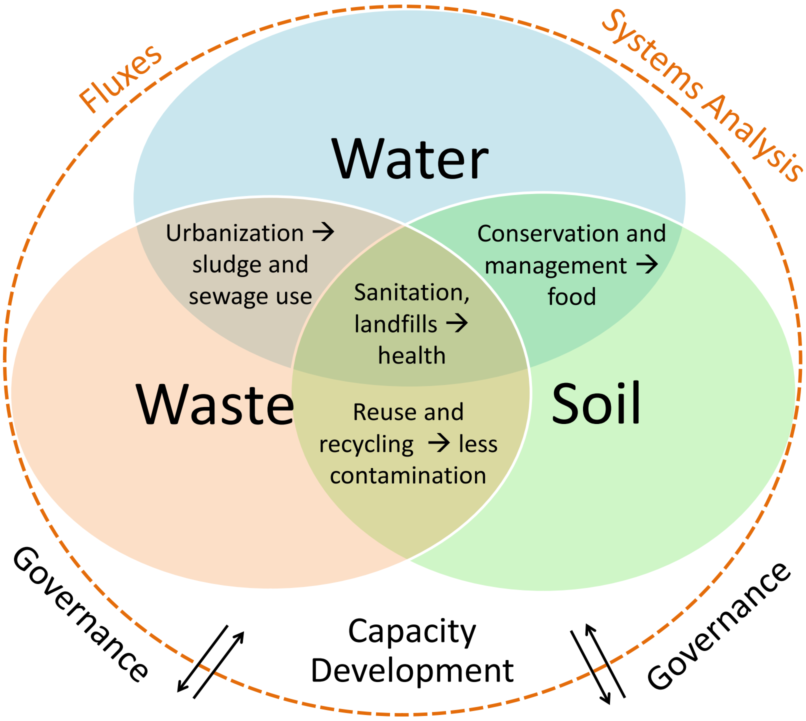

Figure 2: Water, Soil and Waste and example interdisciplinary research and teaching questions related to multiple components of the nexus

Towards teaching and training programmes addressing the nexus

The need for adequate nexus education programmes

Is the nexus concept "mature" and developed enough to be covered in study programmes? Despite that an exact definition of the nexus approach is still needed, there exist differences and similarities of the nexus dealt with in UNU-FLORES to other approaches (IWRM, AWM, Bonn 2011 Nexus conference, etc., Hoff (2011)), as outlined above. These definition issues will be tackled in the near future to arrive at a common understanding and should not constitute a hurdle to an implementation of a nexus related study programme. However, teaching and training programmes are typically disciplinary in nature and miss integration. A specific nexus concept within study courses and PhD programmes needs therefore to include specific integrative and interdisciplinary elements to foster a system understanding. This requires a different and therefore nexus specific teaching programme, as outlined below.

Is there a need for specific nexus education programmes or should the concept be addressed in the framework of existing programmes on water/soil/waste management? Both approaches are necessary for a fast and smooth implementation. The concept should be (i) integrated into existing programmes as cross cutting theme next to their disciplinary education and should be (ii), the focus of a specific programme on the nexus approach. An analysis of the existing Master programmes in the water-soil- waste area in Germany, especially those at TU Dresden, show two types of alternative structures, the "T" type and "I" type (Table 2).

The "T" type course – like "Hydro Science and Engineering" at TU Dresden – aims (i) at a broad understanding of relevant issues (here natural and anthropogenic aspects of water) combined with (ii) an in-depth knowledge on selected disciplinary key issues mirrored by the many elective modules in the 2nd and 3rd semester. (i) reflects the upper bar of the "T", (ii) the supporting pole of the "T". The ideal graduate student holds a disciplinary BSc either in natural or in engineering science and diversifies this background during the MSc study.

The "I" type course – like "Hydrology" at TU Dresden – aims (i) at an in-depth understanding of all disciplinary key issues mirrored by only few elective modules in the 2nd and 3rd semester and (ii) at a broad understanding of associated issues (for hydrology, e.g., meteorology or water management). The ideal graduate student holds a disciplinary BSc in the hydro science and intensifies this background during the MSc study.

Table 2. Examples of existing Master programmes in the water-soil- waste area at TU Dresden (each covering 120 credits in 4 semesters); specification ("T" or "I" type) and characteristics according to web-information (for details see: www.tu-dresden.de)

Study course	**Number of mandatory modules and elective modules (credits)**	**Dedicated mandatory and elective modules for interdisciplinary competence (credits)**	**Specification ("T" or "I" type) and characteristics**
Water management	9 (65) and 36 (25)	2 (15) and >5 (25)	"I" with good portion of interdisciplinary modules (e.g., IWRM)
Hydrology	11 (70) and 34 (20)	0 (0) and >5 (20)	"I" with some interdisciplinary elective modules
Waste management (and contaminated site treatment)	10 (70) and 26 (20)	2 (13) and 5 (20)	"I" with good portion of interdisciplinary modules
Hydrobiology	6 (65) and 36 (25)	1 (10) and >5 (25)	"I" with some interdisciplinary modules
Hydro Science and Engineering*)	7 (40) and 15 (50)	2 (15) and >5 (50)	"T" with choice of disciplinary competence
Tropical Forestry**)	16 (85) and 1 (5)	3 (15) and 0(0)	"I" with good portion of interdisciplinary modules
Vocational Education	9 (74) and 5 (16)	4 (36) and 3 (16)	"T" with emphasis on CD competence

*) also part of a joint EU Erasmus Mundus FloodRiskMaster (with UNESCO IHE, Barcelona Tech and University Ljubljana)

**) modules are adapted currently for an EU Erasmus Mundus Programme

Key issues and topics need to be addressed in a nexus curriculum

Due to the interdisciplinary nature of the nexus approach, content and teaching methods to be integrated into the curriculum will differ from typical disciplinary oriented courses. The structure has to reflect this interdisciplinary nature via a "T" type course with a broad understanding of the nexus itself, combined with governance and issues of systems and fluxes and an in-depth knowledge on disciplinary key issues of water, soil and waste. In brief, it will mirror the structure of UNU-FLORES and related management issues: Integrated water resources management, soil and land-use management, waste management and sanitation (drinking water), systems and flux analysis (industry water processing, cleaning water), water economics and governance. Some key issues relevant for a MSc on "Integrated Resources Management" ("NEXUS" master) are listed in Table 3; other important aspects not included here are: Integrated assessment of water, soil and waste, life cycle analysis, risk management and integrated urban water management.

