

**USING GIS-BASED MULTI CRITERIA DECISION
ANALYSIS FOR PRIORATIZING DRINKING WATER
SUPPLY NEEDS: AN APPLICATION TO SOUTHERN
REGION IN SRI LANKA**

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Degree of Master of Science

Department of Civil Engineering

University of Moratuwa

Sri Lanka

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Thesis submitted in partial fulfillment of the requirements for the Degree
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November 2021

I declare that this is my own work and this thesis does not incorporate without acknowledgement any material previously submitted for a Degree or Diploma in any other University or institute of higher learning and to the best of my knowledge and belief it does not contain any material previously published or written by another person except where the acknowledgement is made in the text. Also, I hereby grant to University of Moratuwa the non-exclusive right to reproduce and distribute my thesis/dissertation, in whole or in part in print, electronic or other medium. I retain the right to use this content in whole or part in future works (such as articles or books).

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Abstract

Using GIS-based Multi-Criteria Decision Analysis for Prioritizing Drinking Water Supply Needs: An Application to Southern Region in Sri Lanka

GIS-based Multi-Criteria Decision Analysis (MCDA) was carried out to prioritize drinking water supply need in the Southern Region, Sri Lanka. The degree of water demand is attributed to population density, water resources availability (Relative Water Balance), water quality (Equivalent Water Quality Index) and new development (Population Pressure) of the region. Spatial distribution of density of Grama Niladhari Division-wise (GND) population was obtained from census data of 2,131 GNDs; assigned to the spatial distribution domestic units available with Survey Department. Water resources availability of each GND was figured out by plotting relative water balance with the aid of average annual rainfall data from the Meteorological Department, Mean evaporation rate and inflow of rivers into the designated research area. Water quality of relevant GNDs was calculated and represented as Water Quality Index (WQI) with the aid of geochemical atlas produced by Dissanayake et al. (1985) and NWSDB treated water quality data. Moreover, the new development of the research area was symbolized with the development corridor stipulated under National Physical Plan for 2050. Four raster files were prepared. To weight criteria, Analytic hierarchy process (AHP) was adopted. To identify the prioritized patches, the weighted linear combination of raster shapefiles was derived as a method of compensatory aggregation. It was understood that a combination of water quality and population density was dominant in the prioritization of water supply needs. The model identified the values as 0.47, 0.39, 0.07 and 0.07 for the main criteria, respectively for relative water balance, equivalent Water Quality Index, population density and population pressure owing to new development. The output of the research was the preparation of an automated GIS tool for prioritization of water supply needs through the GIS model builder facility.

Keywords: Analytic hierarchy process, compensatory aggregation, GIS, MCDA, Spatial distribution, model builder, prioritization, Water Quality Index, weighted linear combination

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List of Abbreviation

AHP	Analytical Hierarchy Process
AWQI	American Water Quality Index
CCME	Canadian Council of Ministers of the Environment
EC	Electrical Conductivity
EWR	Environmental Water Requirement
GIS	Geographic Information System
GND	Grama Niladhari Division
HDI	Human Development Index
JICA	Japan International Corporation Agency
MADM	Multi Attribute Decision Modeling
MAR	Mean Annual Runoff
MCDA	Multi Criteria Decision Analysis
MCM	Million Cubic Meters
MD	Meteorological Department
NASA	National Aeronautics and Space Administration
NSF WQI	National Sanitation Foundation Water Quality Index
NWSDB	National Water Supply and Drainage Board
OWQI	Oregon Water Quality Index
RWB	Relative Water Balance
SD	Survey Department
SEBAL	Surface Energy Balance Algorithm
SLS	Sri Lanka Standards
SMCE	Spatial Multi-Criteria Evaluation
SWSI	Social Water Scarcity Index
TDS	Total Dissolved Solids
UN	United Nations
UNDP	United Nations Development Programme
WLC	Weighted Linear Combination
WQI	Water Quality Index

WSI	Water Stress Indicator
WSS	Water Supply Scheme
WTP	Water Treatment Plant
WWAP	World Water Assessment Programme

CHAPTER 1

INTRODUCTION

1.1. General Description of Water Supply Sector

In the Sri Lankan context, the main drinking water utility provider is the National Water Supply and Drainage Board (NWSDB), which has been established under the regulatory provisions stipulated in the National Water Supply & Drainage Board Law, No. 2 of 1974. Being the sole government entity entitled to the legal monopoly for supplying drinking water in the urban and semi-urban sector, there exists no competitor for the public water supply sector.

The present regulatory framework in Sri Lanka has allotted the responsibility with the NWSDB in supplying drinking water for the entire nation for more than five decades. Presently, the NWSDB covers nearly 35.2% (as of October 2020) of the country's population by utilizing their 324 schemes spread all over the country to produce safe and palatable water to comply with SLS 614:2013: Specification for Potable Water.

Admittedly, rural water supply schemes and other pipe-borne water supply systems operated by local authorities provide a significant contribution towards the water supply sector, serving approximately 10.8% (as of October 2020) of the population of the country.

The un-served remainder of the population within both covered and uncovered areas are the potential areas that need to be expanded by the NWSDB. This is in line with the corporate social responsibility of the NWSDB in providing water to the underserved population of the country.

1.2. General Description of the study area

The study area is the region included within the administrative boundary of the Southern Province and Kataragama Divisional Secretariat (DS). The study area consists of four districts, namely, Galle, Matara, Hambantota and part of Monaragala (Kataragama DSD). There are 2,131 Grama Niladhari Divisions (GNDs) within the study area.

Major water resources in the study area are the five major rivers, namely, Gin Ganga, Nilwala Ganga, Walawe Ganga, Kirindi Oya and Manik Ganga. Apart from these rivers, utilization of groundwater is considerably high in the region. The percentage of dug well and tube well users in the study area are 49.37% and 1.38 %, respectively (Census and Statistics data of 2011).

Mean annual precipitation in the study area varies from 800 to 3,500 mm. Galle and Matara districts are in the wet zone and Hambantota district is in the dry zone of Sri Lanka.

1.3. Requirement for prioritization of water supply need

1.3.1. Donor/Funding Agency's perspective

It is quite evident in Sri Lanka that all ruling entities after post freedom era struggled to uplift the quality of life of citizens. In a bid to secure the high quality of living status in terms of water supply, governments have given priority to supply water based on the population density and priorities decided based on political reasons (Master Plan, 1972). This thesis towards the end will identify that: (i) availability of funding, (ii) financial viability of proposed project, and (iii) ranking order of the demand for water by habitants are the key factors which are attributed to prioritization the water supply needs.

Admittedly, the government of Sri Lanka, during past few decades, has faced an immense pressure in allocating budgetary provisions for infrastructure development projects. As a developing country, Sri Lanka is able to secure funding for infrastructure projects through the National Budget at a rate of 7.8% of national expenditure (The Central Bank of Sri Lanka). However, as per the Western Province Water Supply Master Plan (2013) prepared with JICA funding, the total cost of water infrastructure within the Western Province has been projected to be around 250 billion Rupees during the period from 2015 to 2045 (Main Report, Master Plan update project for Western Province, 2013). The Investment Plan prepared by the World Bank in 2019 suggests that the implementation cost of water supply projects from 2019 to 2030 will be summed up to exceed the budgetary allocations. Hence, it is unarguably understood that there exist a severe gap between funding available and

funding required for water supply sector. Based on above observations related to limited budgetary provision that do not support the infrastructure development needs, prioritization water supply need is inevitable.

1.3.2. Utility Provider (NWSDB)'s perspective

The financial viability of the proposed project is mandatory for a financially independent government entity. As such, the NWSDB has to bear a fraction of the recurrence cost from 15% to 25% (P1 manual of NWSDB, 2019). As a part of the recurrence cost, the premium of the above investment cost is required to be paid annually. This situation has adversely affected the financial stability of the entity, which is liable to allocate other Operational and Maintenance costs. Moreover, the expected tariff increment has not been timely imposed, resulting in the financial viability of upcoming projects being critical.

1.3.3. Public perspective

Access to safe water is indeed a prime right of a person, and it cannot be categorized spatially. However, the prime responsibility of a government is to provide safe water to vulnerable water users with a low level of service (Sustainable Development Goals – United Nations, 2015).

However, each sub-community patch has its own identity in the ranking order of the safe water drinking requirement. Hence, as a community, the demand for safe water may be a dire need than others. If prioritization with a proper scientific basis is not available, the tendency towards discrimination for the needed ones is highly possible. In developing countries context, the order of development projects is not planned and master plan is rarely available. (Sarvajayakesavalu, 2015).

In this research work, the need for water was prioritized to provide a baseline for policymakers to select the most needed water supply project. Since the earlier mentioned two main causes, namely, financial constraints and financial viability of the project are more financially driven factors, this research was intended to view from the public perspective, and the above two criteria will not be taken into consideration for the prioritization of water demand. As an extension of this research

work, it can be proposed that the financial constraints and financial viability of the projects should be evaluated to build up a holistic approach.

