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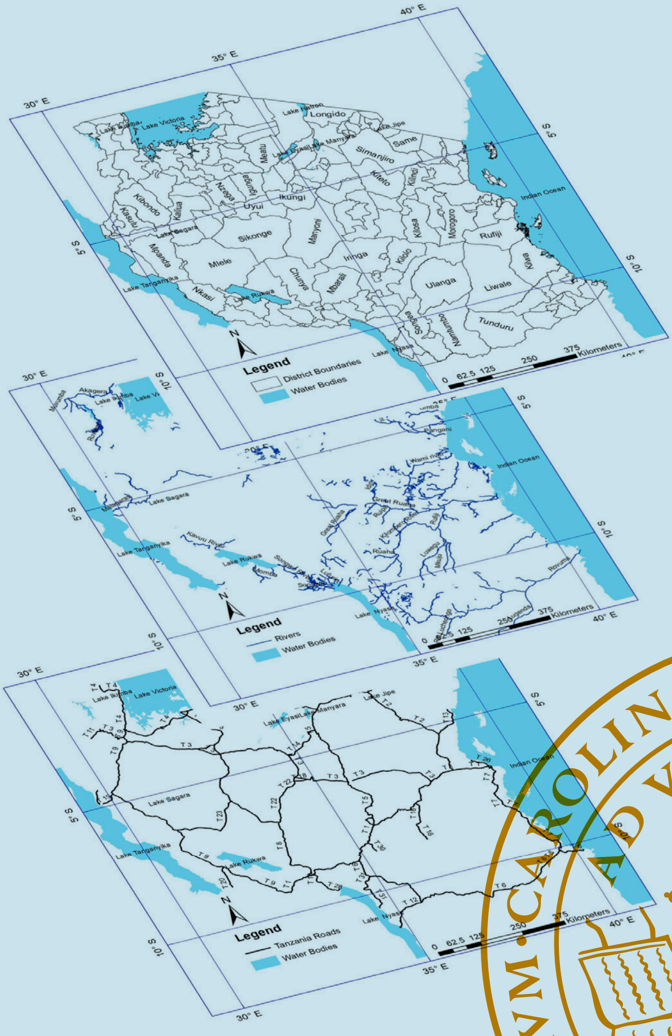

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Investigating Spatial Data Infrastructure Planning in Tanzania using System Modelling and Social Concepts

Alex Lubida

DOCTORAL DISSERTATION

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Abstract

Spatial Data Infrastructure is one of the requirements for sustainable development and many countries worldwide are at different stages of implementation. Several researchers have shown that SDI has helped governments to recover funds due to reduction in duplication of efforts and also has increased efficiency in resource management and planning. Tanzania as other developing countries, is at initial stages of establishing the National SDI with a policy proposal and the national steering committee in place. However, lack of knowledge and experience among the stakeholders, complexity and dynamics of its components and their interaction are major challenges that hamper the growth of SDI. Although many studies have explained the complexity and dynamics of SDI, little has been done that involves stakeholders to model complexities for more reliable plans.

In this thesis, social concepts and system modelling are used to understand SDI planning process in Tanzania. Input data were obtained based on mixed methods approach, including questionnaire survey and workshops involving local and central government officials and other stakeholders that are producers or users of spatial data. This thesis begins with the application of Theory of Planned Behavior (TPB) for understanding spatial data sharing and the results showed that TPB was effective in accounting for intention to share spatial data in Tanzania.

Second part was a methodology for SDI planning in Tanzania based on system dynamics technique and the community of practice concept where an optimum model was developed with consensus of SDI stakeholders. The model, gave the planners an insight about the future effects of today's plans and decisions. The proposed models and concepts are highly recommended for SDI planning and for raising awareness to gain support from policy makers.

Third part was on investigating the Agent Based Modelling (ABM) approach for simulating SDI development. The output was evaluated and was within a reasonable range and depicted the main attributes, roles and interactions of agents. The results will help SDI planners and other stakeholders in making reliable SDI strategic plans.

Finally a case study for an operational SDI was demonstrated. A land use plan was proposed based on a spatial Multi-Objective Optimization approach where influencing conflicting factors needed to be considered and satisfied. NSGA II algorithm was used in optimization. The proposed approach and output can considerably facilitate land use planning. Similar approaches are highly recommended for other countries in Africa of which their cities are under development.

Key words: Spatial Data Infrastructure, System Dynamics, Agent Based Modelling, Community of Practice, Multi-Objective Optimization, Land use planning

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MADE IN SWEDEN

To my beloved family members for your love and prayers

Table of Contents

Abstract

Spatial Data Infrastructure (SDI) is one of the requirements for sustainable development and many countries worldwide are at different stages of implementation. Several researchers have shown that SDI has helped governments to recover funds due to reduction in duplication of efforts and also has increased efficiency in resource management and planning. Tanzania as other developing countries, is at initial stages of establishing the National SDI with a policy proposal and the national steering committee in place. However, lack of knowledge and experience among the stakeholders, complexity and dynamics of its components and their interaction are major challenges that hamper the growth of SDI. Although many studies have explained the complexity and dynamics of SDI, little has been done that involves stakeholders to model complexities for more reliable plans.

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Sammanfattning

En fungerande infrastruktur för rumslig data (SDI – Spatial Data Infrastructure) skapar möjlighet till hållbar utveckling. Forskning har visat att SDI frigör nationella ekonomiska resurser då antalet organisationer som hanterar spatiell data kan krympas och samtidigt ger en ökad effektivitet för resurshantering och planering. Tanzania befinner sig, liksom många andra utvecklingsländer, i en startfas av inrättandet av ett nationellt SDI och här finns både en politiskt agenda samt en nationell styrkommitté för detta ändamål. Bristen på kunskap och erfarenhet hos intressenter, komplexitet och dynamik i komponenterna samt deras interaktion är stora utmaningar som försenar implementeringen av ett fungerande SDI. Även om många studier har utrett komplexiten och dynamiken, har väldigt lite gjorts för att involvera intressenter i planeringen av SDI.

I denna avhandling används samhälleliga koncept samt systemmodellering för att utforska planeringsprocessen av SDI för Tanzania. Indata har erhållits genom enkäterundersökningar och workshops, med både lokala och statliga tjänstemän, samt övriga intressenter som producerar eller använder rumsliga data.

Denna avhandling startar med en tillämpning av Theory of Planned Behaviour (TPB) för att förstå hur rumslig data kan delas i Tanzania. Resultaten visar att TPB är ett effektivt sätt att redovisa avsikten i att dela rumslig data.

Den andra delen är en metodstudie för planering av SDI i Tanzania som baseras på systemdynamik och ett ’community of practice’ koncept. Här utvecklas en optimal modell med konsensus från olika SDI-intressenter och som ger planerare en inblick i vilka framtidens effekter blir av planering och beslut som görs idag. De föreslagna modellerna och koncepten rekommenderas starkt i planeringen av SDI för att öka medvetenheten och för att få stöd från beslutsfattare.

Den tredje delen handlar om att undersöka hur Agent Based Modeling (ABM) kan användas för att simulera en utveckling av SDI. En utvärdering av resultaten visar att modellen inom rimliga gränser kunde beskriva de huvudsakliga kapaciteterna, bristerna och interaktionerna inom en organisation. Resultaten av denna studie blir till hjälp för SDI-planerare och andra intressenter i skapandet av pålitliga strategiska planer.

I den sista delen föreslås en markanvändningsplan baserad på en rumslig optimeringsstrategi för att hantera, beakta och tillfredställa olika viljor och motstridigheter. En NSGA II-algoritm användes för optimeringsprocessen. Den föreslagna strategin och tillvägagångssättet kan avsevärt underlätta vid planering av markanvändning och rekommenderas starkt för andra länder i Afrika under utveckling.

List of Papers

This thesis is based on the following papers,

I. **Lubida, A.,** Pilesjö, P., Espling, M. & Runnström, M. 2015. Applying the theory of planned behavior to explain geospatial data sharing for urban planning and management: cases from urban centers in Tanzania. *African Geographical Review, 34:2, 165-181.*

II. Mansourian, A., **Lubida, A.,** Pilesjö, P., Abdolmajidi, E. & Lassi, M. 2015. SDI planning using the system dynamics technique within a community of practice: lessons learnt from Tanzania. *Geo-spatial Information Science, 18:2-3, 97-110.*

III. **Lubida, A.,** Mansourian, A. & Rajabi, M. 2019. Investigating an Agent Based Modelling approach for SDI planning: A case study of Tanzania NSDI development. (Manuscript)

IV. **Lubida, A.**, Veysipanah, M., Pilesjö, P. & Mansourian, 2019. A. Land-use Planning for Sustainable Urban Development in Africa: A Spatial and Multi-Objective Optimization Approach. *Geodesy and Cartography Journal, 45:1, 1-15.*

Paper contributions

Paper I, AL contributed to the design of the study, performed field data collection, analysis, interpretation and led the writing.

Paper II, AL contributed to the design of the study, performed field data collection and analysis, contributed to organizing meetings and workshops, SDI modelling, simulation, interpretation and helped in writing.

Paper III, AL led the design of the study, performed data collection, contributed to all ABM simulations, analysis and interpretation of results and led the writing.

Paper IV, AL led in planning of the study, performed data collection in the study site, contributed in NSGA-II model running, analysis and interpretation of results and led the writing.

Abbreviations

ABM	Agent Based Modelling
AFREF	African Geodetic Reference Frame
ARU	Ardhi University
BRN	Big Results Now
CODIST	Committee for Development Information, Science and Technology
CoP	Community of Practice
EAS	Expert from Academic Sector
EEO	Expert from Executive Organizations
eGA	eGovernment
EPM	Environmental Planning Management
GIS	Geographic Information System
GNSS	Global Navigation Satellite System
GSDI	Global Spatial Data Infrastructure
ICT	Information and Telecommunication Technology
ILMIS	Integrated Land Management Information System
INSPIRE	Infrastructure for Spatial Information in Europe
IRA	Institute of Resources Assessment - UDSM
ITRF	International Terrestrial Reference Frame
LRMS	Land Rent Management System
LTPP	Long Term Perspective Plan
MAfA	Mapping Africa for Africa
MCoP	Community of Practice
MKUKUTA	Mpango wa Pili wa Kukuza Uchumi na Kuondoa Umaskini Tanzania or National Strategy for Growth and Reduction of Poverty II
MKUZA	Mpango wa Kupunguza Umasikini Zanzibar or Zanzibar Strategy for Growth and Reduction of Poverty
MLHHSD	Ministry of Lands and Human Settlement Development
MOOP	Multi-Objective Optimization Problem
MORIS	Management of Land Information System
NBS	National Bureau of Statistics
NIDC	National Internet Data center
NLUPC	National Land Use Planning Commission
NSDI	National Spatial Data Infrastructure
NSGA	Non Dominated Genetic Algorithm
ODD	Overview, Design concepts and Details
PC-GIAP	Permanent Committee on GIS Infrastructure for Asia and the Pacific
PC-IDEA	Permanent Committee on SDI for the Americas
RCMRD	Regional Center for Mapping
SCP	Sustainable Cities Programme
SD	System Dynamics
SDI	Spatial Data Infrastructure
SDS	Spatial Data Sharing

Sida	Swedish International Development Cooperation Agency
SMOLE	Sustainable Management of Land and Environment
SPSS	Statistical Package for Social Sciences
SRS	Surveys Registration System
TAREF11	Tanzania Geodetic Reference Frame of 2011
TPB	Theory of Planned Behaviour
UNECA	United Nations Economic Commission for Africa
URT	United Republic of Tanzania
VCoP	Community of Practice
VPO	Vice Presidents Office
WGS 84	World Geodetic System 1984
ZAN-SDI	Zanzibar Spatial Data Infrastructure

1 Introduction

Geospatial information has been recognized as a vital resource that supports the economic, social and environmental management and provides the framework necessary for global collaborative and consensus decision-making (UNGIWG, 2007, Rajabifard, 2009, Scott and Rajabifard, 2017). Almost all the issues affecting sustainable development can be studied and modelled within a geographic context (UN-GGIM, 2012). Geospatial information is information about the earth's surface and the objects found on it. It is about a physical object that can be represented by numerical values in a geographic coordinate system or in the form of maps, with databases including data linked to the objects on the map.

The importance of geospatial information has been increasing due to 1) Recent advances in spatial data capture, especially satellite position fixing and remote sensing, 2) Spatial data management, by utilizing GIS and database tools and data access, as noticed by the growth in web mapping, open source software, cloud based archives as well as 3) The development of analytical techniques such as high resolution mapping of urban environments (Kelly, 2007, Huggins, 2018, Käyhkö et al., 2018). Previous studies show that 80% of all local government decisions regarding land management, physical planning, natural resources management, revenue collection and emergency management possess a geographic or geospatial reference (O'Flaherty et al., 2005, Folger, 2011, Cimbaljević et al., 2014, Indrajit et al., 2017). For smooth running of day-to-day activities, governments and other stakeholders require access to accurate, up to date and sufficiently reliable geospatial data. All levels of government's significant resources go into gathering and managing spatial information. If this information is not readily available, land use officers spend a greater portion of their time and resources on data sources identification, collection and management while little time is left for analysis and policy formulation. Decision-making would be much easier and more reliable if it is based on geospatial data.

In most of the developing countries, local authorities are overwhelmed by what they can provide for better urban planning and management (Kombe and Kreibich, 2001, Olofsson and Sandow, 2003, Msangi and Liwa, 2014, Xhafa and Kosovrasti, 2015, Ingwe, 2017). Spatial Data Infrastructure (SDI) is a mechanism which can facilitate geospatial data management, including sharing data and related applications in various levels of government. The US Federal Government defined SDI as an infrastructure that includes applications, standards, technology and institutional governance necessary for effective and efficient spatial data and services management within or across organizations (FGDC, 1994). It considered geospatial information as "soft infrastructure" and due to its importance and to ensure sustainability, infrastructure concept is more understood by governments where polices and budgets can be approved along with other infrastructures. Countries all over the world are developing SDIs in order to manage and improve access and sharing of their spatial data and resources (Scott and Rajabifard, 2017).

Tanzania is one of the most rapidly growing nations in both population and economy. The population projection for 2019 is 55.89 million (URT, 2018a) and its annual economic growth is approximated to 7%. The Tanzania's Development Vision 2025 aims at eradicating poverty and becoming a medium income country by pursuing high quality livelihood, good governance and a strong and competitive economy, through a knowledge-based sustainable development (URT, 2000). Sharing geospatial information as part of other information in Tanzania is provided in the constitution and also in the ICT policy aimed at enhancing sustainable socio-economic development and accelerate poverty reduction (URT, 2016a).

Tanzania government has been pursuing several projects that focus on spatial data management. For instance, the implementation of Sustainable Cities Programme (SCP) that started in 1992 covering eleven municipalities in Tanzania mainland and Zanzibar that used an Environmental Planning and Management (EPM) process (Msangi and Liwa, 2014). SCP is an approach that allows cities priority environmental issues to be effectively planned and managed for sustainable urban development. EPM process facilitates and enhances urban multi-sectoral planning and coordination basing on participatory approach by engaging stakeholders in decision making process. It also addresses urban environmental challenges aiming at promoting sustainable and environmental sound development (UN-Habitat, 2004). EPM emanates from Agenda 21 of the UN conference on Environment and Development. Apart from SCP, there are several sectoral SDIs which were established in Tanzania such as Integrated Land Management Information System (ILMIS) under the Ministry of Lands, Housing and Human Settlements Developments (Mwaikambo and Hagai, 2013, Laseko et al., 2018); Water Point Mapping under the Ministry of Water (Nyitambe, 2013, Georgiadou et al., 2016); Mining Cadastre under the Ministry of Minerals (Hernandez, 2003, Feast et al., 2006, URT, 2016b); ZanSDI/SMOLE project established in Zanzibar (Turner et al., 2016, RGoZ, 2018) and Environmental Information Network (EIN) under the National Environmental Management Council (Larsen, 2014, COWI, 2015, Muhando et al., 2015).