Table 3. Examples of the nexus perspective on selected themes (water, soil and waste)

Nexus perspective	Teaching topics
Virtual water and virtual carbon etc.	Blue, green, grey water, embedded water and carbon, water and carbon trade
Multiple water use (e.g., sewage water)	waste water treatment, amount and quality of sewage water, sanitation issues
Linkage between climate – surface water – ground water – drinking water – waste water – process water incl. land fills	River basin management incl. ecological issues, wastewater and sanitation, nutrient recycling, water and energy, safe aquifer yields
Water and agriculture	Reuse of wastewater for irrigation Recycled nutrients as fertilizer Water productivity
Nutrient fluxes, carbon, soil water, soil water retention	Erosion (+ impacts of CC on erosion), loss of nutrients, impact of over-fertilization,
Soil as basis for food production	Land and water grabbing, food versus biofuels
Soil as buffer, filter and transformer in the water cycle	Soil functions, integrated resources management, sustainable land management
Waste management and energy	Energy needs and gains of waste recycling
Enabling environment for the NEXUS	Governance analysis (institutional and stakeholder analyis), methods for institutional capacity development, organisational development and change management, awareness raising
Transboundary management	Transboundary management of water and waste, coordination and collaboration between states/regions
Environmental economics (or: Green Economy)	Internalisation of environmental impacts, ecosystem services (basic and economical implementations), cost-benefit analysis, cost-effectiveness analysis, economic incentives for development
Sustainable livelihoods	Management of water, soil and waste for sustainable livelihoods of poor communities

Mandatory mentoring of all students should be assured to support a reasonable choice of modules and the balanced distribution of credits representing the various aspects of the nexus approach.

Tools and approaches for NEXUS education and training

Which tools and approaches for education and training are suited for which stakeholders? Do we need to design new tools and approaches?

Full time MSc students

For full time students various tools and approaches are available, but should be tailored to the students and the learning targets. Clark (2000) has introduced four instructional architectures, namely *receptive, directive, guided discovery and exploratory*. The choice of one or several of these teaching possibilities has to be adapted to the learning targets. We propose to use a bundle of methods for teaching nexus related content, i.e. that a blended learning approach should be introduced. Procter (2003) defines blended learning as the "…effective combination of different modes of delivery, models of teaching and styles of learning".

The "classical" *receptive* way of teaching is classroom teaching, i.e. lectures. This is still a reasonable means of knowledge transfer, also suitable for nexus training programs. Web-based or SKYPE-lectures may take advantage of the UNU worldwide institutes, including lecturers from other UNU institutions. Practical training and tutorials *(directive)* are needed, i.e. information transfer directly followed by practical exercises. This is suited for lab work, software training or procedural skills. Another important feature for nexus programs is the integration of problem-based learning and case studies *(guided discovery)*, i.e. that the focus is on problem solving skills. This could be delivered for instance within workshops including actors' workshops, seminars (webinars) and role plays. Interdisciplinary study projects are also needed mirroring the nexus approach. Such projects resemble the *exploratory architecture*, i.e. that the focus is on self directed studies.

Moreover, e-learning should be integrated into teaching programmes as part of the blended learning concept. According to the European Commission e-learning is defined as "...the use of new multimedia technologies and the Internet to improve the quality of learning by facilitating access to resources and services as well as remote exchanges and collaborations..."(CEC 2001).

One big advantage of e-learning is that many learning styles can be served equally: Vester (1975) has shown that different types of learning preferences exist (auditive/ visual/ haptic and intellectual learners). Another advantage is that learning is independent from location and time and that participants have the possibility to find their own learning pace.

An example for a blended learning approach is the 20 cr "FloodMaster" programme at TU Dresden, where two ring lectures (1st on physical aspects of floods, 2nd on risk management) are combined with four workshops (three dedicated to different floods types: flash flood, plane flood, coastal flood and an actors' workshop) and a study tour of a week (typically along the river Elbe). Until now about 200 students finished this special training (for more information on this programme, see Bernhofer et al., 2007). Developed in a BMBF funded project after the severe floods in Germany of 2002, it is now part of the optional modules within Hydro Science and Engineering, an MSc programme at TU Dresden.

An example for sophisticated and technologically advanced e-learning is the e-learning module on Integrated Water Resources Management (IWRM) that was jointly developed by the International Water Research Alliance Saxony (IWAS) and the German IHP/HWRP Secretariat (Leidel et al. 2013). It complements classical learning options at universities as well as at vocational training facilities. This e-learning module is one possibility to strengthen the linkages between natural, social, and engineering sciences in water management and to support the implementation of IWRM (www.

iwrm-education.de). The same structure, i.e. linking interactively different aspects of resources management, could be used for teaching and training programmes addressing the nexus.

Apart from that, setting up a learning management system (LMS) that supports the blended learning approach is important. This would support the realization of *cooperative learning*, i.e. the knowledge transfer is supposed to be improved by enhanced collaboration between students and between students and instructors. Therefore communication tools like discussion forums, chats, blogs, audio/video conferences can be applied. Moreover collaborative tools like wikis, social bookmarks, e-portfolios, collaborative editing (e.g. google docs) or content sharing tools can be integrated into LMS for supporting the teaching. Those tools can be used for developing the above mentioned case studies as well as for interdisciplinary study projects.

Last but not least, exchange programmes and internships at international organizations or organizations of the international cooperation (e.g. the German GIZ) could improve the nexus teaching.

Summing up, it can be argued that a blended learning approach is needed for teaching the complex nexus, meaning that there should be a mixture of proven methods (e.g. seminars) as well as novel approaches (e.g. simulation games, integration of social media) that have to be tested for their suitability for teaching the nexus.