Hence, the research need is to identify the impact of selected parameters to build up a prioritization model for water supply need. NWSDB already processes a draft mathematical model to prioritize the water supply projects which is attached as Appendix N (NWSDB, 2012). However, it is stipulated to compare the water supply projects, and less capable in identifying the priority of specific area due to narrowed spatial sensitivity. For instance, the drinking water need of one part may be severe than other parts of the project area. Hence, there is an alarming requirement to provide an identity to each area parcel. Further, the number of parameters specified in the said NWSDB model is high (16 numbers), most of them are not fair to fit with NWSDB uncovered areas (e.g., Age of the Scheme).

Following analysis of the already stipulated parameters by NWSDB prioritization model was carried out to evaluate the applicability of them with respect to the public perspective.

Table1. 1 Fitness of parameters of NWSDB model with respect to the research objectives

Parameter	In line with Public Perspective	Possibility to define spatially	Fairness of applicability within the research area
Population Density	✓	✓	✓
Demand	×	✓	✓
New Development	✓	✓	✓
Age of the Scheme	✓	✓	×
Level of Service	✓	✓	×
Quality of water	✓	✓	✓
Possibility of Integration	✓	✓	×
Water Resource	✓	✓	✓
Service Coverage	✓	✓	×
Potential Increase of Coverage	✓	✓	×
No of breakdowns	✓	✓	×
Social and Environmental Impacts	✓	✓	×
Financial Viability	✓	✓	×
Alternative Water Resources	✓	✓	✓
Financial Affordability	×	✓	✓
Average Annual Rainfall	✓	✓	✓

By identifying the major drawbacks of prevailing prioritization criteria, research need was aroused to identify the fair parameters and their impact on the Prioritization model. Further, the need to build up spatial models for the above parameters was the secondary requirement to identify the impact of selected parameters.

To satisfy the above two research needs, the research question raised was what the main parameters are, which can be spatially defined and attributed to the

prioritization of water supply need and what is the degree of impact towards prioritization?

In a bid of answering these questions, the identification of parameters was conducted with the aid of the draft prioritization model prepared earlier. By examining the list of parameters mentioned there, the globally applicable criteria were identified with the consultation of experts which is elaborated in chapter 3.

To relate spatially and prepare the spatial model for the parameters, the application of GIS was identified as a handy tool. GIS is capable of providing a platform for raster or/and vector calculation with much ease. Further, Multicriteria Decision Analysis (MCDA) was applied to lever the criteria and obtain the correct weights.

Accordingly, this research presents a GIS-based prioritization model to rank the water supply need of a selected number of communities. This approach is effective for decision making on prioritization order for proposed water supply projects, facilitating the application of water quality index methods and water stress indicator, and helping to communicate complex information, including indices of examined results and optimization output, to a wide range of groups through map-oriented visualizations. In this effort, four criteria namely:

1. Population density
2. Water Quality Index
3. Water Stress Indicator and,
4. New developments

were aggregated to derive the prioritizing GIS model. With powerful functions for visualizing data and analyzing results, GIS can help decision-makers achieve to better ranking order. The integration of GIS, water quality and quantity assessment and population density/population pressure owing to new development synthesizes their functions makes conclusions more acceptable to a variety of stakeholders such as engineers, administrators and the general public. The southern region of Sri Lanka was selected for the validation of the prioritization model.

1.4. Research objectives

This thesis aims to develop a GIS-based prioritization model to rank the need for water supply by a number of communities of a particular region and the model includes water quality and quantity assessment methods, demographic analysis, and GIS technology. Multi-Criteria Decision Analysis (MCDA) was carried out with the aid of GIS technology to build up the model and the results for prioritized areas are presented in maps show the degree of the demand of drinking water. Moreover, MCDA is performed in detail according to the following steps:

1. To evaluate and model the spatial distribution of existing demography, water quality, Water resources availability and population pressure due to upcoming development as a raster shape file.
2. To project water quality of a respective region with Equivalent Water Quality Index and water resource availability as Relative Water balance
3. To identify the prioritized patches, weighted linear combination of raster shapefiles was derived as a method of compensatory aggregation.
4. To propose a GIS framework to prioritize water supply need.

1.5. Justification of parameters

At the beginning of the research, four parameters were selected among the already listed parameters of the draft mathematical model prepared by NWSDB. The selections of parameters were conducted with the aid of expert view as described in Chapter 3.

The main basis of the selection was applicability at the global level and impact towards the existing level of service of the general public.

To cope with public perspective, in other words, without considering financial and economic aspects, prioritization of water supply need was carried out by considering the following criteria:

1. Population density
2. Equivalent Water Quality Index
3. Relative Water Balance
4. New Development Index

1.5.1. Population density

Noticeably, the living status of the urban population, where population density is high, is significantly better than the rural population. The quality of life entertained by the urban and semi-urban population is far advancing than the rural population. Hence, the inhabitants of a city tend to consume more, resulting in higher per capita consumption. This social phenomenon is applicable for water consumption patterns, too. People from highly dense areas consume more water per head than people from rural areas. By Studying NWSDB commercial data, the per capita consumption of urban schemes (lpcd value) is much higher than rural schemes.

The ability to pay for more water is viable for most of the people who live in urban areas. As per the Central Bank report 2019, the per capita income of the rural sector is significantly less than the urban habitants. As per the Household Income and Expenditure Survey of 2016 conducted by the Department of Census and Statistic, the mean household income per month for the urban sector is Rs.88,692.00 while the same for the rural sector is Rs.58,137.00. Further, the urban areas are keen enough to make expenditure on food and beverages (non-alcoholic) around Rs.24,108.00 while people in rural areas are willing to pay only Rs.18,183.00 for their food.

Admittedly, it is not necessarily all highly populated areas require higher per capita demands. For instance, low-income households located within urban areas do not record high per capita consumptions. However, the non-revenue water incurred due to the installation of public water posts within such low-income premises equalizes the demand matched with the average of urban areas (Robert, 2004).

Further, higher population density can lead to higher anthropogenic pollution of available water resources of urban territory. Owing to the lessen palatable water resources, organized water supply with continuously monitored water quality is a must for a highly dense population set (Schiller, 1987).

Allied to the above, spatial distribution of protected point sources is a significant indicator of lack of redundancy drinking water sources within urban territories. As per the Census and Statistics, in Sri Lanka, the protected dug wells are lesser in highly populated areas. Moreover, the spatial distribution of tube wells produced by the Water Resource Board indicates that the distribution of tube wells is minimal in urban areas. Hence, zones with higher populations are lack redundant supply.

1.5.2. Equivalent Water quality index

Drinking water quality is the main driving force behind the level of service of individual water use practice. It can be referred to as the main representative parameter of the quality of the drinking water supply for each individual.

Drinking water quality is attributed to the degree of health status, resulting in a severe effect on the country's economy. Finally, it is one of the best indicators of quality of life. As per the Sustainable Development Goals stipulated by the UN, it is expected to achieve universal and equitable access to safe and affordable drinking water for all by 2030. To achieve this target, it is an urgent requirement to identify vulnerable water users towards waterborne diseases stemming from deteriorated water quality.

Most chronic and acute waterborne diseases are attributed to drinking water quality. Hence, Government has to bear massive expenditures to treat patients with waterborne diseases while compensating other budgetary allocations. This can be prevented by providing remedial measures to provide palatable drinking water to vulnerable communities.

It is observed that the area selected for this study is enriched with numerous water supply sources which detail the water-use practice of the southern region. Hence, the representative figure of a given community depends on the type of water supply.

To build up the macroscopic view of the water quality of the region, it is essential to derive a representative figure for each area unit: Grama Niladhari Division. To come up with an ideal value, it is required to consider all water supply sources and their periodical water quality.

To assess the suitability for water to be used for potable purposes, there are 32 chemical parameters and two bacteriological parameters to comply with SLS

614:2013. Even though considering a large number of water quality parameters at the same time is difficult to conclude, Water Quality Index (WQI) gives an easier way to compare several water quality parameters at the same time with interpreting a summary of the data set (Mahagamage and Manage, 2014). To obtain a fair and reasonable representative composite parameter, the eight most important parameters are taken into account to build a Water quality Index for each water supply source such as the NWSDB supply, dug wells and tube wells. A weighted average of such Water quality Indices is capable of fairly representing the overall water quality of the respective GND.

1.5.3. Relative water Balance

Being an essential biological requirement, drinking water is the most important usage of water. It is immaterial whether water is palatable or not, it is required 2.5 litres to 3 litres per day to maintain the human body functions (De Buck et al., 2015). Besides, the water resource availability for the sake of domestic purposes is affected by vivid array of external influences such as different uses of water, including agricultural and industrial purposes as well as access to safe water and the physical availability of reliable water resources.

In the Sri Lankan context, the drinking water share is compensated by above stakeholders such as industrial users and farmers. However, the priority for drinking water requirement cannot be ignored in water sharing rights. Due to limited water resources and unplanned agricultural and industrial development, there exists a severe deficit between water supply and demand (Bastianssen, 2003). This situation has led to a water stressed situation, especially in irrigable areas.

In a bid of supplying drinking water, it is essential to identify the degree of relative water stress of a given region. This can be achieved through modelling the spatial distribution of degree of water stress within the research area. The degree of water stress is represented by the water stress indicator ($\text{m}^3/\text{capita}/\text{year}$) for each GND. It was computed with the aid of precipitation, evaporation data and river inflow into project area.