Also there are a number of factors that provide opportunities for establishment of an NSDI in Tanzania. For instance a new geodetic control network for Tanzania (TAREF11) (Mayunga and Mtamakaya, 2015, Ulotu, 2015, Ulotu, 2016), ICT improvements countrywide where all regions are connected by Optic Fibre cable, high capacity broadband connection to the rest of the world through EASSy (URT, 2016a), and establishment of e-Government Agency (eGA) and a National Internet Data Center (NIDC) (Esselaar and Adam, 2013, Furuholt and Sæbø, 2018, Ventures, nd).

Development of National Spatial Data Infrastructure (NSDI) in Tanzania started back in 2003, with a first workshop organized by the National Bureau of Statistics (NBS) (Kalande and Ondulo, 2006, Mtalo, 2007, Makanga and Smit, 2008, Mwange et al., 2018). During the workshop, an interim steering committee was formed and NBS was given mandate to lead the NSDI formation in the country. A draft proposal was unveiled in 2007 and NBS included NSDI activities in its five year strategic plan (2009 – 2014) (Lugoe and Yanda, 2007, URT, 2010a).

More workshops focusing on NSDI were held in Tanzania. For instance Malaki (2015) reported on the workshop on open source geospatial solutions in land and forest mapping. Larsen (2014) and Muhando et al. (2015) reported on a workshop on environmental data management in Tanzania. In 2016 the Regional Centre for Mapping (RCMRD) organized a workshop on an NSDI in Tanzania that brought together high level officials to get introduced to the concepts of an NSDI to enhance awareness and the importance having an operational geospatial data infrastructure (RCMRD, 2016). During the workshop a new interim committee was set up to oversee the implementation of NSDI in Tanzania. Also Käyhkö et al. (2018) reported on existence of GEO-ICT project that focuses on capacity building in the area of geospatial and ICT involving four main universities. According to Becker (2011), URT-PM (2011) and Larsen (2014) development of an NSDI is highly prioritized at the Ministry of Lands, Housing and Human Settlements Developments, the Disaster Management Unit under Prime Minister's Office in Tanzania, NBS and the National Environmental Management Council.

In Tanzania, as in many other developing countries, in Africa, nationally important geospatial data that are fundamental datasets exist in various locations (Johansson, 2005, Matthijs, 2005, Kalande and Ondulo, 2006). Same data is collected by various departments multiple times, and in some cases similar data is collected by different departments simultaneously, causing duplication and wastage of resources. Tanzania has substantial problems with the availability, accessibility, management and usage of reliable, accurate and timely spatial data. Thus far, little progress on NSDI in Tanzania has been reported (Mwaikambo and Hagai, 2013, Hagai, 2017, Mwange et al., 2018, Ngereja et al., 2018).

The challenges that attribute to SDI implementation being slow in Tanzania have been studied by several authors (Johansson, 2005, Matthijs, 2005, Kalande and Ondulo, 2006, Makanga and Smit, 2008, Mwaikambo and Hagai, 2013, Hagai, 2017, Mwange et al., 2018, Ngereja et al., 2018) as lack of awareness and motivation, lack of policy, poor knowledge, limited funds, lack of proper coordinating body and lack of political commitment.

In addressing the complexity of SDI development, firstly, it was observed that the status and willingness of individuals and organizations regarding spatial data sharing in Tanzania is one of the areas not well covered in literature. Secondly, several models have been developed (Rajabifard et al., 2003, Omran et al., 2006, De Man, 2007, Grus et al., 2010, Mansourian and Abdolmajidi, 2011). For instance, Vandenbroucke et al.

(2009) proposed a framework that relied on network perspective to characterize SDI, where main players in spatial data community were identified and data flow between them explained. Other authors Hjelmager et al. (2005) and Hjelmager et al. (2008) developed a model using Unified Modelling Language (UML), where scope, activities and actors from enterprise perspective were described. In their research, five roles were distinguished as producers, provider, broker, user and policy maker. Also Mansourian and Abdolmajidi (2011) developed SDI model using system dynamics (SD) technique that represented the complex dynamic behaviour of the SDI while involving all components necessary for SDI development. A model to provide a detailed knowledge about SDI planning, implementation and management for Tanzanian stakeholders is not available whilst there is urgency need to facilitate understanding on part of government officials, politicians, technical persons and other organizations working towards building NSDI in Tanzania (Mwaikambo et al., 2015, Hagai, 2017, Mwange et al., 2018, Ngereja et al., 2018). Likewise, as an SDI is a collaborative effort, and its complexity makes different stakeholders not agreeing on common approach because of their difference in understanding (Capitani et al., 2016). Stakeholders' agreement on SDI development plan is a fundamental requirement for a successful SDI but little exist on the subject matter. Thirdly, due to the pressure from different groups seeking SDI, little has been researched on the bottom-up approach of SDI in order to understand the influence of the interactions of the groups at the micro level on the entire system of NSDI in Tanzania (Capitani et al., 2016, Huggins, 2018, Käyhkö et al., 2018). Lastly, few case studies exist to demonstrate how a successful SDI in Tanzania can benefit different stakeholders (Ngereja et al., 2018). A case study, where different input data are used to solve a multi-objective optimization problem that reduced the work of physical planning.

1.1 Aims and Objectives

The aim of this thesis is to use system modelling methods to understand the complexity of SDI planning process in Tanzania, to develop models to guide stakeholders in developing reliable SDI strategic plans and to raise awareness regarding SDI application where spatial data and Multi-Objective Optimization approach was applied in urban planning process. The overview of the thesis is provided in Fig 1. The specific objectives are as follows;

1. To assess the current situation of geospatial data management in Tanzania and apply Theory of Planned Behavior to explain geospatial data sharing (Paper I)
2. To investigate and address the major challenges in SDI planning process by using System Dynamics and Community of Practice concepts (Paper II)

3. To investigate the possibilities, strengths and weaknesses of Agent-based Modelling (ABM) for simulating Spatial Data Infrastructure (SDI) development process in Tanzania (Paper III)
4. To develop an optimized land-use plan for Zanzibar using Multi-Objective Optimization approach, as a case study of applying SDI for sustainable urban development (Paper VI)

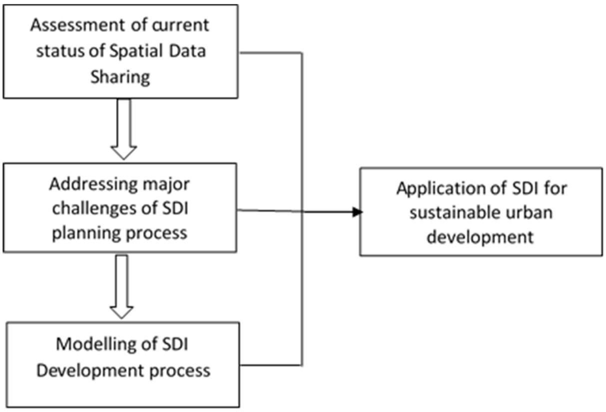

Figure 1:
Overview of the thesis.

1.2 Thesis structure

In this thesis, the first part is the summary of the research work followed by the four papers. In the first chapter, the introduction is given together with the problem statement and objectives. Chapter two is the literature review of the main concepts used in the thesis which are Geographical Information System, Spatial Data Infrastructure, System Dynamics Technique, Agent based Modelling, Theory of Planned Behavior and Community of Practice theory. Chapter three is the methodology that includes the study sites, data collection methods and modelling. Chapter four is the summary of the four papers and chapter five is the overall conclusion and future research.

2 Background

2.1 Geographical Information System

Geographical Information System (GIS), is defined as a system of hardware, software, and procedures designed to support data capture, data management, editing, analyses, modelling, and display of spatially referenced data for solving complex planning and management problems (Lo and Yeung, 2007, Heywood et al., 2011). Most of the local government information can be represented by a unique location using numerical values in a geographic coordinate system. Examples of such information is road network, rivers, lakes, buildings, cadastral maps and various utilities. A Location is contextually simple and intuitive to many people in the sense that they can relate to where they are on a map, follow directions to a place, calculate distances, readily grasping the spatial context of their local environment, inter-relate issues and so on (Lo and Yeung, 2007, Toomanian, 2012). In a GIS, geographical data can be organized by layers, where each layer is representing a common theme and different layers are integrated using an explicit location on the Earth’s surface, thus the geographic location is the organizing principle (Lo and Yeung, 2007, Toomanian, 2012). Geographic data can be handled in a GIS application. By understanding geography and people's relationship to location, decision making is substantially improved (Heywood et al., 2011). Spatial Data Infrastructure is the framework to access geospatial information and services to enable users to serve resources, time and effort (Scott and Rajabifard, 2017).

2.2 Spatial Data Infrastructure (SDI)

Many countries worldwide have recognized SDI as an essential requirement for achieving sustainable development (Feeney et al., 2001, FIG, 2002, Williamson, 2003, Paradzayi, 2005, Ayanlade et al., 2008, Scott and Rajabifard, 2017). By definition, SDI is a set of interacting institutional, technological, human and economic resources that are available for facilitating and coordinating spatial data access, use and sharing (Rajabifard et al., 2002, Nedovic-Budic et al., 2008). This is an initiative that will enable a wide variety of users to access, retrieve and disseminate spatial data in an easy and secure way, providing a platform to facilitate spatial data sharing (SDS) and reduce data duplication (Longhorn and Blakemore, 2008, Mohammadi et al., 2009).

Rajabifard et al. (2002) described the components of SDI (Fig. 2) to include; (1) People (users) (2) Access to data (Data Discovery, Data Access and Data Process); (3) Policy

- Legislation (Mechanism, Policy and Legislation); (4) Standards (contents, data exchange, meta-data and data services) and (5) Spatial data set (data, framework and meta-data).

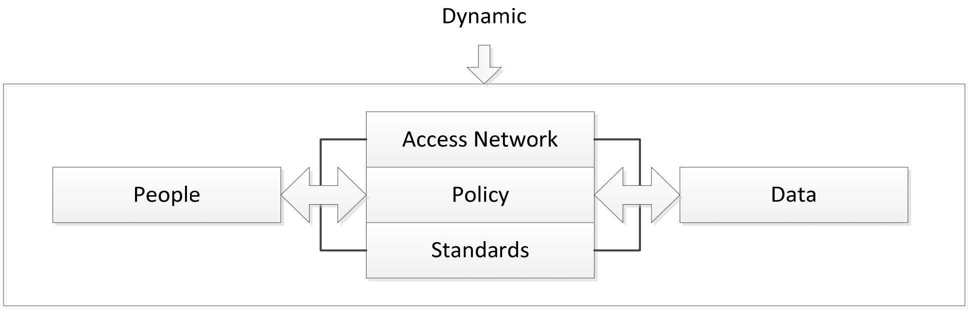

Figure 2:
SDI components (Rajabifard et al., 2002).

Other components of SDI are (6) Technology including Hardware and Software Equipment, Data Communication Network; (7) Organization including Organizations Arrangement and Relationship between Organizations; and (8) Partnership including Investment Funding, Human Resources Development, Public Awareness Raising, Scientific Research and International Cooperation (Kelly, 2007).

SDI activities are implemented at various levels. Rajabifard et al. (2002) developed a model of SDI hierarchy, which is made up of interconnected SDIs at organizational, local, national, regional, and global levels (Fig. 3).

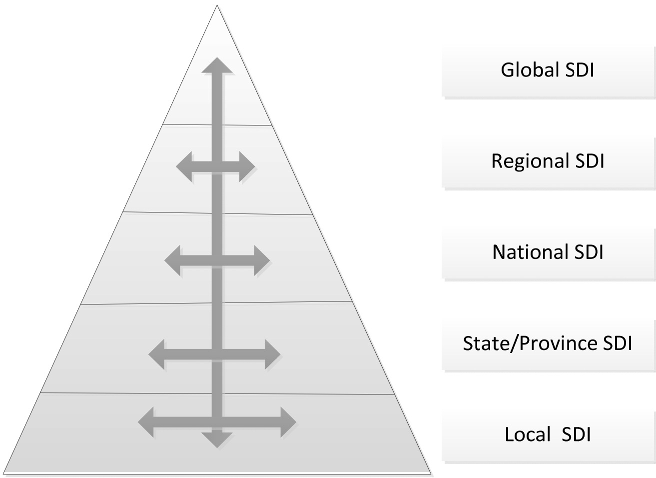

Figure 3:
SDI hierarchy (Rajabifard et al., 2002).

Referring to Fig. 3, most activities in one level affect other levels. For instance, a higher level SDI like global level contains other lower-level SDIs. Moreover, a regional SDI is a part of global SDI and also contains other lower levels. This view is regarded as a vertical relation among SDI levels and is represented by the vertical two-way arrow. Another relationship is the one that represents elements of the same level, such as organizational, management and political relations within an SDI, which is regarded as the horizontal relation and is presented with horizontal two-way arrows.

2.3 Spatial Data Infrastructure (SDI) initiative in Tanzania

Many developing countries including Tanzania are at different stages of planning or implementing a national SDI (Makanga and Smit, 2008, Okuku et al., 2014). Several attempts were done by Tanzanian Government to address the issue of spatial data sharing and management. The ministry introduced Land Rent Management System (LRMS), Surveys Registration System (SRS) and Management of Land Information System (MOLIS) (Mwaikambo and Hagai, 2013). LRMS was an in-house developed application which assists in assessing, collecting, and keeping records related to land owners and respective land rent payment data. It was a standalone system, and was deployed to 40 out of 130 local authority land rent collection centres. SRS was also an in-house application used to manage and speed up the entire process of submission, checking, approving, and registration of all cadastral surveys throughout the country. MOLIS was a web-based land information system developed by a consultant and was being used for performing most of the land management functions at the MLHHSD and the three municipal councils in the Dar es Salaam city.

The Integrated Land Management Information System (ILMIS) project replaces the previous systems and addressing functions of the land sector, delivering tools for handling land management functions such as Cadastral Surveying, land delivery services and Town Planning. It improves the security and reliability of land transactions through an efficient and reliable land information system, which offers the technical framework to harmonize and share land data and also to track efficiency and transparency in delivering land administration services (Mwaikambo and Hagai, 2013, Laseko et al., 2018). The ILMIS project installed by the French National Institute of Geographical and Forestry Information (IGN FI) includes the conversion of 6.5 million pages of paper documents, 18,000 maps and their resulting vectorized parcels integrated with 50,000 titles (Mwaikambo and Hagai, 2013). It is regarded as containing core elements of an NSDI aims at contributing to create reliable land administration services for the customers and improving public confidence in the land issues (Ngereja et al., 2018).

Water Point Mapping System (WPMS) is an information system that provides a baseline of water supply coverage and regular reporting as part of a system of Sector Performing Monitoring (SPM). The system is implemented by the Ministry of Water in Tanzania in collaboration with water sector stakeholders through Water Sector Development Program (Nyitambe, 2013, Georgiadou et al., 2016).

Online Mining Cadastre Portal was established in Tanzania in 2015 as part of the Tanzanian Mineral Sector Development Technical Assistance Project (MSDP). The Nordic Development Bank granted a consortium made up of Swedish Geological AB, Swede Survey and Spatial Dimension the contract to establish a Mining Cadastral Information Management System (MCIMS) in the Ministry of Energy and Minerals. The portal which has been developed through a cloud based FlexiCadastre aimed at strengthening the government's capacity to manage the mineral sector and improve the socio economic impacts of large and small-scale mining. It helps the Government to increase both the transparency and ease of doing business in the mining sector (Hernandez, 2003, Feast et al., 2006, URT, 2016b).