PhD programmes

PhD programmes have to be research driven and require appropriate funding. This has proven to be a considerable challenge for interdisciplinary research due to the disciplinary structure of the reviewing systems of the typical donors. Therefore, communication of the nexus approach to these donors is an important prerequisite to increase the chances for such a funding. In the hosting country of UNU-FLORES there exist a variety of funding options for a PhD programme, single PhDs or exchange of scientists within an existing PhD programme or independently thereof. Some of these options are listed below:

- Utilise existing programmes with an adequately open focus (BMBF-FONA, DFG, VW-Foundation, DAAD, etc.)
- Initiate suitable programmes from donors through lobbying for the NEXUS approach
- Create own programmes / funds by fund raising from independent donors and the public

There exist already concrete concepts to establish such a PhD programme (“NEXUS Academy”, see flores.unu.edu). Besides academic rules and regulations (the “NEXUS Academy” will be very welcomed at the Faculty of Environmental Sciences of TU Dresden since it matches ideally the Faculty's cross-cutting structure and its interdisciplinary profile), the programme itself will again mimic the structure of UNU-FLORES and the partnership to partner organizations.

The PhD programme will also be an obviously well suited way to combine research and education for the nexus approach. This can be supported by collaboration between universities (such as UNU and TU Dresden), non-university research institutes (like the Centre of Environmental Research, UFZ in Leipzig and the Leibniz Institute of Ecological Urban and Regional Development, IOER) and enterprises (like local or international waste or water companies). At the other hand, by developing MSc programmes that integrate cutting edge research in the curriculum.

Lifelong learning

For lifelong learning and vocational training the following tools and approaches are suited: short courses (summer schools), e-learning modules and other distance learning tools, specifically tailored seminars, exchange programmes, on the job training, and many more. The most important aspect is (i) to communicate the necessity of lifelong learning to sometimes still static structures (e.g., in same administrations) and (ii) to connect to the interested target group. Here, the UNEP-CIPSEM course at TU Dresden with its more than 30 yrs. of experiences in post-graduate or quaternary education and its excellent network in developing and emerging countries can serve as a basis (Fig. 3).

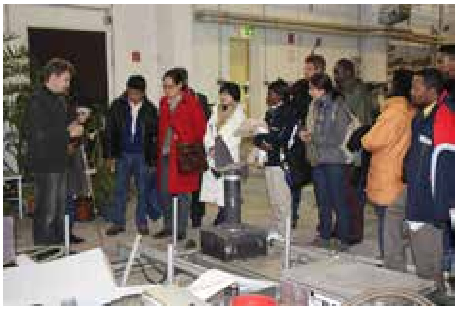

Figure 3: UNEP-CIPSEM - 51st Short Course on Climate Change Adaptation: Soil and Water

Especially the short courses of one moth duration (offered at least annually) would be a perfect multiplier for UNU-FLORES issues. Blended learning including "face-to-face" and "text-based" as well as "web based" learning are especially important for this type of quartary education, as it does not require the same amount of personal presence at the teaching institution and allows to utilise the web.

Special tools and approaches for the nexus education

There is a need for special tools and approaches for the nexus education, since the nexus approach is very broad and complex. For example, simulation and role plays, actors' workshops, use of podcasts and webinars should be discussed. When designing specific nexus elements in existing or newly established programmes it will be essential to reflect the interdisciplinary nature also structurally. A few key ideas are presented below:

Nexus team work: Practical works, seminar tasks and study projects can be assigned to groups of 2 to 5, where each represents a different aspect of the nexus. However, in the end a common document or joint result or common conclusion have to be reached. This fosters not only teamwork itself but also integrative thinking.

Nexus field & lab class: Can be a special example of the above team work, as a group of students analyse (in the field and in the lab) different aspect of the nexus. E.g., the generation of urban waste, its collection and transport, its reuse and the associated water, soil and atmospheric contamination including human health; together with a technically and a socially oriented guideline, how to improve the situation.

Nexus theatre: A special form of an actors' workshop where students, PHDs and external experts (at best also locals from the problem area) are exchanging ideas on solutions of nexus related problems based on a concrete case (e.g., the loss of fertile land due to urbanization or desertification in a certain region) and learn to identify and potentially also to minimise conflicts. While 3rd semester students are primarily active, 1st semester students primarily watch and document the "scene on stage".

Nexus study tour: Ideally, a tour to areas with nexus relevant issues and risks as well as to institutions with nexus related capacity should be organised within the 2 yrs. Master programme. If this is not possible or too costly (at least at an annual basis) an alternative is a virtual tour to nexus related points-of-interest, based on research questions and good examples should be arranged. Here, the research of the UNU-FLORES team as well as of TU Dresden can serve as a starting point, later the research of the Nexus students will add new aspects. For the purpose of the virtual study tour, each Nexus graduate should compile his/her research in a short movie documentation.

These tools can also serve as a model for other interdisciplinary training programmes.

SWOT analysis of a new study programme

Here, despite the not yet completely outlined Master Programme in Integrated Resources Management ("NEXUS" Master) a few points are developed for a SWOT (Strengths – Weaknesses – Opportunities - Threats) analysis. The future programme might use them a starting point for an assessment.

Table 4. Points of a SWOT analysis of a new Nexus study programme

• Strengths (unique benefits, internal): • Transfer and increase knowledge and experiences on the nexus • Based on well working study programmes at TUD (at the moment on the MSc level) • Educating actors step by step (hierarchical manner) • Enhancing regional development through capacity development • Combination of universities and the "UN-Family" (experienced persons) • Train the trainers • Inspiring students by guest lecturers/ experts • Gaining highly motivated students	• Weaknesses (what remains unfulfilled/ difficult, internal): • Heterogeneous groups and thus need to bring different backgrounds to same level • Danger of getting lost because of many topics • Maybe hard to address students from developing countries • Financial constraints for students
• Opportunities (overcome weaknesses, add value, external): • Strengthening of nexus related institutions in developing countries • Study programme as a hub and a facilitator for "exporting" experts to developing countries • Good possibilities for applied research	• Threads (external): • Institutional constraints (bureaucracy, organizational problems) • Funding • Language • Well educated graduates/ staff member stay in Europe or go to U.S. • Job markets not yet available • Sustainability of programme

In a review of existing programmes, no directly nexus related programmes could be identified that are already working. Merely TU München only recently got funding from DAAD for a Water Food Energy Nexus Project (M.Sc and PhD programme), therefore the programme is still under development. Currently, the existing Hydro Science and Engineering (HSE) Master programme can serve as an example for cooperation between UNU and (here) TU Dresden in the field of education. HSE is a MSc study programme that has been established in 2004 at TU Dresden. The accredited programme focuses on the fields of Water and Natural Resources Management, as well as Engineering. The degree course especially addresses students from developing and emerging countries due to the specific problems occurring there, i.e. limited drinking water and raw water resources as well as the devastating impacts of hydrologic extremes like droughts or floods connected with heavy erosion. The programme is organised by the Faculty of Environmental Sciences, Department of Hydrosciences with the participation of the Departments of Forest Sciences and Geosciences, the Faculty of Civil Engineering and was initiated by the Dresden Water Center DKW. Recently – in October 2013 - the Dresden Water Center merged with the corresponding water departments of the UFZ into the joint Center for Advanced Water Research - CAWR (www.ufz.de/cawr/), representing the largest water related research entity in Germany.