Unarguably, the water availability within the selected area is a prominent attribute in prioritizing the requirement of organized water supply.

1.5.4. New Development

In the Sri Lankan context, the population thrust/pressure can be attributed to the possible and ongoing development of the given area. The migratory pattern of the population during the last century shows that the changes of demography have been significantly increased towards urban areas (Sunethra et al., 2001). Apart from the water demand owing to new development; population pressure that is a direct result of higher population density should be weighted in terms of significance in prioritization.

The natural tendency of mankind is to follow the requirement of the basic needs such as food, clothes, shelter etc. In the past millennial era, these requirements have become more complex and undoubtedly the race towards achieving such primary and secondary requirements has been aggravated. Hence, the journey towards finding a better living status was continued. This migratory pattern has been led to the accumulation of people where better opportunities were available. Hence, the new development is one of the main influence factors behind the increasing population density.

It is quite evident to observe that the population density of such economic hubs is subjected to grow exponentially. Hence, the prioritization of water demand for such highly populated patches is an essential requirement to meet the future water requirement.

1.6. Thesis Organization

There are five chapters included in this thesis:

Chapter 1 includes the research background, clarification of the research need, the research objectives and briefly indicates the research methodologies.

Chapter 2 provides an extensive literature review related to Multi-Criteria Decision Analysis, Integration of GIS, Demographic Analysis, Preparation of Water Quality Index and Water Stress Indicator

Chapter 3 describes the theories and methodologies pertaining to preparation of data set for each criterion, weighting and integration of criteria and synthesis of

prioritization model. The evaluation and planning models are integrated with the ArcGIS.

Chapter 4 provides a case study wherein Multi-Criteria Decision Analysis is applied to Southern region of Sri Lanka

Chapter 5 includes the conclusions and the significance of the research study as well as recommendations for future work.

CHAPTER 2

LITERATURE REVIEW

This chapter provides an overview of the Multi Criteria Decision Analysis (MCDA), integration of GIS, demographic analysis, preparation of Water Quality Index (WQI) and Water Stress Indicator (WSI). These evaluation measures and spatial data techniques are occasionally used in this thesis to validate their feasibility and to put forward thoughtful options regarding the order of ranking of the need for water supply to decision-makers.

2.1 Multi Criteria Decision Analysis (MCDA)

2.1.1. Historical background of the use of GIS-MCDA

The pioneers of MCDA were J.C. Borda and N. Condorcet who engaged on ranked preferential voting systems in the 18th century .However, the fundamentals dictating MCDA were originated by F.Y. Edgeworth and V.Pareto, and the latter was the pioneer in the building up the concept of efficiency Later, the forerunner of modern GIS-MCDA system analysis was introduced in urban and regional planning by Chadwick in 1973 (Malczewski, 2015).

In the spatial planning sub-domain, hand-drawn map overlay techniques used by American Landscape Architects was the initial step of GIS driven MCDA (Collins et al., 2001). McHarg (1969) modified the overlay techniques by formulating a procedure that combine mapping data on the anthropogenic and lithogenic attributes of the environment within a research area, and then this information tendering on individual, transparent maps using light to dark graduated color palatte (high suitability to low suitability) and superimposing the individual transparent maps to construct the overall suitability maps for each land use. However, most of the scholars still believe that the forerunner of modern GIS based MCDA technique is C. Eliot (Miller, 1993).

The modern GIS evolution can be separated into three time segments:

1. The GIS research frontier period in the 1950s–1970s: innovation stage
2. The development of general-purpose GIS in the 1980s: integration stage
3. The development of the user-oriented GIS technology in the 1990s to up to date: proliferation stage (Malczewski, 2015).

2.1.2. GIS components of GIS-MCDA

Figure 2.1 implies a basic classification of the GIS-MCDA approaches based on the nature of GIS segment. There are two slabs of the classification. First, the GIS-MCDA approaches can be subdivided into two groups: (i) the raster-data-based, and (ii) the vector data-based methods.

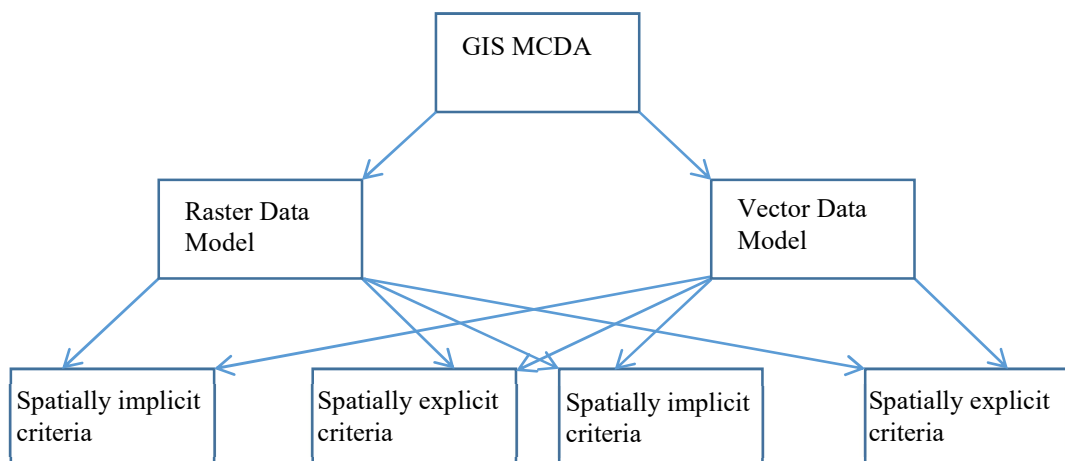


Figure 2.1 GIS MCDA classification based on GIS component.

The use of Raster data models can be observed in the last two decades. Specifically, the applications used for solving land-use problems (Aerts et al., 2005) are one of the examples of the raster-based GIS MCDA approach. Here, the authors were keen enough to build up a raster output by a spatial optimization method. Another interesting research was done by Church et al. (2003) to construct agglomerations of contiguous cells that constitute habitat “patches” for foxes. They built up suitability maps to identify the best places. There are numerous researchers who carried out studies adopting the basis of vector data-based methods (e.g., Jankowski, 1995;

Laaribi et al. 1996; and Feick and Hall, 2004). As the second slab is shown in Figure 2.1, the raster- and vector-based GIS-MCDA approaches can further be divided as per the nature of decision alternatives and evaluation criteria. The nature of both alternatives and criteria can be divided into, spatially explicit and spatially implicitly categories (Malczewski, 2006).

2.1.3. MCDA components of GIS-MCDA

Criterion is a basic term inclusively both the concept of attribute and objective. Accordingly, GIS-MCDA can be divided into two categories: multi-attribute decision analysis (GIS-MADA) and multi-objective decision analysis (GIS-MODA) (see Figure 2.2). As per the past research, a majority of the GIS-MCDA approaches falls into the GIS-MADA category (Malczewski, 2006). Jun (2000) provides an example for GIS-MADA. In this study, he discussed the applicability of several attributes per each main criterion to evaluate the suitability of land use patches for Industrial site selection. The GIS-MODA approach is presented in Malczewski et al. (2012) which he was able to conduct a comparison between multi-objective spatial dispersion models for managing critical assets in urban areas.

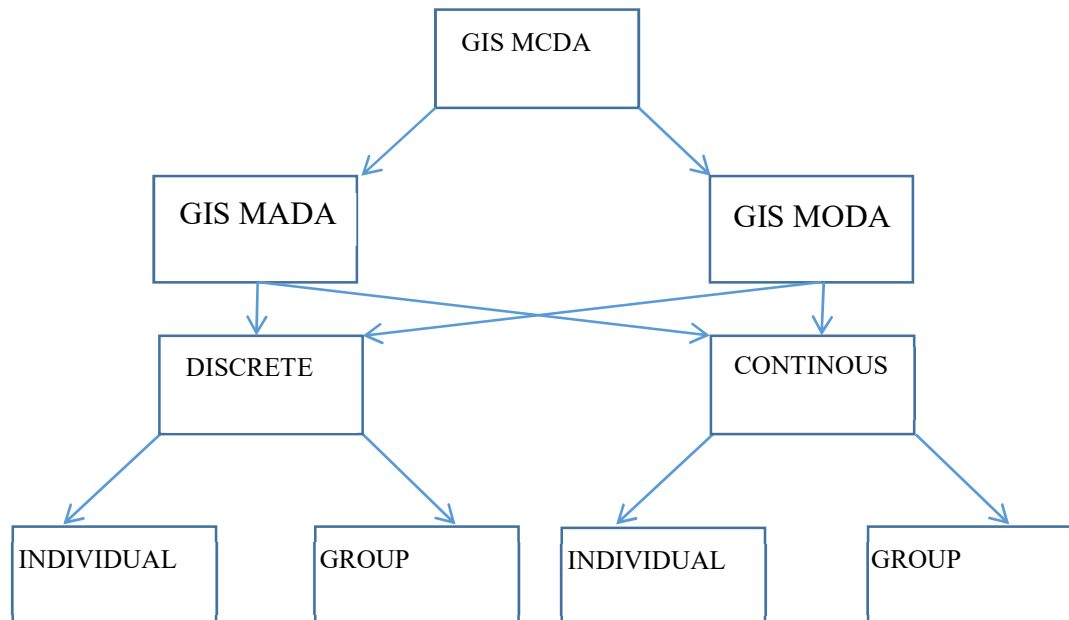


Figure 2.2 GIS MCDA classification based on MCDA component

Several definitions can be referred to and highlighted as per the literature survey conducted, as below:

1. Decision-makers

The decision maker is an entity with the responsibility to make decisions. Most of the time, it can be a group of individuals rather than an individual decision-maker.