National Spatial Data Infrastructure for integrated coastal and marine spatial planning in Zanzibar (ZAN-SDI) is a project funded by Finnish Government and coordinated by the Finnish Environment Institute (SYKE), the Zanzibar Commission for Lands and National Land Survey of Finland (NLS). The overall objective of the project is to improve utilization of geospatial information in spatial planning and management in Zanzibar. This is done by improving the capacities in Zanzibar to use National Spatial Data Infrastructure (NSDI) effectively in integrated coastal and marine spatial planning.

Tanzania Environmental Information Network (EIN) is a project under National Environmental Management Council (NEMC) in collaboration with the Norwegian Environmental Council (NEA) with the aim to establish a data foundation needed to support country level sustainable development in the area of environmental aspects. It is an initiative by African EIN to strengthen the capacity of African countries to use good quality information to guide informed decisions and manage assets on sustainable basis (Larsen, 2014, COWI, 2015, Muhando et al., 2015). All mentioned systems operate in isolation and there is no direct link with other base data like cadastral information.

For Africa, the United Nations Economic Commission for Africa (UN-ECA) is coordinating SDI activities (Yilma, 2013). At the global level, several initiatives exist for developing a Global Spatial Data Infrastructure (GSDI), and also for regional partnerships such as Infrastructure for Spatial Information in Europe (INSPIRE) in Europe, Permanent Committee on SDI for the Americas (PC-IDEA), and Permanent Committee on GIS Infrastructure for Asia and the Pacific (PCGIAP).

Development of SDI is a long term collaborative effort, which requires a clear plan to support the continuity and the integrity of the activities. Considering the complexity of SDIs, for the development of a comprehensive plan, the affecting factors and their interactions should be identified and the plan should be developed in a way to meet all the requirements. Considerable amounts of money are being invested in the development of National SDIs and there has been a growing interest worldwide both politically and commercially.

2.4 Theory of Planned Behavior

The main challenge of improving geospatial data sharing rests on the better understanding of individuals' and organizations' behavior and their social relationships (Wehn de Montalvo, 2003, Omran et al., 2006, Akinyemi and Uwayezu, 2011). Geospatial data sharing among organizations is a complex undertaking. Empirical research on how individuals and organizations in different socio-cultural contexts function in geospatial data sharing is still inadequate (Wehn de Montalvo, 2003, Omran et al., 2006, Akinyemi and Uwayezu, 2011). According to Harvey and Tulloch (2006), the technical aspects have been well addressed, but organizational, political, and socio-cultural aspects that are equally important are less well studied. In any system relying on people, relationships are subjected to the complexity of social coordination and motivation of the involved individuals. A useful social psychological model that can be used to assist our thinking when considering why people perform particular behaviors is the Theory of Planned Behavior (TPB) (Ajzen, 1991).

Paper I adapts the TPB, developed by Ajzen in 1991, as a guiding framework to understand the intentions and behavior in geospatial data sharing among the stakeholders in Tanzania (Lubida et al., 2015). TPB was used because it has been identified by other researchers as having relevance in the domain of geospatial data sharing (Wehn de Montalvo, 2003, Omran et al., 2006). TPB is a theory that links beliefs and behavior, and associates the decision to engage in a particular behavior (behavioral intentions) and the actual performed behavior as illustrated in Fig. 4 (Ajzen, 1991, Wehn de Montalvo, 2003, Francis et al., 2004, Omran et al., 2006).

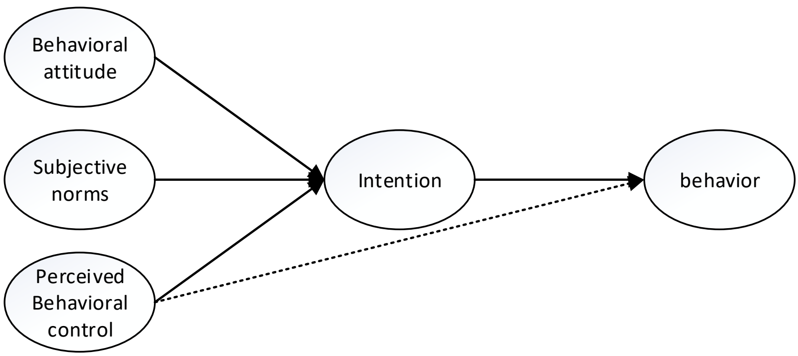

Figure 4:
Design of theory of planned behaviour (Ajzen, 2005).

To illustrate this further, Francis et al. (2004) argue that: 'To predict whether a person intends to do something we need to know: whether the person is in favor of doing it (attitude); how much the person feels social pressure to do it (subjective norm); whether the person feels in control of the action in question (perceived behavioral control)'.

2.5 Community of Practice theory

A Community of Practice (CoP) is referred to as a group of people who share a concern for something they do or a profession, and learn how to do it better as they interact regularly (Lave and Wenger, 1991). CoP was employed in Paper II for the purpose of sharing knowledge in a collaborative settings among the professionals and the SDI community in Tanzania (Mansourian et al., 2015). Through this process, of sharing information and experience, the group members learn from each other (Wenger et al., 2002, Verburg and Andriessen, 2006).

CoP exist in different forms. For instance, Offline CoP refers to the physical settings of a group such as lunch room or fieldwork. Virtual (VCoP) refers to the settings of which a collaboration is done online, while with mobile MCoP members communicate via mobile phones when participating in a community work. A CoP has three key elements: the domain of interest that defines a learning need shared, the community who interacts and learns in collaboration and a shared practice (Wenger et al., 2002). For the community to function well, members will need to establish and maintain a common ground where they share mutual beliefs, knowledge and vocabulary. Common ground is important for sharing the community's knowledge with others and for developing a shared understanding of complex system of ideas that the community develops (Wenger, 2000, Ahmad and Al-Sayed, 2005).

2.6 The System Dynamics Technique for SDI modelling

Development of SDI is complex because of many interacting components. The system dynamics technique is one of the tools that can help to model the SDI and hence prepare reasonable plans or policies (Sterman, 2000). The system dynamics technique is a tool for modelling and managing feedback systems that are complex, dynamic and nonlinear in time. The technique can enhance the understanding of a complex system reducing the development cost and increasing the reliability of the system development (Kresken, 1996, Sotaquir´a and Zabala, 2004).

This technique has been widely used to model numerous complex systems, such as urban, industrial and ecological systems (Forrester, 1961, Forrester, 1969, Dudley and Soderquist, 1999). The system dynamics technique functions use feedback loops which are the building blocks of the system (see Fig. 5). A feedback loop is a structure within which a decision variable or a flow controls an action that is integrated into the system to generate a system state. Information pertaining to the state is then fed back to the decision variable, which in turn is used to control the flow. In short, a flow is a statement of system policies that determine how information about the system is translated into actions. The system includes some other elements and concepts, such as auxiliary variables, time delay, constants and growth engines (Sterman, 2000). A growth engine is a positive feedback loop which makes the system to grow with a small initial force assuming there is no other limitations. The system dynamics model can be used as a virtual tool to simulate real situations.

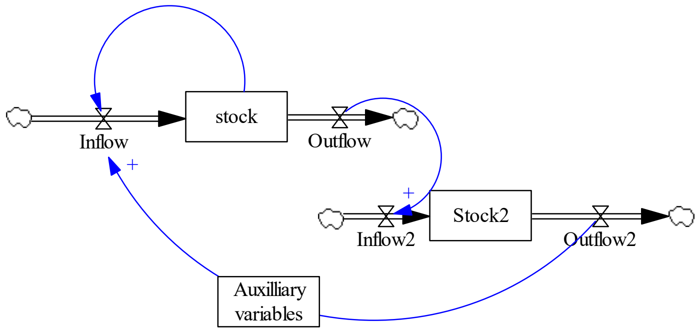

Figure 5:
An example of a stock-flow diagram with feedback loops.

The development of an SDI is a long-term process requiring large financial investments. Apart from that, the SDI system is complex in nature and requires a team to make proper decisions during the design process. As the system dynamics technique can model many components of an SDI as a complex adaptive system, it was observed that it is beneficial to use such techniques for better understanding the SDI development behavior (Mansourian and Abdolmajidi, 2011). Paper II uses System Dynamics and Community of Practice to model and understand the complexity of SDI in Tanzania for future and effective SDI planning.

2.7 Agent Based Modelling for SDI planning

Paper III uses an Agent Based Model (ABM) to investigate the bottom-up approach of SDI development process in Tanzania. ABM is a computational model that is used for simulating the actions and interactions of unique and autonomous agents as individuals or groups in order to view and assess their effects on the system as a whole (Gilbert, 2008, Railsback and Grimm, 2012). It is used to model complex systems with agents being the basic unit.

Agents can be humans, organizations or any other entity that pursue different goals, and they are unique in the sense that they exhibit different characteristics. ABM combines elements from different theories such as game theory, computational sociology, emergence, and other complex systems.

Models are built to solve problems or answer questions about a system. Since the real systems are often too complex and can develop too slowly to be analyzed using experiments. ABM helps to formulate a simplified representation of the system by assigning proper assumptions and algorithms and using equations or a computer program where manipulation and experimentation can be performed. The modelling process is best described as inductive which means the process lets a situation emerge from the lower or micro level of systems to a higher or macro level. Assumptions are made that are most relevant to the situation at hand and after simulation the phenomena emerge from the agents' interactions.

The ABM comprises of the agents and the environment as the main components. A model is an intended representation or simulation of some real or existing phenomenon. The advantages of a model are that it concisely expresses the relationships among the features of the phenomenon, and through its investigation, it allows the discovery of things. An agent in ABM interacts within an environment according to roles and rules set in the model. Agents are used to represent social actors such as individual people, organizations, or biological organisms. They are modelled to react to the environment in which they are situated, where this environment is a model of the real environment in which the actual agents operate (Gilbert, 2008, Railsback and Grimm, 2012).

2.8 Multi-Objective Optimization technique

Multi-Objective Optimization is an optimization problem involving multiple objective functions that are to be optimized simultaneously. It works better in the circumstances where optimal decisions need to be taken in the presence of trade-offs between two or more conflicting objectives (Srinivas and Deb, 1994, Deb, 2001, Datta et al., 2007). The purpose of solving a multi-objective optimization problem is to support decision makers when finding the most preferred Pareto optimal solution according to existing subjective preferences. The assumption is that one solution of the problem must be identified to be implemented in practice. The multi-objective problem can be represented by the following equation:

$$\frac{min}{x \in X^{n_x}} f(x) = \left(f_1(x), f_2(x), \dots, f_m(x)\right) \tag{1}$$

where x is the vector of decision variable bounded by decision space X^{n_x}, and f is the set of the objectives to be minimized.

Pareto optimization is an alternative solution to overcome this issue. Pareto front optimization is a situation of allocation of resources in which it is impossible to make any objective better off without making at least one objective worse off (Fudenberg and Tirole, 1983, Aguirre et al., 2004). A variety of techniques and algorithms has been developed for Pareto optimization.

Among the evolutionary algorithms the Genetic Algorithm (GA) is the most popular. The fast and elitist Non-dominated Sorting Genetic Algorithm (NSGA-II), developed by Deb et al. (2002), is the most recent algorithm with advantages over others and was used in paper IV. The three main features of NSGA-II include the elitist principle in which a superior set of individuals are chosen, an explicit diversity mechanism, and an emphasis on a non-dominated solution (Deb et al., 2002, Datta et al., 2007, Deb, 2014).

3 Methodology

3.1 Study area

The study was done in the United Republic of Tanzania, which is situated in East Africa, with a total area of about 947,300 sq. km. It is located on the east coast between latitudes 1° and 12° South and longitudes 29°-41° East (Fig. 6). It is bordered by Uganda and Kenya to the North, Indian Ocean to the East, Mozambique, Malawi and Zambia to the South, and Democratic Republic of Congo, Burundi and Rwanda to the West. According to the census projections, in 2019 Tanzania has a population of 55.89 million people (URT, 2018a).

Tanzania has a tropical type of climate and is divided into four main climatic zones notably: the hot humid coastal plain; the semi-arid zone of the central plateau; the high-moist lake regions; and the temperate highland areas. In the highlands, temperatures range between 10ºc and 20ºc during cold and hot seasons respectively. The rest of the country has temperatures usually not falling lower than 20ºc. The hottest period spreads between November and February (25ºc - 31ºc) whereas the coldest period is often between May and August (15ºc - 20ºc).

The relief of most of mainland Tanzania lies above 200 m in elevation, except for the islands and some parts along the coastal areas. In the northeast Tanzania lies mountainous terrain that includes an active volcanic mountain, Mount Meru, a dormant volcanic Mountain, Mount Kilimanjaro which is Africa's highest mountain, at 5,895 m, and other mountain ranges, Usambara and Pare mountains. In the west of Mount Meru lies the still-active volcanic mountain Ol Doinyo Lengai and the Ngorongoro Crater, the world's largest volcanic depression.

East African Rift System runs in two north-south-trending branches. The Western Rift Valley branch runs along the western border and is marked by Lakes Tanganyika, the world's second deepest lake, (1,436 m) and Lake Rukwa. The Great Rift Valley branch, extends through central Tanzania and is marked by Lakes Eyasi, Manyara, Natron and Lake Nyasa. The central plateau, covering more than a third of the country, lies between the two branches and is marked by grassland and the Miombo woodlands ecoregion. Southern highlands are formed by the Ufipa Plateau, the Mbeya Range, and Rungwe Mountain in the southwestern corner of the country.

About 59,000 sq km of Tanzania's territory consists of inland water. Lake Victoria, ranks as the world's second largest freshwater lake. Major rivers are the Rufiji, Wami/Ruvu, and Ruvuma. The largest river, Rufiji, with approximately 600 km length has a drainage system that extends over most of southern mainland Tanzania and its mouth in the Indian Ocean. Rufiji Delta contains the largest mangrove forest in East Africa.

Tanzania is having agriculture as the main sector of the economy followed by tourism and mining industry. The country is aiming to eradicate poverty and becoming a medium income nation. Its Development Vision 2025 (URT, 2000, URT-VPO, 2015) highlights main points as improving quality of livelihood, good governance, and a strong and competitive economy. To be able to achieve the vision, Tanzania devised policies and strategies to improve growth momentum to reach targets included in the Long Term Perspective Plan (LTPP) (URT-PO, 2012), Big Results Now (BRN) programme, MKUKUTA II (URT, 2010b) and MKUZA (RGoZ, 2007). As part of improving land delivery services, the government has established a number of policies that include the Land policy of 1995 and the subsequent Land laws of 1999, namely Land Act No.4 of 1999 and Village Land Act No.5 of 1999. Other laws include Land Use Planning Act No.6 of 2007, Urban Planning Act No.8 of 2007 and ICT policy of 2016 (URT, 2016a). The mentioned policies are relevant for managing National Spatial Data Infrastructure (NSDI) as they include access policy (pricing and cost recovery), legal issues, copyright, intellectual property and liability and data sharing agreements (Lance, 2001, Larsen, 2014).

3.2 Study sites

The major study sites consist of municipalities and city councils namely Zanzibar, Dar es Salaam, Mwanza, Dodoma and Mbeya which were involved in the Sustainable Cities program that used the Environmental Planning Management (EPM) process as a new approach in planning and managing cities as shown in Fig. 6 (Msangi and Liwa, 2014). Under this new approach, GIS units were established and staff were trained in order to learn how to manage spatial data in the area of jurisdiction.