The master course in HSE "broadens and intensifies previously obtained academic and practical knowledge in the fields of management, conservation and development of water resources within different climatic zones and construction and operation of water management systems. The program aims for an excellent handling of the entire field of water with its various aspects. The students will be enabled to cope with future professional demands within research and practice worldwide. The master program meets international standards required to pursue and develop careers within national and international administrations and organisations. The master course will lay the basics for engagement in development and consultation agencies, to head the operation of water management systems and to contribute to transdisciplinary research tasks within the entire field of hydro sciences." (from: tu-dresden.de; Dept. of Hydrosciences)

Summary and conclusion

Teaching and training programmes addressing the nexus of water, soil and waste (CD for research and education) need to address primarily the linkages between the components without neglecting sufficient competence in key issues of the components itself. The structure of UNU-FLORES can serve as an excellent starting point to a Master programme dedicated to the nexus: A MSc programme on "Integrated Resources Management" with modules in (urban) water management, soil & land use management, waste management, system & flux analysis and CD & governance. This programme can be jointly hosted by TU Dresden and UNU-FLORES and should be associated to the existing Master programme of Hydro Science and Engineering. No comparable programme dedicated to the nexus exists today.

Before the necessary organisational and academic procedures are completed to start such a new programme, an immediate or at least fast integration of a nexus module in the existing master at TU Dresden can serve as a bridging tool to address some interested students from an international crowed of currently 40 per year. This supports the education at TU Dresden by the additional teaching offered and helps UNU-FLORES to attract students who specialise in the nexus. At the same time the programme offers already nexus related training, is attractive to the possible students from the UNU-FLORES twin in Subsaharan Africa and might help to produce possible nexus PhD candidates. It can almost immediately serve as a sister programme for other nexus related courses. Curricula, course material and lecturers might be exchanged.

The need for decently trained environmental engineers or nexus masters in a world of limited resources and growing demand is large, the risk of an ever increasing pressure on these resources due to the dynamics in population, economy and climate is high, and the disciplinary nature of many decisions of stakeholders is an additional hurdle. But job markets and decision makers will also evolve due to the very same pressures and their human and economical consequences. Therefore, CD for the nexus has to start as soon as possible, in order to facilitate the need for a sustainable treatment of vital and practically non-renewable resources - water, air, soil/land - with all our technical and social skills in the only biosphere we got.

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Institutional arrangements and goverance structures that advance the nexus approach to management of environmental resources

Mathew Kurian & Reza Ardakanian

United Nations University, Institute for Integrated Management of Material Fluxes and of Resources (UNU-FLORES), Dresden, Germany

Introduction

Global trends such as urbanization, demographic and climate change that are currently underway pose serious challenges to sustainable development and integrated resources management. The International Panel on Climate Change noted in 2007 that one key feature of these changes is an acceleration of the global hydro-cycle. This is manifested in the increasing frequency or severity of extreme events such as floods and droughts. Since water is a potent dissolver and transport agent of soils, nutrients, other chemicals and materials and wastes may "migrate" with water and could be "lost" in unwanted places such as oceans which may make recycling infeasible with technologies that are available today. The "volatility" of water resources needs to be accounted for given an increasing demand for food production. At the same time there is a growing concern about soil degradation and the decline in soil quality while the demand for food is going to increase. In this context, environmental quality can be satisfied only if soil, waste and water resources are managed in a sustainable and integrated manner. Given the limitations of the conventional technology transfer model in terms of addressing environmental challenges it is now acknowledged that capacity development approaches that aim to facilitate technology *adaptation* may offer a better chance of success.

The complex relations between demands, resource availability and quality and financial and physical constraints can be addressed by knowledge based policies and reform of professional practice. The nexus approach recognizes the urgent need for this knowledge and its interpretation in a policy- relevant setting that is guided by the understanding that there is a lack of blueprints for development based on integrated management of water, soil and waste resources in the Member States. Generation and application of knowledge is both a priority for individual but also institutional capacity development. It is against this background the UNU-FLORES Institute for Integrated Management of Material Fluxes and of Resources was established in Dresden. UNU-FLORES is supposed to extend and upscale the concept of integrated resource management through adopting a truly integrative perspective by considering inter-related resources (water, soil, waste) and emphasizing fluxes of resources between phases and compartments. Thus instead of traditional input-output model, UNU-FLORES focused on whether the consistent tracing (follow up) and management of resources as fluxes (passage, flow, transport, transfer) would result in sustainable management outcomes. UNU-FLORES will pursue the achievement of sustainable environmental outcomes by serving as a think tank that promotes integrated resources management.

The Water-Energy- Food Nexus and Institutional Arrangements

Early references in the scientific literature to the term "nexus" arise in cell biology (to describe complex electro-chemical interlinkages required for organ and tissue function), in economics (to characterize mutual dependencies of wages, prices, and labor productivity), and in the institutional literature (to trace contractual relationships among multiple, tiered firms) (Steffen et, al, 2011). With specific reference to interlinked natural resource use practices, nexus terminology appears to have begun in 1983 with the Food-Energy Nexus Programme of the United Nations University (UNU), which sought to better understand coupled food and energy challenges in developing countries paying particular attention to technical and policy solutions (Sachs and Silk, 1990). Food and energy as crucial determinants of development (Batliwala, 1982) were considered in their broader environmental context; thus, at least two international conferences were organized to further develop and illustrate the interlinkages among food (agriculture, nutrition), energy (biomass, post-harvest residues, animal traction, fuel, electricity) and ecosystems (land, forests, water) (Scott etal, 2013). The first of these conferences on Food, Energy, and Ecosystems, was held in Brasilia, Brazil in 1984 (Alam, 1988). The Second International Symposium on the Food-Energy Nexus and Ecosystems was held in New Delhi, India, February 12-14, 1986 (Parikh, 1986). Modeling approaches to address the food-energy nexus were also developed and published for the UNU (Pimentel, 1985).