At certain times, the decision-making process involves many interest groups. An interest group is an entity with an interest or stake in a decision concern, Interest groups can be different in form, size, and capacity.

Amid the traditional decision analysis concentrates on the human decision-maker, novel approaches computer-based modelling to provide a wide description of the decision-maker to include the concept of decision-making agent which is a computer program characterized by such properties as autonomy, reactivity, and rationality.

2. Criteria

Decision alternatives are evaluated based on a set of criteria which includes attributes and objectives. Characteristics of a good set of criteria are as below:

- i) Completeness (Coverall aspect of a decision problem)
- ii) Operational (The criteria can be meaningfully used in the analysis)
- iii) Decomposable (The set of criteria can be broken into parts)
- iv) Non-redundant (To avoid duplication)

Decision problems depend on a set of criteria that include attributes and objectives and should possess some properties to adequately represent multi-criteria. The set of evaluation criteria can be defined by the relevant literature, analytical study, and expert opinions. Each criterion must be comprehensive and measurable.

An objective is a statement about the desired state of a system under consideration (e.g., a spatial pattern of accessibility to primary schools) (Malczewski, 2012). An attribute can be described as a property of an element of a real-world geographic system (e.g., transportation system, location-allocation system, or land use pattern).

The methods for defining spatial alternatives depend on the GIS data models (Malczewski, 1999). In the case of raster data models, a decision alternative is often

defined as a single raster of a specified size or a combination of rasters. For vector data analysis, a decision alternative can be defined by a single object (point, line, or polygon) representing a geographic entity.

2.1.4. Standardization

The derived criteria are measured in different scales and must be standardized before proceeding with weighting and combination (Eastman et al., 1995). Standardization, in other words, value scaling is used to bring the raw criterion values into a standardized score (Malczewski, 2015). In order to standardize the raw criterion values, it is required to build up a function for standardized score as a function of raw criterion value. The value function is a mathematical representation of human judgment (Malczewski, 2015). It relates possible decision outcomes (criterion or attribute values) to a scale which reflects the decision maker's preferences.

If a_{ik} is the level of the k -th criterion ($k = 1, 2, \dots, n$) for the i -th alternative ($i = 1, 2, \dots, m$), then the value function,

$v(a_{ik})$, is the worth or desirability of that alternative with respect to that criterion.

Formally, for the k -th criterion (attribute) map, the value function

approach transforms the raw criterion values, $a_{1k}, a_{2k}, \dots, a_{mk}$, into standardized scores (values), $v(a_{ik})$, as follows:

$$V(a_{1k}) = \left\{ \frac{(\max(a_{ik}) - a_{ik})}{r_k} \right\}^\mu \quad (1)$$

where, $r_k = \max a_{ik} - \min a_{ik}$

For $0 < \mu < 1$, a concave value function is generated. If $\mu > 1$, then a convex value function is obtained. However, in most GIS MCDA researches, $\mu = 1$ was taken (Malczewski, 2006).

2.1.5. Weighting criteria

Weight is a value assigned to an evaluation criterion that indicates its importance relative to the other criteria under consideration (Malczewski, 2015). There have been several methods suggested for assessing criterion weights (Hwang and Yoon,

1981). From the perspective of GIS-MCDA, the methods can be classified into two groups: global and local methods.

Global methods are based on the spatial homogeneity of the preference. As a result, it assigns a single value for each criterion. Mostly three global weighting methods are available and applied in GIS-MCDA, namely, ranking, rating and pairwise comparison (Malczewski, 2006). All of these methods require an evaluation of each criterion by decision making agents.

Following methodologies are often applied in GIS-based MCDA to derive relative criteria weights before applying a compensatory aggregation method (Greene, 2011).

1. Ranking: Ranks/orders the criteria, then converts the ranks to weights using:
 - i) Rank sum: each rank value divided by the sum of all rank values
 - ii) Rank reciprocal: 1 divided by each rank value
 - iii) Rank exponent: a rank sum with numerator and denominator raised to a power between 0 to 1, thereby reducing the resulting weight differences
2. Rating : Rates the criteria using a common scale (such as any value between 0 to 1) or point allocation (for instance allocating 100 points among all criteria)
3. Trade off analysis: Direct evaluation of trade-offs between pairs of criteria to determine the cut off values at which they are considered equally important
4. Analytic hierarchy process: Compares criteria pairwise on a fuzzy linguistic ratio scale and subsequently computes overall relative weights based on aggregate calculations of all pair-wise ratios (Saaty, 2005). AHP is more than a criterion weighting method, as it also provides an additive, hierarchical aggregation of criteria.

The pairwise comparison method was developed by Saaty (1980) in the context of the analytic hierarchy process (AHP). It employs an underlying scale with values from 1 to 9 to rate the preferences with respect to a pair of criteria.

The pairwise comparisons are organized into a matrix:

$$C = (c_{kp})_{n \times n} \quad (2)$$

c_{kp} is the pairwise comparison rating for the k^{th} and p^{th} criteria.

The matrix C is the reciprocal:

i.e.,

$$c_{pk} = c_{kp}^{-1},$$

and all its diagonal elements are unity, i.e., $c_{kp} = 1$, for $k = p$.

Given this reciprocal property, only $n(n-1)/2$ actual pairwise comparisons are needed for an $n \times n$ matrix.

Once the pairwise comparison matrix is obtained, a vector of criterion weights, $w = [w_1, w_2, \dots, w_n]$ can be computed.

As per the study carried out by Malczewski (2006), the pairwise comparison method is the most often used procedure for estimating criterion weights in GIS-MCDA applications. The method has been effectively applied in many fields such as site selection problems, land suitability analysis and environmental impact assessment. It has been used in a vivid array of application domains including agriculture, manufacturing, transportation, tourism, health care and waste management.

The pairwise comparison method was instrumental in many multicriteria decision support tools built up by researches such as IDRISI (Eastman et al., 1993), ILWIS-SMCE (Sharifi et al., 2004), and Common GIS (Rinner and Taranu 2006). Further, the same method has been implemented in the ArcGIS/ArcView environment in several GIS-MCDA applications (Zhu and Dale, 2001; Banai, 2005; Boroushaki and Malczewski, 2008; Chen et al., 2010; Ozturk and Batuk, 2011). The pairwise comparison method can be criticized for the ambiguity of the underlining questions (Goodwin and Wright, 1998). The questions simply ask for the relative importance of evaluation criteria without reference to the scales on which the criteria are

measured. This fuzziness may mean that the questions are interpreted in different, and possibly erroneous, ways by decision makers.

2.1.6. Aggregation methods

Compensatory decision rules which do not require pairwise comparison of alternatives are of two types:

1. Additive methods that normalize criterion scores to enable comparison of performance on a common scale:
 - i) Weighted linear combination (WLC): Also known as simple additive weighting, this approach multiplies normalized criteria scores by relative criteria weights for each alternative (Greene, 2011)
 - ii) Fuzzy additive weighting
 - iii) Ordered weighting averaging

2. Non-additive methods that use the original criteria scores:
 - i) Ideal point: Identifies a point in criteria outcome space by specifying the preferred value of each criterion
 - ii) Non dominated set: This identifies the set of alternatives that score at least as high as every other alternative on at least one criterion
 - iii) Reasonable goals method: Extends the non-dominated set to help visually select from the alternatives using a series of two-dimensional graphs of criteria outcome space (Jankowski et al.,1999)

2.1.7. Examples for previously conducted research using GIS-MCDA in the water supply sector

There are ample GIS-MCDA approaches used in the water sector in the past widely. One such example is the suitability map prepared through the spatial distribution of water quality indexing in Aksaray, Turkey (Kavurmaci, 2016). The objective of the study was to come up with a suitable methodology to evaluate the groundwater

quality for Aksaray City in Turkey using the MCDA techniques. As previously highlighted in Section 2.1.5, Analytical Hierarchy Process (AHP) is used as the MCDA technique that was first developed by Saaty (2005) to determine the priority order of alternative decisions and to find the best decision based on certain criteria. As stated in Section 2.4, the AWQI is calculated to reduce a large number of data, so a numerical value obtained from the AWQI expresses the complete water quality at a specific location. In other words, a vivid array of evaluation criteria can be viewed as a single value with this index. This index creates a value related to the quality conditions of the water. This created value is the key value for experts who are the decision-makers in weighing the significance of water quality parameters to determine the usage of water bodies to quality and identification. He proposed to construct a pairwise comparison matrix for each criterion. The experts can choose to weigh each criterion against each other at each level, which refers to the levels above and below it, and mathematically combine the entire scheme. In this study, a pairwise comparison was performed on all related attributes to establish the relative importance of the hierarchy criteria. Criteria weight (WI) was calculated by normalizing the criteria weight (W_i) of each factor.

