and 1-3 dairy cows contributing substantially to family food production (Uddin et al., 2011; Karim et al., 2010; Jahan and Rahman, 2003). Optimal crop-fodder production requires three planting seasons/year and heavy irrigation. But the climate change has a decisive effect on increasing water scarcity which hampers development. This instigates reliance on irrigation from ground water sources which has increased to more than 90% of total water use (Shirazi et al., 2011). Unfortunately, availability of ground water has dropped significantly in recent years. This has led to insufficient water availability for crop and fodder production and for serving animal needs reflected in a reduction in milk yield (Chowdhury, 2010) and competiveness of dairying. Thus, it is important to identify ways to secure dairy production without contributing to water stress at the local level.

Owing to the increasing demand of milk production and increased intensification that might affect water resource and environment, it is important to understand and quantify the water requirement for milk production in different systems of different geographical regions. This would help to gain insight into resource use and environmental impact of water use in order to identify mitigation options in a cost effective way, where it is needed. Therefore, this study envisaged to address the complexity of environmental impacts of water use (i.e. water footprint) in dairy farming systems of production intensities.

1.2. Rationale of the study

Despite the water use (WU) by agriculture including animal production (Liu et al., 2008; Marlow et al., 2009; Nellemann et al., 2009; Steinfeld et al., 2006) there is no consistent method for calculating water use impact assessment (IDF, 2010; 2012). Different methodological approaches to assess water use in existing farming systems confuse stakeholders such as farmers, consumers, industry and governments to address the impacts of water use (Berger and Finkbeiner, 2010; IDF, 2012). Previous work on water volumes (virtual water concept: Allan, 1998) in dairy production (Chapagain and Hoekstra, 2003; Mekonnen and Hoekstra, 2010; Ran, 2010; WFN, 2012) has been based on high-level secondary data (i.e. national average) which are not completely representative of dairy farming systems practices at farm level. The quantification of water volume for a product or service are useful for tallying global virtual water trade but the virtual water concept does not assess the environmental impact that is associated with freshwater use (Ridoutt et al., 2010; Doreau et al., 2012).

Nadira Sultana
Life Cycle Assessment-Based Water Footprint in Dairy Farming Systems of Different Production Intensity
2013 / 180 S. / 27,80 € / ISBN 978-3-89574-838-7
Verlag Dr. Köster, Berlin / www.verlag-koester.de

For the impact assessment of WU, such measurement leads to questionable results and uncertainty towards sustainable production and consumption of good and/or services in local pertinence. For instance, it is widely referenced that approximately 1000 litres of water are required to produce one litre of milk (WFN, 2012). This is attributed to poor understanding of water use without knowledge on the environmental impact of water use types. Milk production with higher water consumption can even have less environmental impacts in one region than production characterised by lower water consumption in another region depending on the regional water scarcity (Ridoutt et al., 2010). Therefore, it is imperative to know the environmental impacts on a given water use in milk, which depends particularly on the type of water being used (i.e. green, blue), assessment of nutrient emissions to water (polluted water), and sources of water. The best way to communicate and promote the competitiveness of dairying is to consider adequately system boundaries as practiced in LCA (Life Cycle Assessment). This calls for characterisation of production systems and identification of the efficiency of production chains. Characterisation would help to provide a clear distinction of water volume and their potential impacts related to water use.

However, variation in methods between studies create difficulties in comparison, on the other hand, there is an increasing interest by international forum for impact assessment based water use calculation on local condition. As such, this study applies a consistent approach to a wide range of milk production systems, with the system parameters based on detailed farm-level data. This consistent approach would make it possible to obtain strategic insights relevant to the global dairy industry and the outcome might be of greatest help to dairy producers to be more water use efficient via better management in order to achieve environmental sustainable milk production system. Nevertheless, the domain research knowledge on water use would be helpful to different stakeholders to design a sustainable water management in dairy farming. Based on the variations in the systems analysed, it should be possible to adapt water use in dairy farming systems and other sectors in agriculture and reduce water stress at the local level.

1.3. Objectives

The application of an LCA-based water footprint calculation method to different geo-graphically defined typical milk production systems was the key research concern of this study. This detailed analysis will compare water use under different case scenarios (i.e. the different farming systems and the production intensity). The study also aims at developing a systematic approach for measuring the water use in dairy farming systems, with a possibility of extending its applicability on a global scale and vice versa. To address the problems of water scarcity and intensification, there is a need in research on how to increase dairy production without off-setting the natural resources, particularly water. Hence, to achieve the target goals, four specific objectives were formulated:

1. Quantify consumptive water use that address underlying drivers, regional variability and their importance in global milk production systems.
2. Evaluation of the differences between virtual water and LCA-based WF calculation method under different cases of international milk production systems.
3. Assessment of Bangladesh milk production systems based on farm economics and LCA-based water footprint at different level of production intensity.
4. Identification of farm-specific socioeconomic factors affecting water use in milk production system in Bangladesh

1.4. Research questions

In order to achieve the objectives mentioned above, this research was targeted at answering the following four *specific questions*:

1. How can we measure consumptive water use in global milk production systems, and what are the underlying drivers and farm characteristics that explain regional variability of water use in milk production systems?
2. Is the LCA-based water footprint suitable compared to virtual water volumes to measure the potential environmental impacts of water use in milk production systems?
3. What is the effective indicator to assess the economy and impacts of water use in the life cycle (cradle to farm gate) of milk production in Bangladesh? How does production intensity influence costs and water use impacts?
4. To what extent do socio-economic factors affect on-farm water use in milk production?

1.5. Outline of the thesis

This thesis is comprised of six chapters. Chapter one is the introductory chapter and it provides the background information on water use in agriculture and milk production globally with some evidence on country specific water situation. The chapter highlights methodological challenges for addressing water use in a agro-ecological system context. The objectives and the research questions are also stated in this chapter. Chapter two addresses the research question 1 as estimates consumptive water use from all types of inputs uses in