International Pronouncements on the water energy food nexus

Formal published recognition of the three-way mutual interactions among water, energy, and food – branded as the WEF Nexus did not appear until 2008 (Hellegers et al, 2008), again with a significant focus on India, given that the Hellegers et al piece emanated from a workshop held in 2006 in Hyderabad, India, which itself built on groundwater irrigation - electricity nexus work cited above. This was followed in short order by Lazarus (2010), Hoff (2011) as further elaborated below, Scott (2011) with emphasis on climate change drivers, Wescoat and Halvorson (2012), Bogardi et al (2012), Granit et al (2013), and Siddiqi and Wescoat (2013) to cite just a few of the burgeoning set of publications on the WEF Nexus. In parallel fashion, and again approximately coterminously with research developments in the mid-2000s, institutional support for the WEF Nexus gained significant momentum via the Bonn Freshwater Conference, the Bonn2011 Nexus Conference, the Stockholm World Water Week, and the now well established Water, Energy, and Food Security Nexus Resource Platform Nexus (http://www.water-energy-food.org/, Ardakanian and Liebe, 2012).

Conceptualizing the WEF nexus in institutional terms

Over the course of a decade and a half working with the Water, Energy, Food (WEF) nexus in South Asia, the Americas, and Europe, it has become clear to us that the term nexus can have negative implications as in covert, non-transparent arrangements, deals cut behind closed doors, and even corruption and graft. This belies the complexity that is intended by our use of the term and instead simplifies the nexus as subterfuge. Furthermore, by placing the nexus in the resource security context, which we have done (Scott et al, 2013; Wescoat and Halvorson 2012) along with numerous others (Bogardi et al, 2012), one is exposed to the military and intelligence situation-room conception of strategic resources to be protected through military force, espionage, and the exercise of state power. This 'guns, gates, and guards' view is indeed the origin of the concept of security. Indeed, international and transboundary initiatives for water management, for example, increasingly must steer clear of "security" which nation states view in sovereignty terms, relations to the United Nations Security Council, etc. (Varady and Scott, 2013). Here, our intent is not to engage directly in debates over the securitization of resources, but instead to relate the Nexus to the more benign human and ecosystem dependence dimensions of resource security (United Nations, 2013). Critical to advancing the nexus is an improved understanding of complex socio-ecological systems, causes of declining resilience in such systems and the role that adaptive management can play in mitigating the effects of such trends.

Complex socio-ecological systems are evident at different levels: (a) From a *policy/legal perspective* complexity maybe evident from "rules in use" that affect decisions relating to allocation of resources, coordination of financial and human resources and equity effects on human populations (Figure 1).

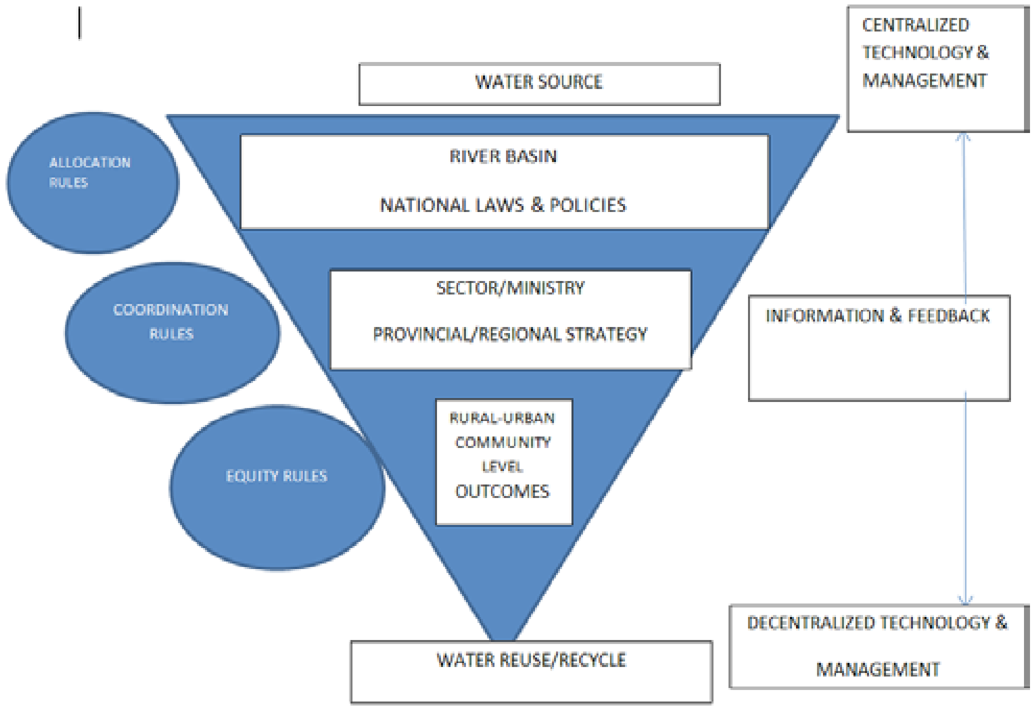

Figure 1: Rules at the Nexus of Soil, Water and Waste Management

Examples of allocation rules include formulas or criteria for allocation of water among different water uses- industry, agriculture and water supply. Coordination rules could include rules that guide allocation of central funds by regional departments/ministries or criteria for monitoring water quality standards for river systems. Examples of equity rules could include daily allocation norms for water supply between rural and urban areas or criteria for allocation of central grants for wealthy and resource poor regions/communities or households. Organizational rules that are evident in from formal rules in operation within public sector and *extent of discretion* that is allowed by administrative culture that characterizes the working of line departments *(examples include forestry, irrigation or agriculture)* and ministries (examples include- finance or planning) may also influence the form and extent of actual rule enforcement.