Experts have evaluated the importance of pairs of grouped elements in terms of their contribution to the higher hierarchy (Eastman, 2003; Wang et al., 2009). Finally, all the values for a given attribute were pairwise compared. The main criteria were compared with each other, and then sub-criteria were evaluated against each other criteria. As the final step of the research conducted by Kavurmaci (2016), 40 wells were compared by these sub-criteria. Decision-makers who are the experts determined the order of importance of the criteria with the aid of 9 points system from 1 to 9. A score of 1 demonstrated equally importance a score of 9 refers to strong importance. In this study, the AHP system was formed from 40 alternatives (wells) to prepare the suitability map for Water quality in Aksaray, Turkey.

Another example for Integrated Water Resource Planning driven by the application of GIS-MCDA was conducted by Joubart (2003). Amid the severe shortage of water availability and limited availability of resources and ever-rising demand for water in Cape Town, South Africa, they considered two objectives, namely, evaluate

alternatives of water resources and water demand management, and weighted the alternatives with the aid of participation of Interest groups consisting of experts in the water industry. Finally, He was able to derive the prioritization order for interventions required to achieve the objectives.

Further, an assessment of the Groundwater Quality Index for drinking Purpose in the Durg District, Chattisgarh was conducted by Jhariya et al. (2017). The intention behind the research work was to classify and characterize the groundwater quality of the region, and they expected to build up a tool for long term planning of groundwater resources. Here, they measured six water quality parameters of 88 samples in the research area. To assign a weight and classify the parameters into a water quality index, they used the Analytical Hierarchy Process (AHP). First, they prepared a set of raster files for each water quality parameter. With the aid of water quality parameters, Jhariya et al. (2017) carried out a pairwise comparison of each criterion to prepare weightage. After assigning weights for the maps prepared, they finalized the work by integrating thematic layers to build up the Ground WQI map.

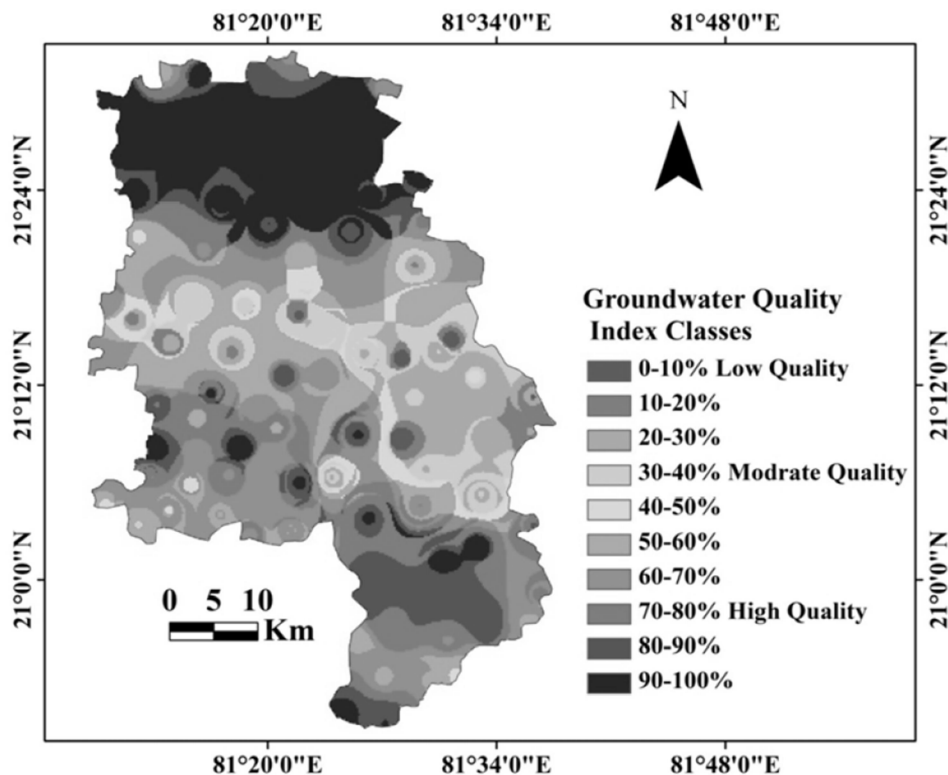


Figure 2.3 Ground Water Quality Index map prepared by Jhariya et al. (2017)

Multi-criteria analysis and GIS modelling for identifying prospective water harvesting and artificial recharge sites for sustainable water supply was carried out by Singh et al. (2016). They used GIS-MCDA to build up site suitability maps for rainwater harvesting and artificial recharge sites. They used three criteria for mapping rainwater harvesting potential, namely: i) surface runoff coefficient, ii) drainage density and iii) Slope. With the aid of the above-mentioned suitability criteria and GIS-based Boolean logic, the potential sites for rainwater harvesting, and recharging was found out. Further, they prioritized those potential sites based on criteria: post-monsoon groundwater level, groundwater fluctuation and water demand. Then, the development of a pairwise comparison matrix and normalization of weights using the AHP technique was carried out. Identification of rainwater harvesting map was prepared after integration of GIS as following figure 2.4.

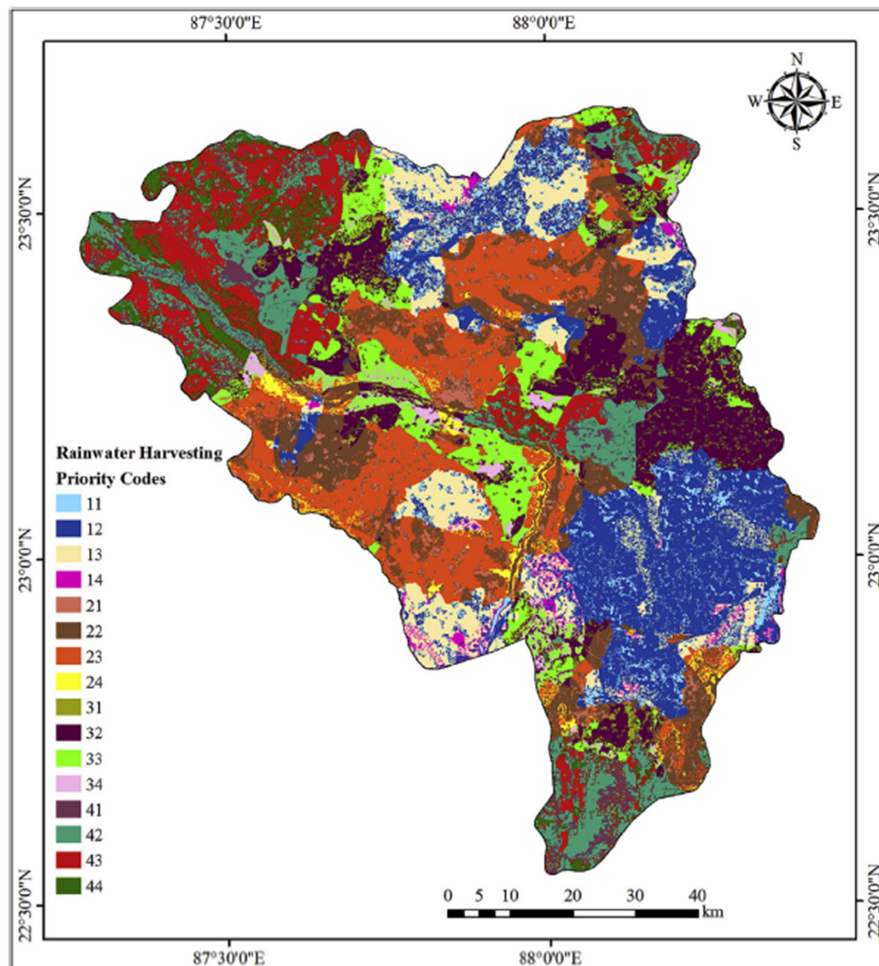


Figure 2.4 Rainwater harvesting map prepared by Singh et al. (2016)

Interesting research pertaining to the use of multi-criteria decision analysis (MCDA) as a decision tool was carried out by Alvarado et al. (2016) to formulate the procedure for ranking the drinking wells according to the vulnerability to contamination. In this research work, three criteria of safeguarding groundwater quality, i.e., natural, anthropic, and technical, were taken into account. It was required to figure out easily accessible representative parameters for the above criteria. Considering those elements, selection criteria were defined which have been represented by population distribution indicator, human development index, land use, the index for aquifer vulnerability to contamination, well age and well yearly pumping rate. The built-up methodology was implemented in the Toluca Valley aquifer in Mexico and implied the generation of the thematic maps of the defined selection criteria. The same scale was developed for each criterion in the MCDA platform, each criterion was weighted according to its significance according to the objective and then, it was integrated with the aid of linear combination. The output is a map that indicates the level of protection priority of the supply wells. This map can provide information to the user quickly and identify the factors that contribute to protecting and/or aggravating the actions aimed to protect the quality of the vital underground resources.