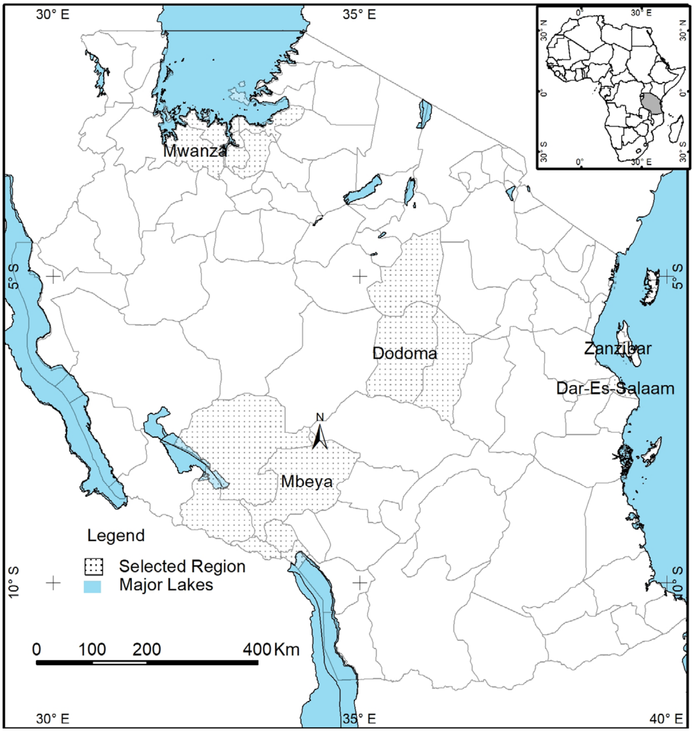

Figure 6:
Map of Tanzania showing study sites (Zanzibar, Dar es Salaam, Dodoma, Mwanza and Mbeya.

Additionally, the research included ministry departments, public agencies, academic and private firms as shown in Table 1. The study sites are briefly described below.

Zanzibar is a semi-autonomous country which is part of Tanzania and lies in the Indian Ocean, between 4°50′ and 6°30′ south of Equator and 39°00′ and 40°00′ east of Greenwich. It is 40 km off the east coast of the mainland, and consists of numerous small islands and two large ones: Unguja (the main island, referred to informally as Zanzibar) with 1,666 km^2 and Pemba with 1014 km^2. Zanzibar is famous for its tourism industry (Anderson, 2013, Sharpley and Ussi, 2014) and its unique history of being a World Heritage Site (UNESCO, 2000, Sida, 2004, Azzan and Ufuzo, 2005, Awadh, 2007, Hall, 2009, Sjöstrand, 2014).

Dar es Salaam is the former capital and Tanzania's largest city and economic center consisting of five Municipal councils; Kinondoni in the North and North West, Ubungo in the West, Ilala in the center Temeke in the South and Kigamboni in the South East. The region had a population of 4.4 million according to 2012 official census. The city is the leading arrival and departure point for most tourists and its port serves many neighboring countries.

Mwanza, on the other hand, is the second largest city located in the north-western part of Tanzania on the southern shores of Lake Victoria. Dodoma, the capital of the country, with a population of approximately 0.4 Million and is centrally located about 453 km west of former capital Dar es Salaam. Lastly, Mbeya city is located on the southern highlands of Tanzania and is largest and most economically important city in the southwestern part of the country.

Table 1:
Other organizations, which participated in the study apart from the central and local government organizations.

Sn	Organization	Functions related to spatial data
1.	Ministry of Lands, Housing and Human Settlement Development (MLHHSD)	Issuing hard & digital copy of maps at different scales and registering land parcels and title deeds
2.	Tanzania Geological Survey (TGS)	Handling information on geology and minerals
3.	Water and sewage units (DAWASCO)	Handling utilities e.g. pipelines and customers
4.	Tanzania Roads Agency - TANROADS	Handling data for roads networks
5.	Telecommunication company (TTCL)	Handling communication networks, phones and optical fibres
6.	Tanzania Communication Regulatory Authority (TCRA)	Handling mobile phones, postcode, satellite communications, broadcasting
7.	National Bureau of Statistics (NBS)	Provide current and projected population data
8.	National Institute for Medical Research (NIMR)	Handling health data
9.	Ardhi University (ARU)	Academic institution for land matters
10.	Institute for Resources Assessment (IRA-UDSM)	Academic institution for land-use matters
11.	Tanzania Posts Corporation (POSTA)	Handling post codes and address
12.	National Environmental Council of Tanzania (NEMC)	National technical advisory and regulatory agency responsible for the protection of the environmental and sustainable use of the natural resources in Tanzania.
13.	Sustainable Management of Land and Environment (SMOLE)	Zanzibar Spatial data on land management and socio-economic development
14.	Car Track (Miles)	Fleet Management & Assets Tracking
15.	National Land Use Planning Commission (NLUPC)	To prepare regional physical land use plans, formulate land use policies for implementation by the government and to specify standards, norms and criteria for protection of beneficial uses and maintenance of the quality of land.
16.	Tanzania Electric Supply Company (TANESCO)	Handling distribution, managing electricity and gas and also handling customers
17.	Rural Energy Agency (REA)	To promote and facilitate improved access to modern energy services in rural areas of Mainland Tanzania
18.	Tanzania GIS user Group	Sensitizing people on SDI. Possess servers for storing standardized spatial data
19.	Infobridge	Private company specialized in working with spatial data
20.	Tanzania Forest Services (TFS)	Handling land uses for forest management
21.	Tanzania National Parks (TANAPA)	Manages fifteen National Parks which form part of larger protected ecosystems set aside to preserve Tanzania's rich natural heritage
22.	Ngorongoro Conservation Area Authority (NCAA)	Manages Ngorongoro, a protected and world heritage site.
23.	Tanzania Wildlife Research (TAWIRI)	Conducting and coordinating wildlife research

3.3 Field data collection

During data collection, a mixed method approach was employed, including direct observations, in-depth interviews, focus group meetings and documentation analysis (Creswell and Plano Clark, 2007). A mixed method approach allows methods from different methodological paradigms to be employed with the aim of solving a problem at hand. For this case developing an SDI plan, creating sharing experience and learning among the community members were the main issues being solved. Apart from the mentioned methods, informal interviews were conducted during the entire period of fieldwork. Key informants from the government authorities and other stakeholders were identified and contacted. Prior to actual data collection, a pilot study was carried out in order to pre-test the research instrument. After necessary corrections were made, actual data collection started by visiting the study sites, observing and performing interviews. It was estimated that about 25 organizations and 22 city and municipal councils are actively involved in GIS activities. The number of GIS experts working in the specified organizations and councils were estimated to be around 200. Since it was judged impossible to get answers from all of these within reasonable time it was decided to target approximately 35% of the experts, evenly distributed among the organizations and users.

3.3.1 Phase I: Geospatial data sharing

Primary data collection involved a questionnaire survey based on structured and open-ended questions distributed in both hard copies and using online platforms. The questionnaires were divided in two parts: first part covered questions regarding challenges related to acquiring, use and managing spatial data while the second part focused on capturing information about actual performed behavior on geospatial data sharing. For the first phase of this research, a total of 72 questionnaires were distributed, and 43 were returned, representing a return rate of 60%. Constructs were rated using a seven-unipolar adjective scale (Ajzen, 1991). It involved questions (with examples) related to individual behavior, i.e. attitudes (e.g. 'For me to share (giving) spatial data is 1 = Extremely difficult; 7 = Extremely easy'), SNs (e.g. 'My close friends approve me sharing spatial data 1 = Strongly disagree; 7 = Strongly agree'), PBC (e.g. 'I can decide to share data or not 1 = Strongly disagree; 7 = Strongly agree'), and intentions (e.g. 'I intend to share spatial data 1 = Strongly disagree; 7 = Strongly agree').

3.3.2 Phase II: SDI development situation

Primary data collection involved a questionnaire survey which focused on understanding the current state of SDI in Tanzania. The questionnaire contained both structured and open-ended questions distributed in both hard copies and online. Three types of questionnaires were prepared targeting three groups; experts in spatial data management, managers of units and employers. First target group involving experts, provided information on the technical, technological and social aspects of spatial data in the organization. The 2nd group involving potential users informed about the situation of spatial activities from user perspective and the 3rd group which comprised of managers and decision makers informed about spatial data issues within the respective organization from management point of view. Secondary data were obtained from different sources and included published papers, policy documents, and technical reports relevant to the study.

For the second phase, thirty-two organizations and local government authorities were contacted, in which 87 individuals were given the questionnaires. 57 individuals from 23 organizations responded to make a 66 % response rate. Complementary interviews were conducted afterwards in order to get better understanding of the issue at hand. This was done by providing additional or same but modified questions to some respondents and through verbal communication. Apart from interviews, the research team arranged for workshops at different stages where the results and the proposed models were presented and based on comments, the models were improved.

3.3.3 Phase III: SDI planning

Phase III data collection comprised of questionnaires surveys, stakeholders meetings, literature search related to SDI implementation in Tanzania. The focus for the ABM model was to identify;

- The potential organizations for partnership in an NSDI implementation.
- Roles of different organizations in implementing spatially related projects.
- Activities done by the organizations related to SDI.
- Actions by organization meant for successful implementation of spatial projects.

The questions were mainly related to knowledge about the SDI, awareness level, knowledge of standards, and technological level of organization. Other questions were related to the financial resources for hiring, training, improving technology and improving standards, and promoting SDI culture. The questionnaires were directed to GIS experts, GIS managers and employers of the selected organizations. Twenty four organizations were involved in phase three of data collection. The selected organizations focuses on sectors related to road construction and maintenance, water distribution, waste water management, electricity, telecommunications, postcodes, addresses, mapping, and land use/land cover data. In addition, secondary data were obtained, such as; National Bureau of Statistics Strategic Planning, The National Spatial Data Infrastructure policy proposal 2007, The National Environmental Act, and the National Information and Communication Technology Policy.

3.3.4 Phase IV: SDI case study

Primary and secondary data for SDI case study were collected in Zanzibar with the aim of obtaining the requirement for the land-use planning optimization. Key government authorities from selected organization working with GIS/SDI were interviewed. Both closed and Open-ended questionnaires and workshops were used to collect important information relevant to the objectives of the research. The approach used provided flexibility for emerging new topics that helped to improve the model. Secondary data such as government reports, policies, master plans, spatial data and land-use maps (refer Table 2) were obtained during field work and were vital for building up the model.

Table 2:
Spatial data for land use modelling.

Sn	Spatial data	Description
1	Land use maps	Residential, education, commercial factory/industry, park, government
2	Hot points	Schools, hospitals, monuments
3	Statistical data (social economic variables and Population projection	Ward/block level +age and other statistics
4	Buildings	Buildings layer
5	Roads	Major roads, streets
6	Land parcels (cadastral)	Land use as attributes
7	Utility networks	Water, electricity, telephone

3.4 Data analysis

The returned questionnaires both open-ended and closed-ended were used in the analysis to determine the meaning in the information gathered. Before analysis, all the open-ended responses were read and the common themes were identified and grouped together. The themes were coded in a format which can be analyzed by a standard statistical package. Data analysis was done by using the Microsoft Excel package and the Statistical Package for Social Sciences (SPSS) software Version 19.0 for Windows. The coded themes as well as the coded closed-ended questions were entered into the statistical software in order to generate frequency and percentage tables.

Modelling of SDI for Tanzania was done in two phases. First phase was the modelling of SDI using System Dynamic technique where the global behavior of relationships among relevant factors were analyzed to help understand the contribution of individuals. Results from the modelling were a key to understanding better planning of SDI for the country (Mansourian et al., 2015). Second phase was using ABM approach where the relationships of the individual agents were analyzed in order to study the behavior of the SDI in the country.

4 Summary of Papers

4.1 Paper I

Spatial Data Infrastructures (SDI) development is based on a framework available for facilitating and coordinating spatial data access, use and sharing (Rajabifard et al., 2002, Nedovic-Budic et al., 2008). Assessment was done in Tanzania to understand the level of geospatial data sharing for efficient planning and management. Moreover, the study examined the willingness of individuals and organizations to engage in geospatial data sharing based on the Theory of Planned Behavior (TPB). Field data collection was done based on a mixed method approach to the selected local and central governments staff and others from relevant organizations. After data collection, all field data were analyzed and the summary of results are presented below.

The results showed existence of several fundamental datasets, which are useful for SDI development. Problems with data acquisition and management were mentioned by respondents, mainly being lack of resources. Generally, majority of respondents (79%) indicated lack of awareness is a main concern for the slow development of SDI in Tanzania. This is followed by lack of policy, lack of capacity building, lack of a proper lead organization. Individual response rates based on TPB variable scales showed that majority of the respondents were optimistic towards geospatial data sharing in Tanzania.

Correlation was calculated in order to measure the association between the variables intention, attitude, Subjective norm, and perceived behavior control. The output showed that all correlations among the variables were all positive. The reliability of each construct was (0.85) which is within acceptable limits since alpha ≥ 0.700. Multiple regression was conducted using the independent variables attitude, SN, and perceived behavioral control as predictors of intention. In this case the regression coefficient serves as a measure of the extent to which the intention to share geospatial data can be predicted from the three main components (attitude, SN, and PBC). The overall regression model is significant at 0.05 and the independent variables attitude ($B = 0.272$) is significant at $p = 0.031$, SN, ($B = 0.195$) is close to significance at $p = 0.052$, and PBC ($B = 0.288$) is significant at $p = 0.014$.

Availability of geospatial datasets that are consistent with Mapping Africa for Africa (MAfA) initiative under United Nations Economic Commission for Africa (UNECA) exist within organizations and local governments (Johansson, 2005, Kalande and Ondulo, 2006, UNECA, 2008). The datasets are vital for the provision of services at different jurisdiction levels. The Survey and Mapping Division (SMD) department under the Ministry of Lands and Human Settlement Development together with the dedicated offices within all municipal and town councils are charged with the task of providing spatial information in Tanzania (Silayo, 2005). For instance, SMD is responsible for cadastral maps, 1:50,000 and 1:250,000 topographic maps at national level, which are sold to ordinary users in both hard copy and digital form (Kalande and Ondulo, 2006). GIS units exist in many organizations and local government offices. The units are mainly for analysis and processing of raw spatial data and making simple maps. Since the units are not coordinated country wide, duplication of efforts occur at different levels. The problem with inadequate geodetic reference is being dealt by the initiative of United Nations Economic Commission for Africa (UNECA) Committee for Development Information, Science and Technology (CODIST). This is done by establishing the African Geodetic Reference Frame (AFREF) which is expected to use Global Navigation Satellite System (GNSS) technology following the standards of the World Geodetic System 1984 (WGS84) and the International Terrestrial Reference Frame (ITRF) Systems (UNECA, 2008, Yilma, 2013, Mayunga and Mtamakaya, 2015, Ulotu, 2016). GNSS refers to satellite constellation that provides positioning, navigation, and timing services on a global or regional basis.

In the analysis of individual behaviour, one can conclude that overall the respondents were optimistic towards geospatial data sharing in Tanzania. According to the results of the regression analysis, 67% of the variation in the intention can be explained by the direct measures of attitude, SN, and PBC. The actual sharing behaviour measured by attitude, social pressure, and PBC were found to influence the willingness of individuals to engage in geospatial data sharing across the organizations.

Results from this research show that there is a high potential for geospatial data sharing in Tanzania, and that there is an urgent need for an NSDI development, which at the moment is in its conception stage. The respondents were very positive towards geospatial data sharing, although a number of inhibiting factors were mentioned, such as lack of detailed knowledge on SDI as well as absence of an institutional framework responsible for implementing sharing of spatial data countrywide. The sharing framework such as a geoportal with standard format layers is vital for supporting data sharing. Regression analysis was used to test the hypothesis based on the TPB. The attitudes, SNs and PBC, were found to significantly influence the individual's intention to share spatial data in Tanzania. Focusing on creating awareness, especially by showing clear benefits of SDI, will help decision makers to support the development of SDI.