(b) From a *research perspective* complexity may be evident in differential impacts of material fluxes, nutrient flows, aquifer recharge rates, sediment transfer at the level of plots, farms, watershed and/or river basins and along axis of gender, age or ethnicity. Specification of boundary conditions involving both spatial and temporal dimensions are known to be important predictors of policy relevance of research outputs (c) From a *program management perspective* complexity may be evident in a non-linear relationship between poverty and the condition of the bio-physical environment at different scales (Figure 2). For example, if there is a relationship between soil erosion and livelihood diversification opportunities of farmers then will the relationship hold irrespective of the scale of public interventions covering village or district level administrative jurisdictions? (Kurian 2010a). On the other hand if the relationship between poverty and the environment is not as direct as was previously presumed then how should public programs be structured? Should financing follow the conventional sector approach or follow sector wide/ budget support approaches (Dasgupta et, 2005)?

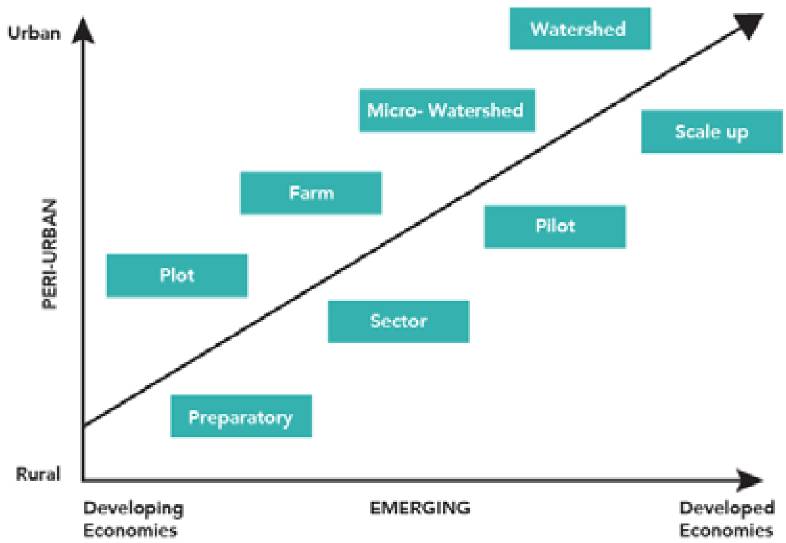

Figure 2: The importance of boundary conditions in managing complex socio-ecological systems

Complex socio-ecological systems that successfully deal with "shocks" in the policy, environmental or socio-economic realm are usually characterized by resilience. Some have argued forcefully that resilience is a measure of: (a) the amount of change the system can undergo and still retain the same control on functions and structure, (b) the degree to which the system is capable of self-organization and (c) the ability to build and increase the capacity for learning and adaptation (Resilience Alliance, 2001). Resilience is an important property of a system because the loss of resilience moves a system closer to a threshold, threatening to flip it from one equilibrium state to another (Berkes, 2002). Highly resilient systems can absorb stresses without undergoing a flip, they are capable of self-organization based on relationships of trust and have the ability to respond to unpredictable "events" through approaches that place a premium on learning by doing and trial and error (Kurian and Dietz, 2013a).

The concept of resilience is based on the assumption that cyclical change is an essential characteristic of all social and ecological systems. For example, resources crises such as a forest fire are important for renewal of ecosystems in as much as demographic growth and educational opportunities can serve to renew communities. But such processes of renewal and change are seldom linear and predictable leading to uncertainty. Systems theory emphasizes that uncertainty can be addressed by understanding inter-dependence and inter-connectedness of social and bio-physical systems. Robust feedback loops between policy/programme interventions, structural changes within communities of resource users and bio-physical processes are known to be important in regulating the effects of uncertainty (Berkes, 2002, Scoones, 1999). Systems that respond effectively to uncertainty are usually supported by information flows on bio-physical and institutional processes. Information flows are verifiable, dis-aggregated and more frequent making them amenable to decision maker's preference for easily accessible information that tracks achievement of public policy objectives (Kurian and Turral, 2010c).

The notion of adaptive management may resonate with decision makers in developed economies who are confronted with challenges of a loss of capacity to exploit a system's potential for novelty (*examples include Climax forest*), declining redundancy of critical components (*examples include nitrogen fixing species in climax forests*) and the risks of cascading failure arising from heightened inter-connectivity (*for example, energy production and supply systems in urban centres*). On the other hand the concept of adaptive management in the context of developing and/or emerging economies can relate to building capacity for dispersed problem solving. The first generation debate on political decentralization furthered the idea of dispersed problem solving by emphasizing autonomy. The second generation debate on fiscal decentralization it is recognized should emphasize issues of political accountability (Kurian, 2010b). The goal of adaptive management should be not on producing the highest biological or economic yield but on furthering our understanding of how accurately organizations can adapt to "uncertainty" by using feedback from management outcomes to shape policy and program interventions at appropriate scales (Kurian and Dietz, 2013b).

Divides in Environmental Governance

Environmental governance in developing and emerging economies suffers from fragmented approaches to planning and policy implementation. Fragmented approaches arise from competition among urban and rural local governments for central fiscal transfers, overlapping jurisdictional boundaries and inadequate management coordination among line departments and ministries. In many instances fragmentary approaches are supported by a poor evidence base on the relationship between infrastructure construction and environmental outcomes. For example, absence of dis-aggregate, reliable and more frequent information at appropriate scales makes it difficult to predict the environmental outcomes of constructing dams, tube wells or storm drains in terms of sediment capture, aquifer recharge and wastewater reuse respectively. Institutional fragmentation is also supported by weak feedback loops between legal and policy formulation, spatial and temporal variation in bio-physical environment and socio-economic change within communities of environmental resource users. As a result decision makers cannot design program and project interventions with precision and may be unable to respond effectively to feedback from consumers on changes in service delivery parameters (*affordability, reliability or quality*) or to the effects of increased variability in frequency, intensity and duration of environmental shocks (*droughts or floods*).

The intellectual basis for fragmentary approaches to planning is supported in large measure by divides in approaches to environmental governance. Five divides in environmental governance are evident in emerging and developing countries as described below:

1. *Infrastructure versus services:* Many developing countries have invested heavily in infrastructure including hydro-power dams, water and wastewater treatment and irrigation. While much of this expansion has been justified to increase food productivity and promote human security there have been others who have questioned how this may have been achieved at the expense of investments in maintaining infrastructure. Further, the benefits of infrastructure construction in several cases may have bypassed those segments of society who needed public support the most. An explicit focus on service parameters such as affordability, reliability and quality has until recently been overlooked by conventional planning processes and structures (Kurian, 2010b).