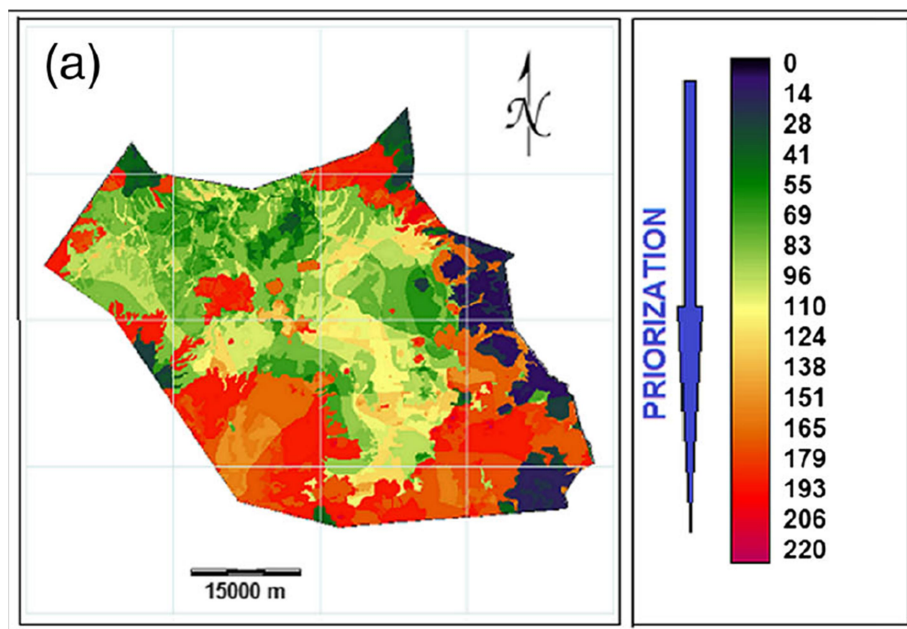


Figure 2.5 protection priority map of the supply wells prepared by Alvarado et al. (2016)

Another study of identifying the best alternative to supply water to Santa Marta city, Colombia was carried out by Henry Amorocho-Daza et al. (2019) using MCDA techniques. They revealed that this decision-making methodology enables stakeholders to evaluate the alternatives of the complex water supply problem in a systemic manner. They considered non-economic criteria and economic criteria to weigh the economic performance against the benefit. The results of this study support the implementation of the best alternative for addressing the water supply problem in Santa Marta by considering the preferences of stakeholders. The author's used the pairwise comparison method (AHP) to weight the criteria since it ensures the accuracy during the relative judgement of elements and enables the stakeholders to develop a structured perspective of the problem throughout all decision processes. GIS-based Multi-Criteria Decision Analysis for identifying water distribution points was conducted by Bassam Qashqo (2018) to analyse the neediness of water in Lapilang and Suspa regions in Nepal. In this case study, two objectives were highlighted: 1) ensure water accessibility according to standards 2) minimize the cost was needed to be satiated. The operationalization of the above objectives was done by assigning three criteria/attributes. The author stressed that these criteria were perceived as factors that increase or decrease the suitability of alternatives. The alternatives were represented by raster cells. In this case study, the numbers of alternatives are significantly high (nearly 1 million cells). After the preparation of the criteria, the following steps were followed;

1. Deriving suitability maps for each criteria by standardization process (the alternatives are reclassified/ranked order on one common interval scale)
2. Assigning weights to the suitability maps. Further, he performed the weightage analysis work by Analytical Hierarchy Process (AHP) which is based on pairwise comparison method.
3. As the third step, applying compensatory decision rule to combine all maps in to one single map. In this case study, weighted linear combination (WLC) was used as the additive method.

He implemented the MADA based on $10\text{ m} \times 10\text{ m}$ cell size advanced raster analysis in ArcGIS software. The final outcome of the research was to plot the priority map for drinking water neediness in the research area.

2.1.7 Examples of previous research of the use of GIS-MCDA in sectors other than water supply

Being a sophisticated tool in decision making, it is quite evident that the GIS-MCDA approach has been applied throughout the different sub-sectors such as social, technology, finance, entertainment etc. It is vital to observe the standardization and method of assigning weights for the criteria. Further, the assessment of multisectoral criteria against each other can be done by reviewing previously conducted research studies.

Methods involving GIS-MCDA have been used in sociology, as noted by the research carried out by Harper et al. (2016), which is interesting research pertaining to the social viability of the wind farm industry in the United Kingdom. Previously, it was learnt that wind energy is the most suitable mode of renewable energy with respect to British conditions. However, such a decision was totally motivated with respect to the technical viability. In this research, Michael et al. (2016) formulated the multi-criteria decision analysis including social responsibility as a criterion. They formulated the research work to conduct the suitability analysis of locating wind farms strategically within the onshore locations. Later, they found that the actual viability of the onshore wind farm is lesser than 5 % of original estimates. All related parameters were aggregated into three layers (criteria), namely, 1. economic viability 2. social acceptability and 3. exclusions (legislative restrictions). Since exclusion provides the allowable area for the development, the other two parameters were evaluated against each other by preparing a two-dimensional model where three zones were demarcated as low/potential/good/excellent. Hence, the weighting of the two parameters is 0.5 each.

The planning of habitats is another major area that has applications of the GIS-MCDA approach. Specific research work has been done by demographers in Spain to evaluate the suitability of dam sites in Spain for building up habitats under mass

tourism proposals (Jeong et al., 2016). In this research, locations of housing were identified using four base criteria: 1. socio-economic parameters, 2. physical parameters, 3. nature-related parameters, and 4. environmental parameters. It was needed that numerous criteria (16) were aggregated under the above four sub-groups. The categorization under the above four groups was carried out with the aid of decision-makers and the directives provided by different legislations such as European Directives. All 16 types of data were prepared as GIS layers as raster datasets which had a cell size of 10 m × 10 m. Standardization of the above datasets was done on a common scale of 0–1 by using a fuzzy set. In order to aggregate the criteria, they used a sensitivity analysis using five different scenarios. The weights of the final fitted model to the above groups were 0.23, 0.27, 0.17 and 0.33, respectively.

Another land suitability analysis done related to human settlements has been carried out by Piyathamrongchai (2019). It was unarguably agreed that systematic and effective land suitability evaluation is an indispensable prerequisite to achieving sustainable and optimum utilization of land resources. However, it is essential to identify the complex multi-criteria and objective decision-making process. In the study conducted by Piyathamrongchai (2019), he was able to produce a model framework for multi-criteria land evaluation using an integrated Geographic Information System and Multi-Criteria Decision Analysis (GIS-MCDA) technique based on fuzzy logic. This land evaluation model was calibrated for identifying suitable land for human rehabilitation in two Districts of Southern Bhutan that covered an area of 2,294 km². The human rehabilitation program is intended to evaluate land for residential and agricultural purposes. Based on government legislation, a total of seven main criteria and 20 sub-criteria considering social, economic, climate, environments and topography were taken into account, and weighting was done by evaluating relative importance by the field experts. Then, the suitability maps were generated by the GIS-MCDA model. The model inherited sensitivity analysis to validate the robustness of the land evaluation model and the stability of criteria against the subjectivity of the expert's judgements. The suitability class had a span of areal values ranging from 0.2% to 36.0%. This study

revealed that over 50% and 47% of the study cannot be considered for residential and agricultural land use, respectively. The highly viable area for future residential and agriculture is only 5.01 km² (0.2%) and 18 km² (0.8%), respectively. Since the objectives were contradictory to each other, it was required to trade-off between two objectives. Priority weight for criteria in residential objective was as 1. Topography (0.405), 2. Proximity to economic infrastructures (0.212) 3. Proximity to social service centres (0.323). Meanwhile, the priority weights for criteria in the agricultural suitability objective were: 1. topography (0.32) 2. soil (0.295) 3. Climate (0.263) 4. Accessibility (0.112). Suitability maps for each objective were then generated using the AHP process and weighted linear combination method.

Agriculture is another mainstream sector that GIS-MCDA analysis has been used to identify the suitability areas for rain-fed farming. Hossein et al. (2016) carried out a study in Golestan Province, Iran to evaluate the rainfed farming performance using GIS-MCDA analysis. First and foremost, they prepared the required thematic maps including soil, climate and topographic variables. They weighed all the criteria using local experts and based on Food and Agricultural Organization (FAO). Then, the layers were overlaid using Weighted Overlay Analysis (WOA) in ArcGIS. By overlaying the main variables; they were able to produce the suitability map for rain-fed farming. As the major finding, they tabled that the slope is the most dominant factor in deciding the suitability of the land for rain-fed farming in Golestan Province, Iran.