4.2 Paper II

A System Dynamics model was developed using state flow diagrams, based on the data collected and a Community of Practice theory. The model reflected the main components of current and future plans as obtained during interviews, information presented in an NSDI policy proposal for Tanzania (Lugoe and Yanda, 2007) and the Tanzania Statistical Master plan (URT, 2010a). Four steps were followed during making the model. The first step was to identify the main factors affecting the current status of SDI. In this step 17 factors were identified and used in the model. The second step was to construct a dynamics hypothesis by identifying and analyzing the relationship among the factors using state flow diagrams in the Netlogo software (Wilensky, 1999). The third step was to define numerical relationships among the factors involved in the model and lastly to refine the model in collaboration with the stakeholders. The factors were classified as stocks; an entity that accumulates or depletes with time and flows; a rate of accumulations or depletion in a stock.

Results obtained were presented to the Expert from Academic Sector (EAS) and Expert from Executive Organization (EEO) groups to identify the existing activities, knowledge and knowledge gaps among the community. This methodology generated a learning process based on defining, redefining and negotiating ideas, assumptions and terminology. The learning process continued throughout the subsequent stages. During planning learning occurs as the community works together and this increases the knowledge of stakeholders and facilitates awareness creation of politicians.

Two models were created and simulated. The first model was to capture the current situation of SDI development in Tanzania and it contains all the main factors affecting SDI as well as their interactions. The main factors were; coordination, budgets, awareness, partnerships, technology, standards, data quality and skill formation. From first model,

- Participating organizations are at different levels, involved with SDI activities such as map production, database creation and web services.
- Some organizations sell their spatial data to different organizations and individuals and earn income.
- Local companies are usually subcontracted to execute spatial data related tasks. However, for extensive mapping projects and web service installation and maintenance, foreign companies are instead, subcontracted due to limited capabilities of the local companies in terms of skills, technology and finance.
- As map production projects increase available data, lack of coordination results in duplicated efforts in data production. Significant amounts of funds are wasted due to data duplication.

The relationships were described mathematically in the model. For the current status of SDI, the results from three factors namely; standards, data quality and SDI awareness were generated as shown in Fig. 7. The plotted lines shows number of years against percentage increase.

Figure 7:
SDI Development – standards, data quality and SDI awareness.

From Fig. 7, the progress for the three factors namely; standards, data quality and SDI awareness was not good because of several factors including low investment for SDI activities, and lack of coordination and experts in the field. Currently, SDI income is too meagre to support SDI activities which needs sizable investment. Also it was realized that the internal private sector companies were not given enough projects to help build capacity. SDI growth index was designed as a function of six factors; SDI awareness level, technology preparedness, level of partnership, data quality, quality of standards and level of skills. For the current setup, no growth engine is realized to support the growth of SDI. Therefore, for the simulated 10 years, the results showed that there will be very little progress.

The second model was capturing the optimum state, after various refinement based on discussion with the stakeholders. The model is shown in Fig. 8 with all main factors and their relationships. From stakeholders' discussions it was concluded that the model should focus more on increasing number of participating organizations, supporting local experts, establish a reliable funding scheme and establishing a strong coordinating body.

Fig. 8 shows the System Dynamic model with stocks, shown by boxes, flows, shown by large arrows and feedback loops shown by small arrows. Stocks consists of variables such as quality of standards, participating organizations, technology SDI awareness etc. Flows consist of variables such as increase quality of standards, joining rate, culturing, production rate etc. Feedback loops showing the relationships among the stocks and flows whether is positive or negative.

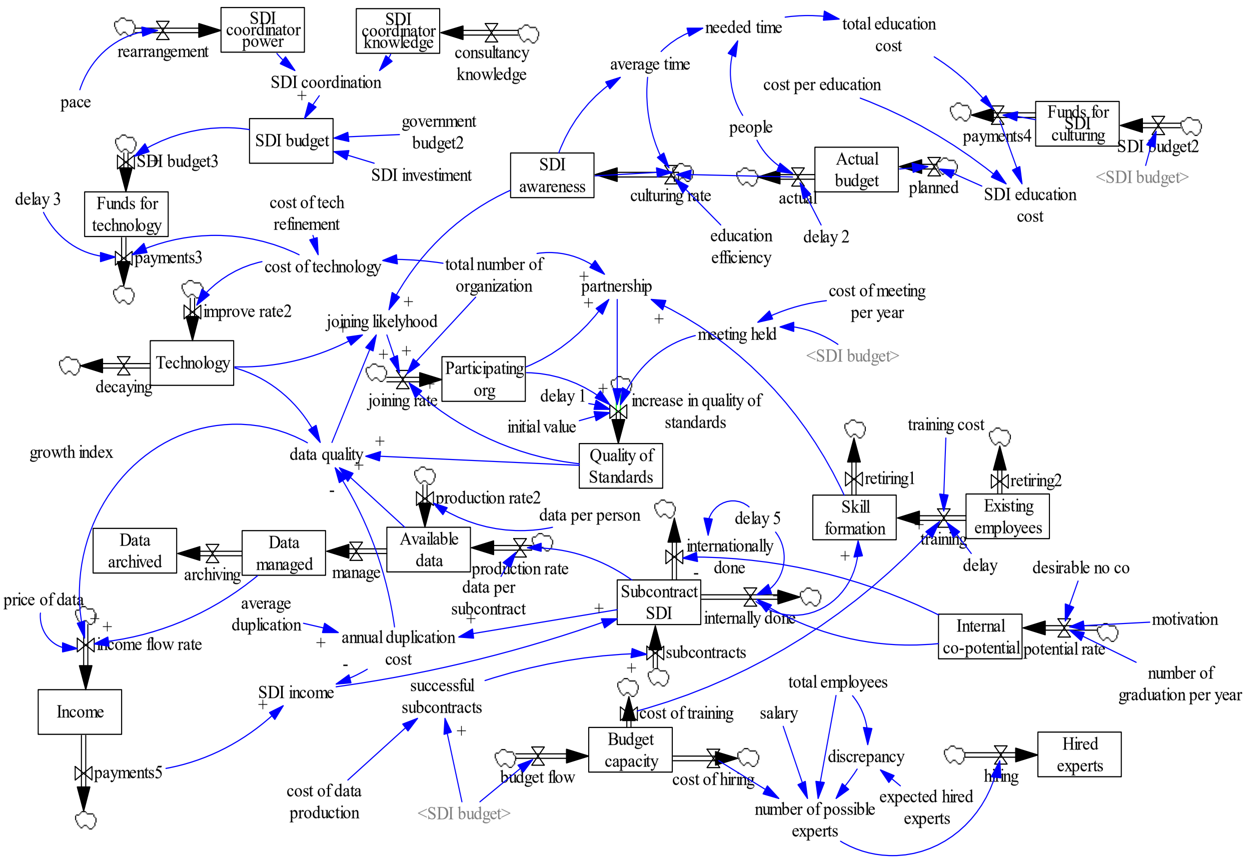

Figure 8:
Stock and flow SD model showing the optimal model of SDI Development after adding support for local staff and establishment of a strong coordinating body

From revision of the relationships and equations, the four growth engines were realized (Fig. 9).

- First growth engine (a); as number of participants in a partnership increases, the quality of standards improves. In this case, a wider group is involved in improving the standards and hence facilitates data integration which will make more organizations to be motivated to participate in the SDI implementation.
- Second growth engine (b); by supporting local sector a good market for spatial data will be formed, more experts will be motivated to establish large companies and therefore there will be an increased number of experts to support SDI development.
- Third growth engine (c); supporting local sector helps to increase data quality and reduce data acquiring costs paid to the foreign companies. Expenses served will increase the income for SDI implementation.
- Fourth growth engine (d); the greater the number of skilled people participating, the higher the quality of standards and data quality expected. Applicability and usability increase the income.

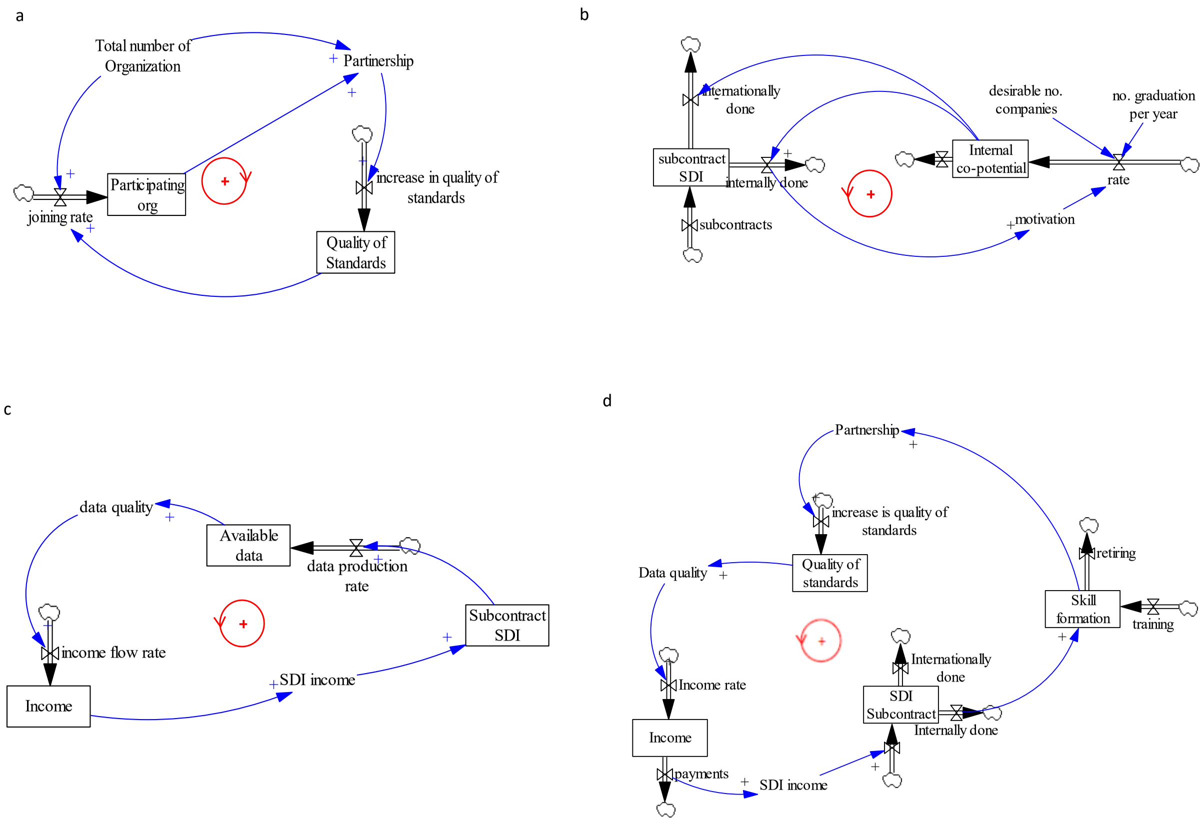

Figure 9:
Extract of Stock and flow from Fig. 8 to show the main growth engines (GE). GE (a) –increase number of participants improves quality of standards. GE (b) – build capacity for local staff. GE (c) – increase income for SDI and GE (d) – increase number of skilled staff to improve quality of standards

The results of the optimal model in Fig. 8 is shown in Fig. 10. This was after fine-tuning and adding the growth engines. The plotted lines shows the growth of quality of standards, data quality and SDI awareness based on the modified plan.

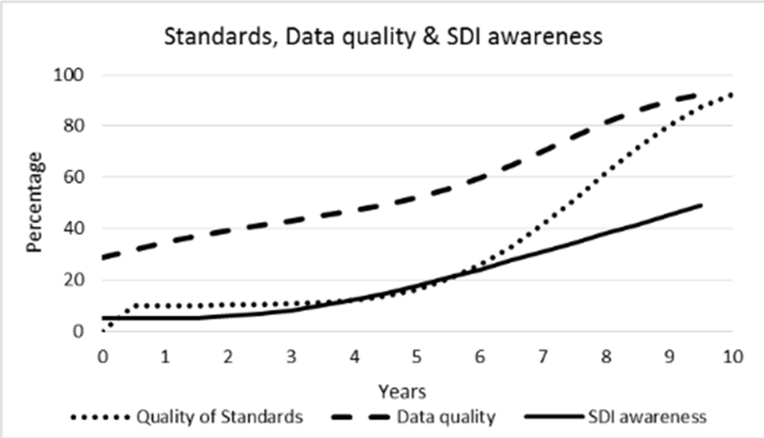

Figure 10:
Optimal model – standards, data quality and SDI awareness.

SDI growth index for the optimum model is shown in Fig. 11. The four growth engines shown in the optimum model are the key in the SDI development. The SDI growth for the optimum model for 10 years was simulated and is about 67%. In the following years, the SDI will still continue to grow further as the growth engines become stronger.

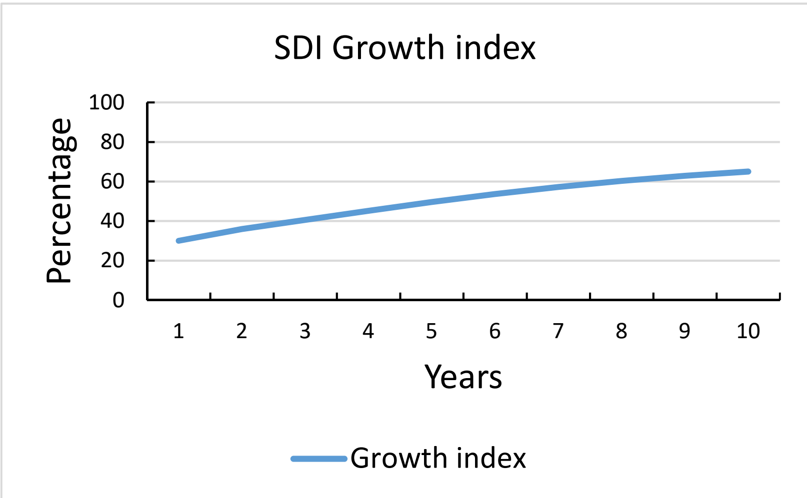

Figure 11:
SDI growth index for optimal situation in 10 years.

To validate the developed SDI model five tests, including the boundary adequacy, the structure assessment, the extreme conditions, the parameter assessment, and the sensitivity analysis test, were conducted. All the tests were passed successfully. One test, the behaviour reproduction, could not be conducted because no data is available about the future of SDI in Tanzania.

Integrated community of practice and SD was used to understand the complexity of SDI. In this context sharing knowledge and learning can facilitate and improve SDI planning. Group collaboration resulted in establishment of a common ground which brought member understanding of SDI closer to each other. SDI model development was more tangible for decision makers and can help in raising awareness and hence help to successfully implement an NSDI in Tanzania.

4.3 Paper III

The ABM was developed with the aim to better understand the interactions among the main agents in SDI development in the study area. In the model, the three main agents; organizations, projects and actions were represented. Organizations were the ones performing activities related to SDI and were represented by three groups namely; public agencies, mapping agencies and ministries. The fourth group, the Private Sector Companies (PSC) was a subsidiary group (refer Table 3). Organization in this case were main agents employing worker and Private Sector Company (PSC) agents for doing actions or projects in order to increase their attributes, eventually reaching the objectives.

In the model, nine attributes were used to characterize the organizations. The attributes were budget, technological level, standards and procedures, authorization, culture, data sharing, knowledge level, spatial knowledge index and data availability.

Table 3:
Agents used in ABM simulation.

Organizations	Projects	Actions
Public agencies	Spatial data production	Training staff
Mapping agencies	Spatial data sharing	Employment
Ministries	Using standards	Improving technology
Private sector companies	Creating and maintaining database	Increasing awareness
		Budget
		Updating spatial data

The ABM was based on the situations where organizations strive towards fulfilling selected objectives for the attainment of best level of SDI development.

- 1st objective was the summation of reward from project on spatial data production and project on geodatabase.

- 2nd objective was the summation of reward from project spatial data sharing and from project standards.