2. *Centralized versus decentralized government:* A focus on infrastructure construction in many cases led to expensive technologies being selected. Big dams and sophisticated treatment technologies were the order of the day following the Lewisian model of economic growth. As a result central fiscal transfers were perpetuated and there was little incentive for local governments to rely on local revenue sources to match their expenditure plans. Accountability was compromised, service charges sky rocketed and poor consumers who were unable to pay suffered from lack of public services. Decision making power remained concentrated with higher tiers of government and

donors. Local initiative and autonomy suffered as a result and prospects for adaptive environmental management were compromised. As a result political decentralization began to gain importance in academic and policy discussions.

3. *Public versus private management models*: In response to growing disenchantment with centralized management due to their inability to protect environmental resources there was a phase of utility privatizations notably in South America. During the 1990's the political mood also favoured community based natural resources management that emphasized themes of co-production and participation. Based on lessons emerging from the earlier wave of utility privatizations public- private partnerships gained ground. Deregulation involved retaining asset ownership with public agencies but engagement with the private sector through a variety of institutional contractual arrangements ranging from Build Own Operate (BOT) to divestures and concessions. One of the outcomes of such experiments with public-private partnerships have been institutional innovations ranging from budget support to Output Based Aid (OBA).

4. *Short term versus reliance on long term planning perspectives:* Centralized government structures and processes have placed great emphasis on budgets as a mechanism for allocation of public finances. Conventional budget preparation involves consolidation and aggregation of expenditure plans of several ministries and line departments. The process of appropriation usually can take a year and in developing countries the links between disbursements and achievement of public policy outcomes are seldom clear. As a result there has been a disproportionate emphasis on capital costs of infrastructure with little discussion of costs relating to operation and maintenance. In recent years some have even questioned the methods that have been employed to compute capital costs and have argued forcefully to take a longer term view of the lifecycle of infrastructure projects to ascertain the possible revenue streams that may be possible to finance infrastructure operation and maintenance.

5. *Efficiency versus equity:* The emphasis on infrastructure construction led to a focus on utility and system efficiency. The subsequent interest in community based natural resources management led to an interest in issues such as equity in benefit distribution along lines of gender, age or ethnicity. In the case of water, for example both approaches generated their own set of metrices and methods ranging from measurements of Non-Revenue/Unaccounted for Water to perspectives on multiple uses of water services. While non-revenue water and monitoring of physical systems emphasized quantitative data and measurements, multiple use perspectives often highlighted qualitative data and participatory data collection techniques.

The Nexus: Overarching Research Questions on Governance and Institutional Structures

Based on the above discussion we can identify three broad over-arching questions that can guide thinking on institutional arrangements and governance structures that advance the nexus approach to management of environmental resources: water, waste and soil.

(a) **The question of Intersectionality** - what are the critical mass of factors at the intersection of material fluxes, public financing and heterogeneity and changes in institutional and bio-physical environment that can define the scope and relevance of the nexus approach to environmental management?

(b) **The question of interactionalit**y - How can feedback loops be structured to capture both vertical and horizontal interactions between (a) legal and policy reform, (b) structural changes in economy and society and (c) variability in the bio-physical environment? and

(c) **The question of hybridity** - what role can trans-disciplinary approaches play in building capacity through support for innovative planning instruments and monitoring and assessment methods, advances in pedagogic and didactic techniques, formative and summative assessments and accreditation and certification of blended learning curriculum for achievement of nexus competency.

Science-Policy Interface and Integrated Management of Water, Waste and Soil Resources

The ongoing debate on IWRM that was spurred by a presentation by IWMI has challenged many development practitioners to re-think paradigms of sustainable development and integrated resources management (Giordano, 2013). Similarly, in development circles there are policy questions with regard to the usefulness of large scale underground drainage systems compared to condominial sewers for decentralized waste management. In the area of solid waste management there are policy challenges related to the need to balance requirements for waste incineration plants and landfills with the fact that the local economy in many developing country benefits in terms of employment from informal waste collection and disposal. In the area of soil management there are important trade-offs that decision makers have to make based on the impact that improved techniques can have on soil run-off while at the same time considering the benefits that sediment transport offers over time for populations further downstream of large water catchments. How large the impacts of soil erosion are at plot, farm or watershed scales requires a good scientific understanding. Three basic principles can guide the process of developing management options that respond to the challenges posed by soil degradation and decline in soil quality (Lal, 2013): (1) replace what is removed, (2) respond to what is changed, and (3) predict what will happen from anthropogenic and natural perturbations. Following these basic principles helps to develop site and region specific management options. Further, good science is also required to distinguish between findings at varying scales and their generalizability in terms of policy advice in a regional context. With respect to monitoring of groundwater levels and quality there is an acute need for a better scientific understanding of aquifer characteristics and their behavior in the event of special stresses such as changes in temperature and rainfall or human induced economic activity such as large scale mining operations. From a governance perspective good science is required to understand the comparative benefits of employing centralized versus decentralized technologies and public versus private management models for infrastructure construction and Operation and Maintenance (O&M). Furthermore, there is an established need to inform and convince decision makers of equity effects *(dis-aggregated by gender, age or ethnicity)* of the impact that scientific experiments to reverse soil erosion, water scarcity and water quality will have on local populations.

Data Gaps Identified by the Bonn Conference

The Bonn conference held in November 2011 pointed out that "integrated planning across the nexus, involving also city and spatial planning, environmental protection and forestry, can unlock significant efficiency gains". The subsequent RIO+20 conference emphasized the importance of adopting a NEXUS approach to land, water and waste management. The background paper prepared for the Bonn conference reviewed a number of case studies to conclude that while there are no blueprints or panaceas there are some underlying principles that can guide the implementation of the nexus approach (Hoff, 2011). For instance, cross-sectoral management can minimize tradeoffs, build synergies and increase resource use efficiency. In particular in multi-use systems, wastes, residues and by-products can be turned into a resource for other products and services and co-benefits can be produced. Productive sanitation in combination with wastewater reuse is an example of recycling and closing loops of water, nutrients and other resources. Other examples include multifunctional and green agriculture, natural or constructed wetlands, agro-forestry, crop-livestock systems, land rehabilitation with biofuel crops such as jatropha, and wastewater-energy integration. Reusing waste products instead of discharging them into the environment can also reduce clean-up costs. The background paper prepared in the run-up to the Bonn conference highlighted the following knowledge gaps of relevance to the work program of UNU-FLORES:

1. There is a lack of consistent and agreed upon water quality standards for different crops and production systems which would standardize and promote wastewater reuse and hence increase water use efficiency.