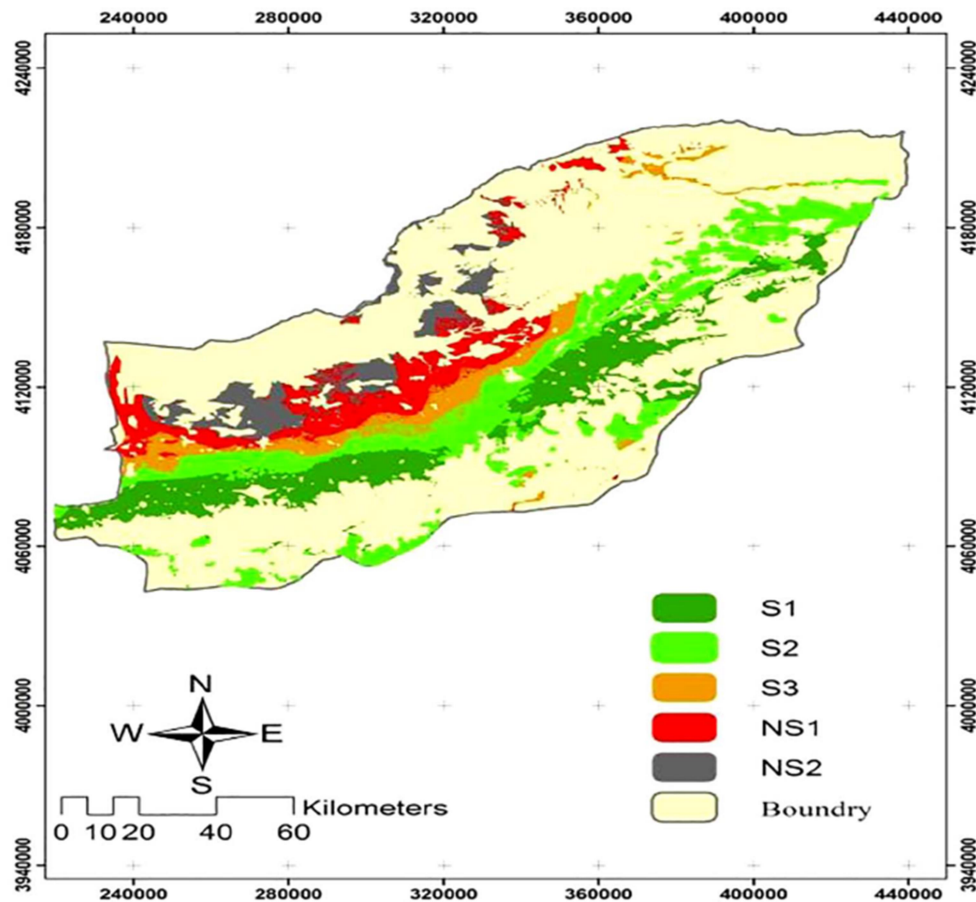


Figure 2. 6 Suitability map for rain fed farming prepared by Hossein et al. (2016)

2.2. Demographic analysis

Concerns about demographic effects on the water use practice are fuelled by recent demographic trends. For example, in the last 70 years, the world’s population has tripled (Bernstein, 2002). On the other hand, urbanization has become an emerging icon of modern demographic change. The rural population is outnumbered by the world urban and semi-urban population (UN, 2018).

It is observed that the population density has been used as a decision making criteria in many sectors such as economics, health, and infrastructure development, etc. The population density of an area is an indicator of the quality of living in an urban environment (Rahman et al., 2011). Further, they have stressed that the population density has been considered inversely related parameters to the quality of the urban

environment. It emphasized that utility development such as water supply is a dire need in highly dense areas to uplift the living condition.

Since the population density is attributed to the spatial distribution of the demography, GIS is a handy tool to interpret and model the demographic pattern in any given territory. As per the research conducted by Sirisena et al. (2017), GIS was used to interpret the correlation of the prevalence of dengue and population density. However, the detail of population was projected in a broad manner as district wise population density was derived in this research. Hence, it could have been much more precise with smaller territory such as GND.

It is evident that population density is a decisive tool in urban planning. Green space is a predominant feature in the urban built environment. Population density is a required factor for the calculation of green spaces per capita. Senanayake et al. (2013) presented a method to analyze the population density of the Colombo Municipal Council (CMC) area and their requirement of green spaces for comfortable living, a vector feature class was created incorporating the population of each GN division utilizing an attribute table. Since the census data for 2012 was unavailable at the time of research, the most recent available population data with a resolution of GN divisions belong to the census carried out in the year 2001. In order to determine the population (2012) in GN divisions within the CMC area, a projection was made considering 2011 Colombo district preliminary population data (Department of Census and Statistics, Sri Lanka, 2012) and population growth rate of CMC area using statistical methods. The GND-wise population density was built up as a vector file by the researchers. Subsequently, the population density of each GN division was determined in a GIS platform.

Interesting research work has been carried out by Hummel et al. (2007) about the population decline and German Water supply Schemes. It emphasized that the developed water supply scheme will act as “attractors” to a certain region where the population tend to settle. On the other hand, the population decline of a certain region due to migration will lead to uneconomical water supply systems. Further, it stressed that with respect to water supply systems, demographic growth and shrinkage processes must be regarded as occurring simultaneously; temporal as well

as spatial effects have to be considered, along with quantitative and qualitative aspects of demographic changes.

Urbanization: The movement from rural to urban society is recently identified as the factor that leads to urbanization and the need for improved infrastructure (UN Habitat, 2016). Urbanization is one of the key characteristics of global demography. A majority of the world's population (4.2 billion out of 7.6 billion in 2018) lives in cities. This trend is expected to sustain in the projected future up to 2050 (WWAP, 2012). It further reveals that the urban population is expected to rise as the vast majority of urban population growth is expected to occur within the world's least developed regions. It implies that the population is expected to grow in Sri Lankan cities are exceptionally high. This has added an extra burden on scarce resources like water and the situation is worsening by climate change. Water stress-induced by population density is attributed to punctuated economic growth and numerous health risks (WWAP, 2012) Although statistics indicate that water supply and sanitation coverage levels in urban areas are often higher than in rural areas, even the best-planned service provision systems can be thrown into disarray by a rapid influx of people (Hummel et al., 2007) In highly populated areas, the tendency towards faecal groundwater contamination is very high. Hence, it will affect the reliability of water resources adversely. Since the vulnerability of sources increases alarmingly, the need for water supply in highly dense areas is very high. As per the research conducted by Lewis et al. (1981), it was suggested that remedial measures such as lateral separation against faecal contamination can be proposed only for population density less than 100 person/ha. This situation has been further explained and utilized in research conducted by Howard et al. (2005) about the preparation of effective water supply surveillance in urban areas in developing countries. The intention of this research was to prepare a model to identify the target zones to collect data to gain a better picture of water surveillance. Using a zoning approach, they used four criteria to categorize the zones according to their vulnerability. One of the criteria was population density. They attributed the water quality to the population density owing to the possible faecal contamination. The population density was included because more densely populated areas have greater faecal

loadings within the environment and this mechanism has been already explained by the literature that indicates these are associated with greater vulnerability to infectious disease (Woodward et al., 2000). ‘Vulnerability in this context includes both the effects arising from the greater pathogen exposure and the increase in the number of people likely to be affected by the introduction of a pathogen. Adhiambo et al. (2018) have described the effect of anthropogenic activities derived by urbanization towards the pollution of surface water sources.

On the other hand, the severe depletion of water resources can occur due to rapid urbanization. When it comes to watershed management, urbanization is attributed to the removal of forest cover, resulting in less soil infiltration and supporting surface runoff. Chung et al. (2012) described the impact of the degree of urbanization on water resources depletion.

Amid the abundance of water resources, the urban areas lack piped water connections resulting considerable proportion of unsafe water users. In the Sri Lankan context, it is said that 7% of urban households do not have the access to a secure water source. However, considering neighbouring South Asian countries, it is in a much better condition (World Bank, 2018).

To tally with the aggravated population growth in cities, Trans basin water resource sharing has been highlighted by George et al. (2008). He further stressed that if the population grows at a rate of 3.5%, the average unmet demand under projected supply availability and a precipitation exceedance of 75% would be 297 MCM and the city, and applying the study to the water demand patterns in Hyderabad, India, the authors have predicted to the need to import more water from other sources.

As population growth is perceived by some to be the most important demographic trend affecting water resources (Boberg, 2005), the effect of population growth is magnified by the population density. In other words, the impact of demography on limited water resources is aggravated by the dense population where the population growth rate is high.

In the Sri Lankan context, the urban population is largely underestimated (WWAP, 2012). As per the UN’s World Urbanization Prospects (UN, 2018), Sri Lanka’s

urban population is currently 18.5 per cent of the total (placing it as the 11th least urbanized country on Earth). Hence, the population-based measurements of urban growth have so many limitations. Based on its primitive classification, demarcating of urban areas are baseless due to the urban population living in peripheral areas (Uchida & Nelson, 2010)

Globally, spatial methods are widely considered appropriate to capture and analyse the dynamics of urban expansion (Angel et al., 2005; Seto et al., 2011). It emphasises the usage of remote sensing in terms of satellite data to analyse the situation. Majority of studies related to meta-analysis applied data produced by NASA Landsat Satellite (Seto et al., 2011). It suggests the validity of application in the spatial distribution of built-up area rather than administrative unit wise population.

2.3. Water Quality Index methods

2.3.1. Evolution of Water Quality Index methods

Water quality index is defined as a technique that provides a ranking of the composite effect of individual parameters of water quality to the overall water quality/ The systems most relevant to it is a system of water quality index (WQI) is a method that certify the quality of water in a simple way that can respond to changes in the basic characteristics of water (Ichiwana et al., 2016).