Completing projects and actions improves the attributes for the organizations.
Fig. 12 shows, organizations, projects and actions linked up using UML class diagram. Organizations selects objectives and is subjected to attributes check to determine whether it has capability to run the project or improve attributes by performing actions or hire PSC. From the figure, for instance, organization and project are linked by “perform_project” while organization and actions are linked by “perform_action”. Also organizations and PSC are linked by “hire PSC” through another class diagram “check organization attributes”.

ABM simulation process, projects and actions have different length and timing. This is due to the nature and type of the given project or actions. For instance, a project on spatial data production is estimated to be finalised within five years, while project on geoportal and data sharing, within one year. Also a project on creating a geodatabase is set for five years and a project for developing data standards and procedures is set for one year. A project on creating geodatabase is set to be an initial project and gets high priority in the process of selection due to its importance in the SDI development. In the model, the organization is checked if it had once done geodatabase project before engaging in other projects.

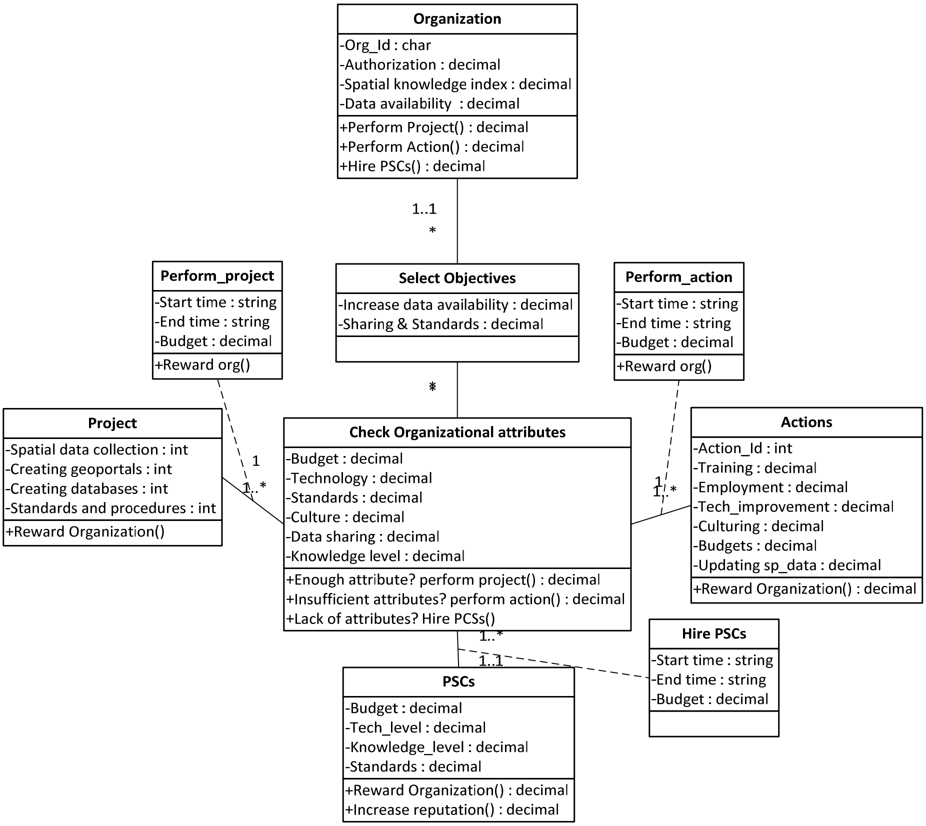

Figure 12:
Showing organizations, projects, and actions linked up as presented by a UML class diagram. Organization selects objectives to fulfill, after checks, decision is made whether to perform a project, perform an action or hire PSCs.

Actions as well were set into reasonable timing. For instance, training was estimated to be done in 6 months, employment within two years. Other are technology improvement within one year, culturing within one year, budget updated once per year, and updating spatial data were set on monthly basis.

The modelling process was represented by a sequential diagram, as shown in Fig. 13 below. From the figure, interaction of agents and its attributes and the order those interactions occur in the SDI development process are shown. Instances are positioned across the top of the diagram. The processes are marked by vertical bars while interactions are shown as arrows. All instances are connected by arrows and apart from arrows there are messages indicating the type of interactions performed.

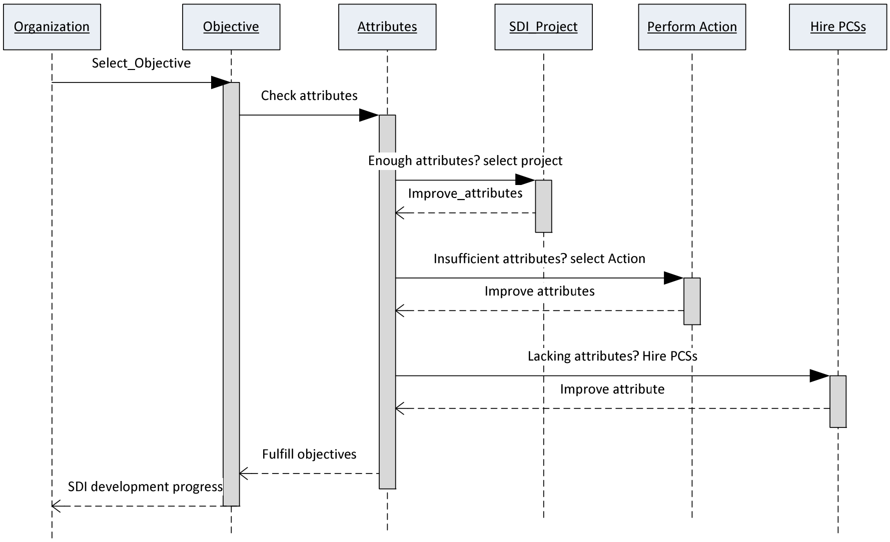

Figure 13:
Sequential diagram showing the interactions among agents and attributes in the SDI development process.

The results of ABM simulations were based on checking the performance of organizations in fulfilling the two objectives; 1. Data availability and 2. Standards and data sharing. For the objective data availability, the output was the summation of rewards of organizations that performed projects on spatial data production and geodatabases. Fig. 14 shows the summation of data availability for fifteen years. National Mapping Agency (NMA) reaches the target after approximately 100 months, or around 8 years.

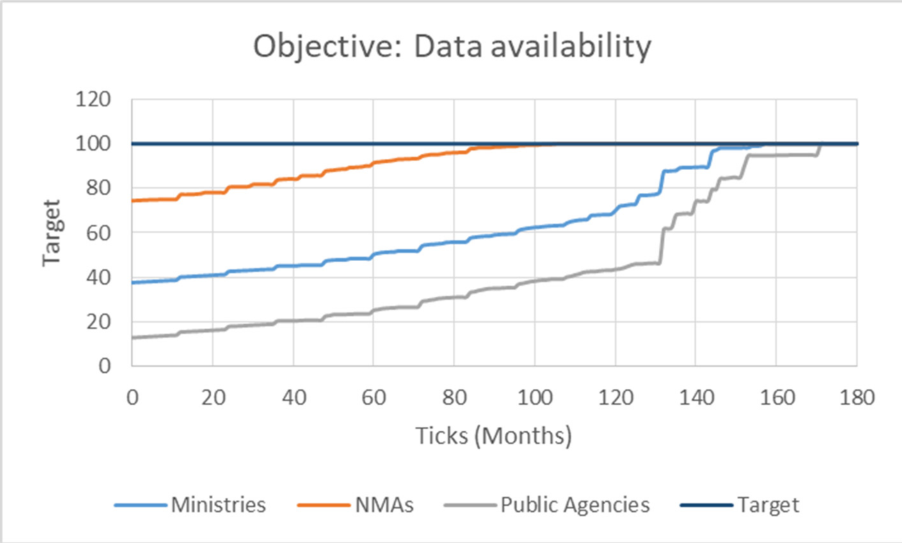

Figure 14:
Summation of data availability for the three main organizations.

Development of SDI requires generation and storage of a lot of spatial data. Producing new data and creating a geodatabase, were important projects for the organizations. Mapping agencies, in this case named NMAs, have knowledgeable staff, good technology, and good standards but inadequate budgets, and therefore reaches target in the shortest time (Fig. 14). Ministry departments have other different roles parallel with SDI, with fewer knowledgeable staff, limited technologies and budgets, and do not follow standards. They reach the target after approximately 14 years.

The second objective, standards and data sharing if important for facilitating and coordinating the exchange and sharing of spatial data between stakeholders in the spatial data community. As demonstrated in Fig. 15 below, national mapping or NMAs reaches the target for standards and data sharing after approximately 7 years. Public agencies reach targets approximately 9 years. Ministry departments reach target after approximately 12 years. Based on Fig. 15, national mapping agencies reach the target for standards and data sharing in shortest time because they have knowledgeable staff, good technology, and good standards.

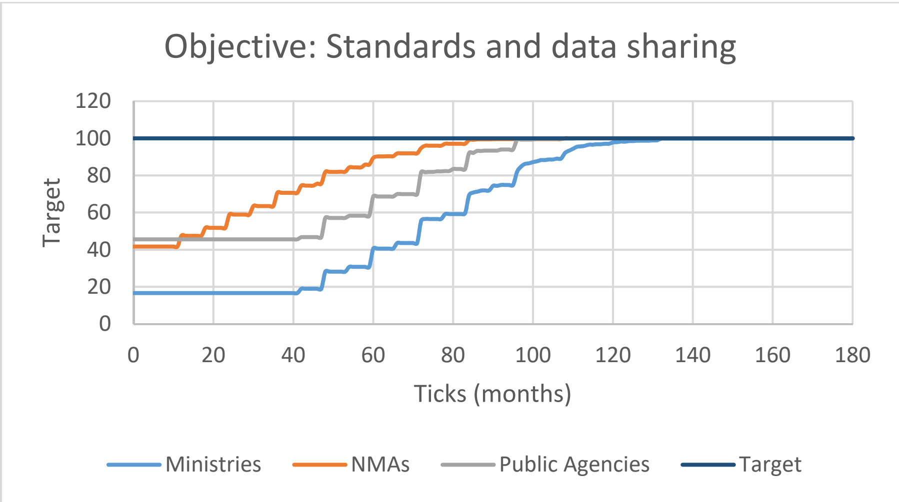

Figure 15:
Standards and Data sharing among the main organizations.

Public agencies on the other hand reach the targets in about 9 years, which can be related to the presence of fewer knowledgeable staff, limited technologies and poor standards. However, public agencies were able to solicit funds for many important projects. Ministry departments reach the target after about 12 years. This can be related to having fewer knowledgeable staff, inadequate technologies and budgets, and poor standards.

Another group of results was based on prioritizing attributes to be improved in order for organizations to successfully carry out projects. The output was priority tables. The third group of results, individual organizations, was made to select projects and actions either randomly or by using specific requirements. Different paths taken by agents were recorded. The recorded variables were; time spend, activities involved and cost. The results from this modelling were found to be very relevant for supporting successful SDI planning in Tanzania. The ABM was able to handle interactions of organizational attributes based on simple rules. The resulting emergency behaviour of agents were analysed and the priority areas identified. By changing parameters and simulating the development of SDI for different scenarios, it was realized which factors should be considered with high priorities in Tanzanian SDI's strategic planning.

4.4 Paper IV

A successful Spatial Data Infrastructure creates a platform to facilitate the spatial data sharing and access among different stakeholders including all who are involved in land use planning (Scott and Rajabifard, 2017). Paper IV in this thesis describes a methodology for producing a land use by optimising several objective functions that are in conflict with each other (Lubida et al., 2019). A fast and elitist Non-dominated Sorting Genetic Algorithm (NGSA-II) algorithm was used in this work since it was the found to have many advantages over others (Deb et al., 2002, Datta et al., 2007, Deb, 2014). The city of Zanzibar was selected as a case study because it was in the process of revising its land use.

The mixed method approach was employed to collect data in Zanzibar. Based on data availability and analysis, literature review and relevant policies, the research team selected the two most important objectives to be considered in the modelling.

The objectives functions were

- Maximizing land-use compatibility defined by

$$F1 = maximize\ \sum_{i=1}^{1467} \sum_{n=1}^{8} (9 - n) \qquad (2)$$

where "i" denotes the number of the search cells and "n" is the number of neighbour cells with similar land-use types as the centre cell, and

- Minimizing travel distance defined by

$$F2 = Minimize\ (\sum_{i=1}^{n} \sum_{j=1}^{m} M\_dist_{ij} + \sum_{k=1}^{p} \sum_{l=1}^{q} M\_dist_{kl}) \qquad (3)$$

where "i" represents residential cells and "n" is the total number of residential cells; "j" represents destination cells of residential cells (schools, shopping, etc.), and "m" is the number of destinations (here m= 10); "k" represents tourist cells and "p" is the total number of tourist cells; "l" represents destination cells for tourists (stone city, recreational areas, etc.) and "q" is the number of destinations (here m= 5), and M_*dist_ij* shows the distance from a residential cell to the nearest cell of a target destination.

The (NSGA-II), developed by Deb et al. (2002), was conceptualized and written in MATLAB language. A flow chart (Fig. 16) shows the process of the algorithm being divided into two stages; Stage A and B. Stage A involves defining parameters such as number of primary populations, number of runs, number of offspring and land-use proportions.

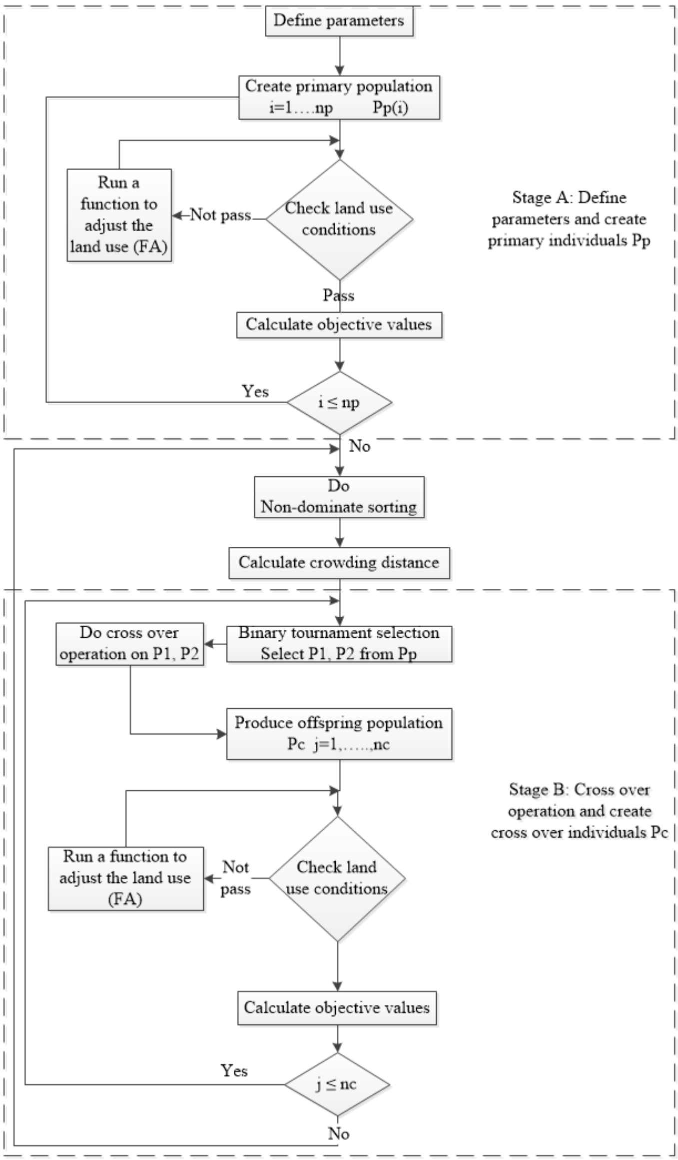

Figure 16:
Flow chart showing the NGSA II algorithm implemented in this study.