2. More data are needed on sustainably available water resources, in particular on safe aquifer yields and for so-called 'economically water scarce' regions, such as sub-Saharan Africa

3. There are scarce data on consumptive water use in the energy sector, compared to withdrawal data.

4. The effects of increasing energy or water scarcity on food and water or energy security, as well as potential synergies between land, water and energy management, are not well understood. Questions include to what extent can higher availability of one resource sustainably reduce scarcity of another, and how might this work at different spatial scales?

5. New nexus indicators/metrics which address sustainable resource use, human well-being and equity as well as integrated assessments of water, energy and food sectors, are required for future quantitative trade-off analyses. System thinking, robust analytical tools, including life cycle analysis, and consistent data sets across the water, energy and food sectors are essential for building synergies, avoiding tensions, and to monitor and inform policies and regulations across the nexus.

Key Questions Posed by the International Kickoff Workshop, November 11-12, Dresden

1. What are the advantages of a centralized versus a decentralized approach to implementation of integrated management approaches?

2. Which institutional structures and mechanisms have proven helpful for implementing integrated and cross-sectoral management strategies?

3. How effective are inter-institutional/ministerial/organizational mechanisms in implementing integrative approaches?

4. Are these structures and mechanisms similar or what are the differences at various scales (*from local to global*) and in various regions?

5. Which type of economic incentives will be required/ helpful to foster nexus approaches?

6. Is there/what is a common approach to institutional capacity development?

Key Research Questions of Relevance to Capacity Development

A. Why does good science not always equate to good policy?

Efficiency matrices can rely on quantitative analysis of large data sets while equity matrices demand greater engagement with qualitative perspectives to support and validate arguments. An important point that needs to be made here is that environmental decision making involves *trade-offs* at multiple scales *(across space- vertically and horizontally and over time)*. Some of the most important trade-offs are not guided by the supremacy of quantitative data sets alone. Where the stakes are not so high rigorous data analysis may help clinch the argument. But in situations where the stakes are extremely high the trade-offs that are made can be influenced by political rather than statistical significance. One opportunity is to focus on identifying data gaps and devising methodologies for data collection that combine quantitative and qualitative perspectives with the potential to influence decision making at strategic nodes of the governance framework.

B. Why does statistical significance not always equate with what is politically expediant?

Once data has been collected one needs to be creative about analysis. The emphasis could be on identifying messages and strategies for engagement and presentation that enable us to use evidence to influence decision making. The focus should be on identifying and conveying information that is politically nuanced and where required backed up with rigorous data analysis. Information is key and data and data analysis is a means to help us define the message for decision makers who in many situations have to make political choices. For example: what strategies can we employ to highlight the public health impacts of inadequate water and waste management? What strategies can we employ to engage with decision makers at multiple levels (catchment-regional, watershed-district, village-farm, household-plot) on choices relating to allocation of financial resources, soil conservation practices or water/waste management strategies?

Institutional Arrangements and Governance Structures: Preliminary Hypothesis

1. Management of water, waste and soil resources could be guided by principles of efficiency, equity and environmental sustainability
2. While integrated management may be a desirable goal its actual realization may be economically costly and politically difficult to achieve
3. The nexus approach could enhance the possibility of integrated management of environmental resources by identifying through trial and error factors that influence governance of water, soil and waste resources that lie at the intersection of: (i) spatial dynamics of material fluxes, (ii) socio-ecological differences in resource use and (iii) rules that guide allocation of public finances.
4. The nexus approach to management of water, waste and soil resources is premised on the fact that there are no blueprint solutions to complex socio-ecological challenges. Instead, solutions have to be crafted at the appropriate scale: IWRM, decentralization and participation may prove to be selectively useful strategies in different environmental and socio-political contexts.
5. IWRM may necessitate working at different spatial scales- but basin may not always be the appropriate unit of analysis for water, soil and waste resources.
6. Decentralization would necessitate engaging with issues of accountability in allocations of financial and human resources within the public sector- notably inter-governmental fiscal transfers to agriculture, water and public health departments
7. Participation would necessitate engaging with consumers to ascertain their views on reliability, affordability and adequacy of environmental services- for example by ascertaining the cost of infrastructure investments in fields of water, waste and soil management.
8. Results based financing has proven useful in enhancing accountability of public sector decision making with regard to social infrastructure (schools and health).
9. Economic incentives such as budget support, cash conditional transfers, cash on demand and output based aid have resulted in improvements in service delivery outcomes. What are their potential applications in the field of water, waste and soil management?
10. Successful design, implementation and evaluation of results based financing strategies would require developing capacity for trans-disciplinary approaches to planning and environmental management.

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UNU-FLORES

Institute for Integrated Management of Material Fluxes and of Resources

The United Nations University Institute for Integrated Management of Material Fluxes and of Resources (UNU-FLORES) was established in Dresden,Germany in 2012 with the support of the Federal Ministry of Education and Research (BMBF) and the Ministry for Higher Education, Research and the Arts (SMWK) of the Free State of Saxony, Germany. As part of the United Nations University (UNU), the Institute helps to build a bridge between the academic world and the United Nations. The UNU encompasses 16 research and training institutes and programmes in 12 countries around the world. UNU as a whole aims to develop sustainable solutions for pressing global problems of human survival and development.

UNU-FLORES develops strategies to resolve pressing challenges in the area of sustainable use and integrated management of environmental resources such as soil, water and waste. Focusing on the needs of the UN and its member states, particularly the developing and emerging countries, the institute engages in research, capacity development, advanced teaching and training as well as dissemination of knowledge. In all activities, UNU-FLORES advances a nexus approach to the sustainable management of environmental resources.

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ADVANCING A NEXUS APPROACH TO THE SUSTAINABLE MANAGEMENT OF ENVIRONMENTAL RESOURCES

UNITED NATIONS UNIVERSITY
Institute for Integrated Management of Material Fluxes and of Resources (UNU-FLORES)

Ammonstraße 74
01067 Dresden
Germany

Tel.: +49 351 892193 70
Fax: +49 351 892193 89
E-mail: flores@unu.edu

flores.unu.edu