Several alternative land-use plans, named primary population were randomly created. Conditions were defined, and the land uses were checked if they fit in. the process continues until the requirements were achieved. Stage B involved using binary tournament selection, where two individuals were selected for the cross over process. The proportions of all land use were checked. All land-uses which had higher or a lower proportion compared to the defined proportions were selected and by randomly removing or adding them the required amounts the defined proportions were achieved. Requirements were set, process continues until the requirements were fulfilled. Afterwards the two objective values were calculated. The process continued and terminated when the criterion was achieved.

Input data were prepared based on spatial and non-spatial data obtained from the study site. The algorithm was tested and evaluated to account for sensitivity and repeatability. The algorithm was run six times with the same parameters and found to give acceptable results. The output land use maps based on Pareto front were presented. Results from sensitivity analysis indicated that a population of 20 individuals with 2500 runs had the most optimized results for the objective functions. Final results for the objective functions were based on these parameters. For instance Fig. 17 shows the Pareto front for a population of 20 for 1000 and 2500 runs. The figure shows how iteration enhances both the objective functions. Using 1000 iterations the distance range for compatibility function values had increased from 5364 to 5480, and the range of travel distances had decreased from 8623 km to 8488 km. These changes illustrate the evolution of the algorithm after 1500 additional runs.

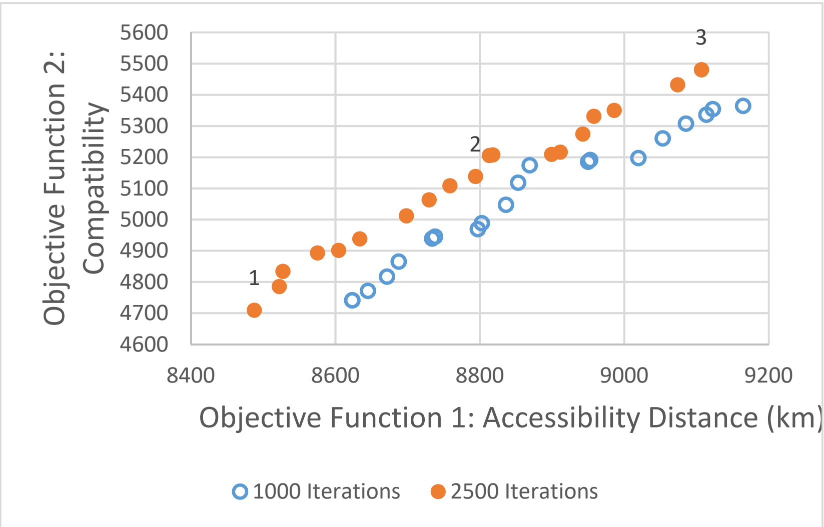

Figure 17:
Optimal Pareto front after 1000 and 2500 iterations respectively, based on two objectives of minimum travel distance (km) and compatibility. “1” and “3” are two possible solutions by emphasizing on accessibility and compatibility respectively. “2” is a solution by giving the same weights to the two objective functions.

In case of 2500 iterations, the distance ranged from 8488 to 9107 km, and values for compatibility varied from 4709 to 5480. When the results were compared from the first Pareto front and the 1000 runs, the minimum travel distances were realized to be reduced by 1112 km. Thus the compatibility optimal values were increased by 116 cells compared to primary population and 1000 runs, respectively.

Based on the above results, three maps were generated. First one was the land use map when the objective function of maximizing compatibility is prioritized and the second was when the objective function of minimizing travel distance is prioritized. The recommended plan is the trade-off map that shows a good mix of land-use types with minimum travel distance. In this case, the travel distance of 8758.68 km and a compatibility value of 5108.

The optimised land-use plans provide the planners and decision makers with a scientific way of managing land-uses by avoiding biasness. Multi-objective genetic algorithms applied to urban land-use planning have significant potential for assisting land managers, planners, and decision makers in solving complex resource allocation problems with conflicting objectives. Environmental, social, and economic factors were all considered in the objective functions applied in this study, and therefore in the resulted set of plans. The findings have implications on how urban land-use types should be planned by authorities in order to attain sustainable development of the city. This study helps in advocating the benefits of SDI to the experts and politicians in Tanzania.

5 Conclusions and Future Research

5.1 Conclusions

The main conclusions drawn from this thesis work are from several studies that have been performed where system modelling and social concepts were employed to understand the SDI development in Tanzania. Regarding on assessment of spatial data sharing, the results showed that there is high potential for geospatial data sharing in Tanzania justified by parallel efforts identified during this study. For instance, the existence of standards that are followed by some institutions, base maps and sharing platforms like ILMIS and recognition of importance of SDI by important government offices such as the NBS under Presidents Office, DMD under Prime Minister's Office, and Survey and Mapping Division. Regression analysis showed the TBP variables were found to significantly influence the individual's intention to share spatial data.
An integrated methodology of the System Dynamics techniques and the Community of Practice (CoP) theory for SDI planning in Tanzania is proposed. The SD techniques modelled and presented the complexity of SDI in terms of its main affecting factors and their interactions. Community of Practice theory provided the necessary framework for sharing knowledge, learning interactively about SDI and making agreement that improved the model. Hence, CoP increased the knowledge of the stakeholders.

Additionally, an Agent Based Modelling (ABM) simulation was employed to better understand the SDI development process and make better planning in Tanzania. The ABM was able to handle interactions of organizational attributes based on simple rules. The resulting emergency behaviour of agents were analysed and the priority areas identified. By changing parameters and simulating the development of SDI for different scenarios, factors to be prioritized were realized. Information about high priority factors is a key for realistic SDI plan.

A case study of using spatial data in solving the multi-objective optimization problem to support sustainable urban development was performed in Tanzania's island of Zanzibar. Data availability and accessibility issues which are part of the ongoing initiative of developing a national SDI in Zanzibar and on Tanzania mainland were found to be a key for successful land use optimization. Multi-objective genetic algorithms applied to urban land-use planning have significant potential for assisting land managers, planners, and decision makers in solving complex resource allocation problems with conflicting objectives. In this regard, the role of the experts such as planners and managers is reduced and biasness is minimized.

5.2 Future Research

This thesis work highlights some potential areas for further investigation.

Most of the work on this thesis (Papers I and II) were published in 2015, it was difficult to account for the changes that happened to date. In this respect, further research is recommended to validate the results.

Future research regarding TPB on individual and organizational influence on spatial data sharing is recommended in order to ascertain the effect of several other individuals as well as organizational groups.

The proposed methodology of using the System Dynamics techniques and the Community of Practice (CoP) theory as well as the ABM approach can be used to other countries with same level of SDI development for producing reliable SDI plans.

Multi-objective optimization employed in this research involved two objective functions because of the limitation of available data. Including more influencing factors in the optimization process may result in a better land use outputs. Also, the objective function such as travel distance may be formulated in different ways by considering the travel behavior of citizens. Similar approach for land use optimization can be applied in other countries in Africa where the cities are under development and are in need of the land use plans.

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References

Aguirre, A. H., Rionda, S. B., Coello Coello, C. A., Lizárraga, G. L. & Montes, E. M. 2004. Handling constraints using multiobjective optimization concepts. *International Journal for Numerical Methods in Engineering,* 59**,** 1989–2017.

Ahmad, K. & Al-Sayed, R. 2005. Community of practice and the special language ‘Ground’. *In:* Clarke, S. & Coakes, E. (eds.) *Encyclopaedia of Knowledge Management and Community of Practice.* Hershey (PA): The Idea Group Reference.

Ajzen, I. 1991. The theory of planned behavior. *Organizational Behavior and Human Decision Processes,* 50**,** 179–211.

Ajzen, I. 2005. *Attitudes, Personality, and Behavior: Mapping social psychology,* Berkshire, McGraw-Hill Education.

Akinyemi, F. O. & Uwayezu, E. 2011. An assessment of the current state of spatial data sharing in Rwanda. *International Journal of Spatial Data Infrastructures Research,* 6**,** 365–387.

Anderson, W. 2013. Leakages in the tourism systems: case of Zanzibar. *Tourism Review,* 68**,** 62 - 76.

Awadh, G. O. 2007. “Tourism and Heritage Conservation: 21st Century Challenge” Case: Zanzibar Stone Town. *Manifestation of African Perspectives Dialogues on Urbanism and Architecture.* Faculty of Architecture - TU Delft, The Netherlands.

Ayanlade, A., Orimoogunje, I. O. O. & Borisade, P. B. 2008. Geospatial data infrastructure for sustainable development in sub-Saharan countries. *International Journal of Digital Earth,* 1**,** 247-258.

Azzan, R. M. & Ufuzo, S. S. 2005. The Role of Spatial Data and Infrastructure in an Information Society: Conflicts and Implications for Zanzibar. *FIG Working Week 2005 and GSDI-8 From Pharaohs to Geoinformatics.* Cairo, Egypt.

Becker, P. 2011. Scoping study for capacity development in disaster management between Tanzania and Sweden. Lund: Disaster Management Department, Office of the Prime Minister, Tanzania and MSB, Sweden.

Capitani, C., Mukama, K., Mbilinyi, B., Malugu, I., Munishi, P. K. T., Burgess, N. D., Platts, P. J., Sallu, S. & Marchant, R. 2016. From local scenarios to national maps: a participatory framework for envisioning the future of Tanzania. *Ecology and Society,* 21**,** 4.

Cimbaljević, M., Bučić, A. & Jovanović, M. 2014. The Importance of Introducing GIS and its Application on a Local Government Level – An Experience from Serbia. *Researches Reviews of the Department of Geography, Tourism and Hotel Management,* 43**,** 97–108.

COWI 2015. Study of Coastal and Marine Datasets in Tanzania. *FINAL REPORT. Revision 1.2.* Dar es Salaam: COWI Tanzania.

Creswell, J. W. & Plano Clark, V. L. 2007. *Designing and conducting mixed methods research,* Thousand Oaks, CA, SAGE Publications.

Datta, D., Deb, K. & Fonseca, C. M. Multi-objective evolutionary algorithms for resource allocation problems. *In:* Obayashi, S., Deb, K., Poloni, C., Hiroyasu, T. & Murata, T., eds. 4th International Conference, EMO 2007, 2007 Matsushima, Japan, March 2007. Springer, 401-416.

De Man, E. 2007. Are spatial data infrastructures special? *In:* Onsrud, H. (ed.) *Research and theory in advancing spatial data infrastructure concepts.* Redlands: ESRI Press.

Deb, K. 2001. *Multi-Objective Optimization using Evolutionary Algorithms.,* Chichester, Wiley.

Deb, K. 2014. Multi-objective Optimization. *In:* Burke, E. K. & Kendall, G. (eds.) *Search Methodologies: Introductory Tutorials in Optimization and Decision Support Techniques.* 2 ed. London: Springer.

Deb, K., Pratap, A., Agarwal, S. & Meyarivan, T. 2002. A Fast and Elitist Multi-objective Genetic Algorithm: NSGA-II. *IEEE Transactions on Evolutionary Computation,* 6**,** 182-197.

Dudley, R. G. & Soderquist, C. S. 1999. A simple example of how system dynamics modeling can clarify and improve discussion and modification of model structure. *The 129th Annual Meeting of the American Fisheries Society.* Charlotte, NC.

Esselaar, S. & Adam, L. 2013. Understanding what is happening in ICT in Tanzania: A supply- and demand-side analysis of the ICT sector. *Evidence for ICT Policy Action: Policy Paper 11.* Cape Town: Research ICT Africa.

Feast, B., Davids, J., Mills, T. & DeVries, P. 2006. Mining Cadastre in Africa – Lessons Learnt. *5th FIG Regional Conference: Promoting Land Administration and Good Governance.* Accra, Ghana.

Feeney, M.-E. F., Rajabifard, A. & Williamson, I. P. 2001. Spatial Data Infrastructure Frameworks to Support Decision-Making for Sustainable Development. *Proceedings, Presented at the 5th Global Spatial Data Infrastructure Conference.* Cartagena de Indias, Columbia.

FGDC. 1994. *Coordinating Geographic Data Acquisition and Access: The National Spatial Data Infrastructure* [Online]. Washngton DC: FGDC. Available: https://www.fgdc.gov/policyandplanning/executive_order [Accessed 19-10-2015 2015].

FIG 2002. The Nairobi Statement on Spatial Information for Sustainable Development. *F.I.G. Publication No 30.* Nairobi: FIG.

Folger, P. 2011. Geospatial information and geographic information systems (GIS): An overview for Congress. *Congressional Research Service Report 7-5700.*

Forrester, J. W. 1961. *Industrial Dynamics,* Cambridge, MA, MIT Press.

Forrester, J. W. 1969. *Urban Dynamics,* Cambridge, Massachusetts, MIT Press.

Francis, J. J., Eccles, M. P., Johnston, M., Walker, A., Grimshaw, J. & Foy, R. 2004. Constructing questionnaires based on the theory of planned behavior. *A manual for health services researchers.* Newcastle Upon Tyne: Centre for Health Services Research.

Fudenberg, D. & Tirole, J. 1983. *Game Theory*, MIT Press.

Furuholt, B. & Sæbø, Ø. 2018. The role telecentres play in providing e-government services in rural areas: A longitudinal study of Internet access and e-government services in Tanzania. *Electronic Journal of Information Systems in Developing Countries,* 2018**,** 1-14.

Georgiadou, Y., Verplanke, J., Lungo, J. H. & Mbise, M. 2016. Water point mapping in Tanzania: making the voices of data collectors audible. *7th Rural water supply network (RWSN) forum: water for everyone.* Abidjan.

Gilbert, N. 2008. *Agent-Based Models,* London, SAGE Publications, Inc.
Grus, L., Crompvoets, J. & Bregt, A. K. 2010. Spatial data infrastructures as complex adaptive systems. *International Journal of Geographical Information Science,* 24**,** 439-463.
Hagai, M. 2017. Diffusion of Spatial Data Infrastructure: Private more inspired than the Public Sector - A Case of Tanzania. *Journal of Environmental Science and Engineering,* 6**,** 160-164.
Hall, A. 2009. *A Green Lung for the Stone Town: The challenge of developing a green structure for the users of Zanzibar historical city core.* A Master Thesis in Landscape Architecture, Swedish University of Agricultural Sciences.
Harvey, F. & Tulloch, D. 2006. Local-government data sharing: Evaluating the foundations of spatial data infrastructures. *International Journal of Geographical Information Science,* 20**,** 743–768.
Hernandez, A. 2003. Mining Cadastre in Tanzania. *FIG Working Week 2003.* Paris.
Heywood, D. I., Carver, S. & Cornelius, S. 2011. *An Introduction to Geographical Information Systems*, Prentice Hall.
Hjelmager, J., Delgado, T., Moellering, H., Cooper, A., Danko, D., Huet, M., Aalders, H. & Martynenko, A. 2005. Developing a modelling for the spatial data infrastructure. *22nd International Cartographic Conference* A Coruña: ICA Spatial Data Standards Commission.
Hjelmager, J., Moellering, H., Cooper, A., Delgado, T., Rajabifard, A., Rapant, P., Danko, D., Huet, M., Laurent, D., Aalders, H., Iwaniak, A., Abad, P., Düren, U. & Martynenko, A. 2008. An initial formal model for spatial data infrastructures. *International Journal of Geographical Information Science,* 22**,** 1295-1309.
Huggins, C. 2018. Land-Use Planning, Digital Technologies, and Environmental Conservation in Tanzania. *Journal of Environment & Development,* 27**,** 210-235.
Indrajit, A., Loenen, B. V. & Oosterom, P. V. 2017. Multi-Domain Master Spatial Information Management for Open SDI in Indonesian Smart Cities. *AGILE 2017: Proceedings of the 20th AGILE Conference on Geographic Information Science: Societal Geo-innovation.* Wageningen: Wageningen University.
Ingwe, R. 2017. Crowdsourcing-Based Geoinformation, Disadvantaged Urbanisation Challenges, Sub-saharan Africa: Theoretical Perspectives and Notes. *Quaestiones Geographicae,* 36**,** 5-14.
Johansson, J. 2005. *Improving access to geographic information: Exploring the national spatial data infrastructure initiative in Tanzania.* M.Sc., University of Umeå.
Kalande, W. & Ondulo, J. 2006. Geoinformation policy in East Africa. *Proceedings of XXIII FIG Congress.* Munich, Germany.
Käyhkö, N., William, C., Mayunga, J., Makame, M. O., Mauya, E. & Järvi, A. 2018. Building Geospatial Competences in Tanzanian Universities with Open Source Solutions. *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences,* 42**,** 93-99.
Kelly, P. 2007. Role of Spatial Data Infrastructures in Managing Our Cities. *Spatial Information Management Toward Legalizing Informal Urban Development.* Sounio, Athens, Greece: International Federation of Surveyors.
Kombe, W. & Kreibich, V. 2001. Informal land management in Tanzania and the misconception about its illegality. *The ESF/N-Aerus Annual Workshop 'Coping with Informality and Illegality in Human Settlements in Developing Countries'.* Leuven and Brussels.

Kresken, T. 1996. Technology Briefing Report: System Modelling. *Esprit Project 22010.*
Lance, K. 2001. Spatial Data Infrastructure: Concepts and components. *Kenya Spatial Data Infrastructure Workshop Proceedings.* Nairobi: Kenya Institute of Surveying and Mapping.
Larsen, R. 2014. Environmental data management in Tanzania. *A workshop review.* Dar es Salaam: NEMC-Tanzania & Norgwegian Environmental Agency.
Laseko, B., Apollo, L., Milledrogues, A., Roffer, C. & Burke, C. 2018. Developing an Integrated Land Management Information System (ILMIS) For Tanzania. *2018 World Bank Conference on Land and Poverty.* Washington DC, March 19-23: The World Bank.
Lave, J. & Wenger, E. 1991. *Situated learning: Legitimate peripheral participation,* Cambridge, MA, Cambridge University Press.
Lo, C. P. & Yeung, A. K. W. 2007. *Concepts and techniques of geographic information system,* Upper Saddle River, NJ, Pearson Prentice Hall.
Longhorn, R. A. & Blakemore, M. 2008. *Geographic information - value, pricing, production, and consumption,* Boca Raton, Fla, CRC Press.
Lubida, A., Pilesjö, P., Espling, M. & Runnström, M. 2015. Applying the theory of planned behavior to explain geospatial data sharing for urban planning and management: cases from urban centers in Tanzania. *African Geographical Review,* 34**,** 165-181.
Lubida, A., Veysipanah, M., Pilesjö, P. & Mansourian, A. 2019. Land-Use Planning for Sustainable Urban Development in Africa: A Spatial and Multi-Objective Optimization Approach. *Geodesy and Cartography,* 45**,** 1-15.
Lugoe, F. N. & Yanda, P. 2007. The national spatial data infrastructure policy proposal for Tanzania. 2nd draft. Dar es Salaam.
Makanga, P. & Smit, J. 2008. A review of the status of Spatial Data Infrastructure Implementation in Africa. *South African Computer Journal,* 45**,** 357 - 365.
Malaki, B. 2015. Open-source geospatial solutions in land and forest mapping and management. *Geospatial Workshop.* Dar es Salaam: Embassy of Finland - DSM, Buni Innovation Hub, TANZICT.
Mansourian, A. & Abdolmajidi, E. 2011. Investigating the system dynamics technique for the modeling and simulation of the development of spatial data infrastructures. *International Journal of Geographical Information Science,* 25**,** 2001-2023.
Mansourian, A., Lubida, A., Pilesjö, P., Abdolmajidi, E. & Lassi, M. 2015. SDI planning using the system dynamics technique within a community of practice: lessons learnt from Tanzania. *Geo-spatial Information Science,* 18**,** 97-110.
Matthijs, J. 2005. *Access to spatial geographic information on mountainous areas: Building spatial data infrastructure in Tanzania (Unpublished M.Sc thesis).* M.Sc., Eindhoven University of Technology.
Mayunga, S. D. & Mtamakaya, J. D. 2015. The New Tanzania Geodetic Reference Frame (TAREF 11). Dar es Salaam: Ministry of Lands, Housing and Human Settlements Development, Tanzania.
Mohammadi, H., Rajabifard, A. & Williamson, I. P. Enabling spatial data sharing through multi-source spatial data integration. GSDI 11 Conference, 15–19 June, 2009 2009 Rotterdam.
Msangi, Y. & Liwa, E. J. 2014. A GIS Based Decision Support System for Identification of Suitable Sewerage Pond Sites in Tanzania. *American Journal of Geographical Information System,* 3**,** 10-22.

Mtalo, E. G. 2007. SDI Development Status in Tanzanian: How ready is the country? *Paper presented at the TIC Workshop on National Land Cadastre, 24-26 Jan 2007.* Dar es Salaam: Ardhi University.

Muhando, C., Makota, V., Richmond, M., Holmern, T., Limstrand, I. & Larsen, R. 2015. An Overview of Environmental Data and Data Owners in the Coastal Area of Tanzania - an Emerging Environmental Spatial Data Infrastructure *In:* Keyyu, J. e. a. (ed.) *The 10th TAWIRI Scientific Conference on The future of Wildlife Conservation in the face of Increasing Anthropogenic Demands "at Naura Springs Hotel, Arusha, 2nd- 4th December 2015.* Arusha: Tanzania Wildlife Research Institute.

Mwaikambo, E. & Hagai, M. 2013. Role of Land Information System in Instigating Development of a National Spatial Data Infrastructure in Tanzania. Peer Review Paper. *FIG working week.* FIG.

Mwaikambo, E., Rajabifard, A. & Hagai, M. 2015. Modelling cost estimation for accessing spatial data using fuzzy logic and time-driven activity based costing in the context of an NSDI. *Journal of Spatial Science,* 60**,** 137-151.

Mwange, C., Mulaku, G. C. & Siliba, D. N. 2018. Reviewing the status of National Spatial Data Infrastructure in Africa. *Survey Review,* 50**,** 191-200.

Nedovic-Budic, Z., Pinto, J. K. & Budhathoki, N. R. 2008. SDI effectiveness from the user perspective. *In:* Crompvoets, J., Rajabifard, A., VanLoenen, B. & Fernández, T. D. (eds.) *A multi-view framework to assess spatial data infrastructures.* Melbourne: Melbourne University Press.

Ngereja, Z. R., Liwa, E. J. & Buberwa, F. 2018. Adoption of Geospatial Governance in the Context of E-Goverment in Tanzania: Addressing Bottlenecks in Spatial Data Infrastructure Development. *FOSS4G 2018.* Dar es Salaam: The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences.

Nyitambe, J. E. 2013. Water Point Mapping System (WPMS) Governance and Service Delivery: The Case of Rural Water Supply in Tanzania. *Advancing a Nexus Approach to the Sustainable Management of Water, Soil and Waste.* Dresden: United Nations University.

O'Flaherty, B., Bartlett, D., Lyons, G., Keankeo, W., Endig, M., Schulz, J. & Birnbaum, D. 2005. Towards a stage model for GIS and SDI deployment in local government. *Pacific Area Conference on Information Systems.* Bangkok.

Okuku, J., Bregt, A. & Grus, L. 2014. Assessing the Development of Kenya National Spatial Data Infrastructure (KNSDI). *South African Journal of Geomatics,* 3.

Olofsson, J. & Sandow, E. 2003. Towards a more sustainable city planning – A case study of Dar es Salaam, Tanzania. *MFS-Report.* Umeå: Department of Social and Economic Geography, Umeå University.

Omran, E.-S. E., Crompvoets, J. & Bregt, A. 2006. Benefits and bottlenecks for SDI development in Egypt. *GIS Development.,* 2**,** 32-35.

Paradzayi, C. 2005. Spatial Data Infrastructure as a Vehicle for Sustainable Development in Zimbabwe. *FIG working week and GSDI8.* Cairo, Egypt: FIG.

Railsback, S. F. & Grimm, V. 2012. *Agent-based and Individual-based Modeling. A practical introduction,* Princeton, Princeton University Press.

Rajabifard, A. 2009. Realizing Spatially Enabled Societies – A Global Perspective in Response to Millennium Development Goals. *18th UNRCC-AP Conference.* Bangkok: United Nations - Economic and Social Council

Rajabifard, A., Feeney, M.-E. F. & Williamson, I. P. 2002. Future directions for SDI development. *International Journal of Applied Earth Observation and Geoinformation,* 4**,** 11-22.

Rajabifard, A., Feeney, M.-E. F. & Williamson, I. P. 2003. Spatial Data Infrastructures: concept, nature and SDI hierarchy. *In:* Williamson, I. P., Rajabifard, A. & Feeney, M.-E. F. (eds.) *Developing Spatial Data Infrastructures. From concept to reality.* London / New York: Taylor and Francis.

RCMRD. 2016. *RCMRD Organizes National Spatial Data Infrastructure Stakeholders Workshop in Tanzania* [Online]. Nairobi: RCMRD. Available: https://www.rcmrd.org/archives/295-rcmrd-organizes-national-spatial-data-infrastructure-stakeholders-workshop-in-tanzania [Accessed 15-12-2018 2018].

RGoZ 2007. Zanzibar Strategy for Growth and Reduction of Poverty (ZSGRP). Zanzibar: The Revolutionary Government of Zanzibar.

RGoZ 2018. ZanSDI - Spatial Data Infrastructure for Zanzibar. *In:* Zanzibar, C. o. L. (ed.). Zanzibar: Commission of Land - RGoZ.

Scott, G. & Rajabifard, A. 2017. Sustainable development and geospatial information: a strategic framework for integrating a global policy agenda into national geospatial capabilities. *Geo-spatial Information Science,* 20**,** 59-76.

Sharpley, R. & Ussi, M. 2014. Tourism and Governance in Small Island Developing States (SIDS): The Case of Zanzibar. *International Journal of Tourism Research,* 16**,** 87–96.

Sida 2004. A Future for the Past: Historic Cities in Development. Stockholm: Sida.

Silayo, E. H. 2005. Searching for an affordable and acceptable Cadastral survey method. *FIG Working Week 2005 and GSDI-8: From Pharaohs to GeoInformatics* Cairo.

Sjöstrand, J. 2014. *Cultivating authenticity: Perceptions of Zanzibari culture and history within the heritage management of Stone Town.* Master's Thesis in Urban and Regional Planning, Stockholm University.

Sotaquir´a, R. & Zabala, G. C. A. 2004. Reusability in System Dynamics: Current Approaches and Improvement Opportunities. *The 22th International Conference of the System Dynamics Society.* Oxford: System Dynamics Society.

Srinivas, N. & Deb, K. 1994. Multi-objective Optimization Using Non-dominated Sorting in Genetic Algorithms. *Evolutionary Computation,* 2**,** 221–248.

Sterman, J. D. 2000. *Business Dynamics: Systems Thinking and Modeling for a Complex World,* Boston, Irwin/McGraw-Hill.

Toomanian, A. 2012. *Methods to improve and evaluate spatial data infrastructures.* PhD, Lund University.

Turner, S., Killian, B. & Venäläinen, R. 2016. Evaluation of Finland's Development Cooperation Country Strategies and Country Strategy Modality: Tanzania Country Report. Helsinki: Ministry for Foreign Affairs of Finland.

Ulotu, P. E. 2015. Optimal Vertical Datum for Tanzania. *Journal of Land Administration in Eastern Africa,* 3**,** 381-391.

Ulotu, P. E. 2016. Integration of Tanzania New Gravity Network and Database into Vertical Spatial Reference System. *International Journal of Engineering Science and Computing,* 6**,** 2619-2622.

UN-GGIM. 2012. Monitoring Sustainable Development: Contribution of Geospatial Information to the Rio+20 Processes. Available: http://ggim.un.org/2nd%20Session/GGIM%20paper%20for%20Rio_Background%20paper_18May%202012.pdf [Accessed Feb, 13, 2019].

UN-Habitat 2004. The sustainable cities programme in Tanzania 1992–2003. *The SCP documentation series, Vol. 2.* UN-Habitat.
UNECA 2008. Determination of fundamental datasets for Africa. *Geoinformation and socioeconomic development. Working Paper.* ROME: FAO.
UNESCO. 2000. *Stone Town of Zanzibar* [Online]. Paris: UNESCO World Heritage Centre 1992-2015. [Accessed 18-03-2015 2015].
UNGIWG 2007. Strategy for developing and implementing a United Nations Spatial Data Infrastructure in support of Humanitarian Response, Economic Development, Environmental Protection, Peace and Safety
URT-PM 2011. An Integrated Disaster Management Training Manual (IDMTM) For Tanzania. Disaster Management Department. Prime Minister's Office. United Republic of Tanzania.
URT-PO 2012. The Tanzania Long Term Perspective Plan (LTPP) 2011/12-2025/26: The Roadmap to Middle Income Country. Dar es Salaam: Presidents Office Planning Commission. United Republic of Tanzania.
URT-VPO 2015. National Communication Strategy on Environmental Sustainability, Growth and Poverty Reduction in Tanzania (2015 - 2019). Dar es Salaam: Vice President's Office - Tanzania.
URT 2000. Tanzania Development Vision 2025. Dar es Salaam: Planning Commission.
URT 2010a. Tanzania statistical master plan 2009/10–2013/14. Dar es Salaam, Zanzibar: National Bureau of Statistics, DSM and Chief of Government Statistician Zanzibar.
URT 2010b. National Strategy for Growth and Reduction of Poverty II. Dar es Salaam: Ministry of Finance and Economic Affairs.
URT 2016a. National Information and Communications Technology Policy. *In:* Ministry of Works, T. a. C. (ed.). Dar es Salaam.
URT 2016b. Tanzania Mining Cadastre Portal - Map. Dar es Salaam: Ministry of Energy and Minerals.
URT 2018a. National Population Projection. Dar es Salaam: National Bureau for Statistics, Ministry of Finance and the Office of Chief Government Statistician, Zanzibar.
Vandenbroucke, D., Crompvoets, J., Vancauwenberghe, G., Dessers, E. & Van Orshoven, J. 2009. A network perspective on Spatial Data Infrastructures: Application to the sub-national SDI of Flanders (Belgium). *Transactions in GIS,* 13**,** 105-122.
Ventures, S. nd. Silicon Dar: Unveiling Tanzania's First Technology District. Dar es Salaam: Sahara Ventures.
Verburg, R. M. & Andriessen, J. H. 2006. The assessment of communities of practice. *Knowledge and Process Management,* 13**,** 13-25.
Wehn de Montalvo, U. 2003. In search of rigorous models for policy-oriented research: A behavioural approach to spatial data sharing. *URISA Journal,* 15**,** 19–28.
Wenger, E. 2000. Communities of practice and social learning systems. *Organization,* 7**,** 225-246.
Wenger, E., McDermott, R. A. & Snyder, W. 2002. *Cultivating communities of practice: A guide to managing knowledge,* Harvard, Harvard Business Press.
Wilensky, U. 1999. *NetLogo,* Northwestern University, Evanston, IL, Center for Connected Learning and Computer-Based Modeling.
Williamson, I. P. 2003. SDIs - Setting the scene. *In:* Williamson, I. P., A. Rajabifard, and M. F. Feeney (ed.) *Developing spatial data infrastructures: From concept to reality.* London: Taylor and Francis.

Xhafa, S. & Kosovrasti, A. 2015. Geographic Information Systems (GIS) in Urban Planning. *European Journal of Interdisciplinary Studies,* 1**,** 85-92.
Yilma, A. D. 2013. Spatially Enabled Africa. *Proceedings of Global Geospatial Conference.* Addis Ababa, Ethiopia.

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