In the mid of 18th century, Germans tendered the concept of water quality to grade water levels based on degree of pureness/contamination (Lumb et al., 2011). Later, the correlation between human health and the degree of water quality was discovered and that cholera outbreak was attributed to deteriorated water quality (Snow, 1854) from the interpretation for water quality, and thereafter scientists routinely adopted the technology to represent the water quality.

Horton (1965) applied the measure of digital indices to quantify water quality of the Ohio River, and a numerical system for the water quality index (WQI) was used based on certain proportions. An improved water quality index model called the National Sanitation Foundation Water Quality Index (NSF WQI, later named AWQI) was developed in 1970 by Brown, McClelland, Deininger and Tozer with reference to Horton index (Ichiwana et al., 2016). The ranges of sub-index and

weighting vary from 0 to 100 and 0-1, respectively, and the results come up as the sum of the relative values. Although the AWQI model was less complex, it had the limitation of sensitivity owing to the fluctuation of single parameter with respect to Water Quality Guideline on the WQI. Therefore, Brown et al. (1973) tendered a multiplicative model based on the NSF WQI (later called MWQI).

In General, drinking water quality is quantified with respect to the baselines of physical, chemical, and biological characteristics of water according stipulated as per the water quality guidelines or standards (Al-Janabi et al., 2012). In Sri Lankan perspective, the stipulated standard for drinking water quality is SLS 614:2013 : Specification for potable water. It possesses two Parts namely physio-chemical and biological parameters.

It was evident that the Oregon Water Quality Index (OWQI) method was practiced extensively to evaluate surface water quality globally in the past couple of decades. To assess water quality in OWQI, aggregated amounts are integrated to build a score representing different quality graduations (Cude, 2001). The OWQI model was coupled with numerous environmental indicators has become a tool to interpret water quality status descriptions and water quality assessment analysis. Moreover, the OWQI approach was almost rarely used in Sri Lankan environment to detail the water quality. But, the OWQI method has been applied globally for application in surface water management and extensively adopted in daily environmental communications on water quality (Dunnette et al., 1979).

A different approach was proposed in the late 1990s, namely, Canadian Council of Ministers of the Environment (CCME) using the Canadian Water Quality Index (CWQI). It was entirely a different approach from the index based the NSF method. NSF method scores tended to be much higher in comparison to the CWQI scores. As a result, the grades of the water quality for AWQI and MWQI turned out to be superior in relation to CWQI. In contrast, the correspondence in terms of water quality grades between OWQI and CWQI was much closer and better. Overall, the CWQI formulation appeared to be the most stringent, followed by OWQI model to grade the quality of water for the aquatic uses. Hence, The CWQI is a better tool to guide users in collecting sufficient water quality data from sampling stations and

putting them into index values. According to several technical reports within Canada, the index was improved to be the ultimate measure after the study was ended in a successful manner in the British Columbia (Zandbergen et al., 1998).

Being one of the most leading Asian countries, China has indigenous techniques to manage water quality assessment. Chinese primary water resource is surface water. Based on the Chinese Secure Guarantee Plan for Public Drinking Water Resources, some concepts were defined to present a security assessment of municipal drinking water resources. By integrating and coupling water quality, water scarcity, redundant capacity and the security assessment indicator system, Zhu et al. (2010) conducted a safety assessment of general drinking water resources in China. Based on the results for the water quality security evaluation, the water quantity and risk-resistance capability of water resources in cities were assessed in their research. Water quality assessment was the first step toward the protection and management of water bodies. On the basis of the Chinese Surface Water Environment Quality Standard (GB3838, 2002), the water quality evaluation index was classified into five levels, 1 to 5, respectively representing 5 types of water quality classes: excellent, good, medium, poor, and very poor. There are two methods for evaluating the quality of surface water resources, namely the single-factor assessment (abbr. CNWQI-S) method and the comprehensive assessment (abbr. CNWQI-C) method. For CNWQI-S, the maximum individual index is treated as the water quality assessment index for the relevant projects. The results for CNWQI-C need to be computed based on the relevant equations and requirements (Li et al., 2012).

In the South Asian region, significant applications of WQIs can be observed. Among these applications, Chaurasia et al. (2018) performed groundwater quality assessment using a water quality index (WQI) in parts of Varanasi District, Uttar Pradesh, India. In a bid to formulate a WQI, they considered twenty-two parameters. The said researchers found that only 20% of the samples were complied with Bureau of Indian Standard (BIS, 2012).

Rawat et al. (2018) conducted a research pertaining to formulation of Water Quality Indices and GIS-based evaluation of a decadal groundwater quality. For computation

of WQI, 13 quality parameters have been chosen by the researchers. They obtained 44 samples to represent both pre-monsoon and post-monsoon period.

Summary of structures of WQI is as below;

Table 2.1 Summary of structures of WQI models

Summary of structures				
Name	No of parameters used	Parameter weighting	Aggregation techniques	Defined range
Horton Index (1960)	8	4 for DO and 1 for other parameters	Simple additive technique	Five categories
				Very good (91-100)
				Good (71-90)
				Poor(51-70)
				Bad (31-50)
NSF WQI (1965)	11	The expert panel judgement	Both additive and Multiplicative functions	Five categories
				Excellent (90-100)
				Good (70-89)
				Medium(50-69)
				Bad (25-49)
OWQI	8	Sub index values directly used as weighting factors	The weight arithmetic function	Five categories
				Excellent (90-100)
				Good (85-89)
				Fair(80-84)
				Poor (60-79)
CWQI	4	Not required	Used fixed mathematical functions	Five categories
				Excellent (95-100)
				Good (80-94)
				Fair(65-79)
				Marginal (45-65)
Malaysian Index	6	Expert based	Simple additive technique	Parameter based individual rating scale used

Table 2.2 Parameters considered

Comparison of parameters																											
Name	Physical					Chemical								Biological		Additional parameters					Toxics, pesticides and trace metals						
	T(C ⁰)	Col.	Tur	SS	TS	pH	DO	BOD	COD	Co n	Al	Cl ⁻	NH ₃ - N	F.Col	T.Col	T.Ph	T.Su	NO ₃	T.Hardnes s	Cd	Mn	Zn	Cn	Hg	Fb	Cr	
Horton Index (1960)						Y	Y			Y	Y			Y													
NSF WQI	Y		Y		Y	Y	Y	Y						Y		Y		Y									
OWQI	Y				Y	Y	Y	Y					Y	Y		Y		Y									
CWQI																				Y			Y		Y	Y	
Malaysian Index				Y		Y	Y	Y	Y				Y														

2.3.2. Examples of previous research of the use of WQI in Sri Lankan Context

AWQI was widely verified at dozens of research in Sri Lankan context (Roshan et al., 2017). Canadian Water Quality Index was extensively used in the Sri Lankan research arena. One of them is the Water Quality Index (CCME-WQI)-based Assessment Study of Water Quality in Kelani River Basin, Sri Lanka conducted by Mahagamage et al. (2014). Further, Determination of Water Quality Status of Polgolla Watershed Using CCME Water Quality Index was carried out by Rajapaksha et al. (2016). They stressed that CWQI is developed based on three important elements, namely: a) the number of water quality parameters not meeting water quality standard limit, b) the number of times the standard limits are not met, and c) the extent to which the standard limits are not met. With the application of CWQI, it was justified that the temporal and spatial variation of water quality parameters are possible to be accounted by CWQI. Water quality monitoring programmes conducted by the Central Environmental Authority was keen enough to adopt same technology to interpret the water quality status of Kelani river, Ma oya and Dandugam Oya (CEA, 2013). Gunarathna et al. (2016) presented the Water Quality Assessment of a tank cascade system using the CCME Water Quality Index. It emphasized that CCME-WQI can be successfully used to draw meaningful and easily understandable conclusions about cascade systems from large data matrix on water quality.

Apart from above popular WQI methods, following water quality index method was used by Harshan et al. (2016). They proposed to adopt nine physio-chemical and biological parameters to build up WQI for groundwater sources in Jaffna peninsula.

One of the studies conducted by Cooray et al. (2019), based on the water quality index (WQI) calculations, it was found that only 3.8% in the wet season and 2.6% in the dry season of total water samples were categorized as the “excellent” type, and all other water sources require a further treatment before consumption. The intention of that research was to investigate the ground water quality of CKDu prevalence areas.

2.4. Water Scarcity and Water Stress

Water Scarcity is always a function of demography. It depends on the magnitude of population and the availability of water resources. The human water consumption varies in vivid array of needs such as agriculture, domestic consumption and industrial/institutional requirements.

To measure the water stress of any given territory, a number of indices have been developed in the past (Amber Brown et al., 2011). Most of the time, these indices have been developed on a specific country basis.

2.4.1. Falkenmark Indicator

Falkenmark Indicator (Falkenmark, 1989) is one of the most widely spread method used all over the globe. The level of water scarcity in a certain country was determined based on following threshold values: If the amount of renewable water in a country is below 1,700 m³ per person per year, that country is said to be experiencing water stress; below 1,000 m³ it is said to be experiencing water scarcity; and below 500 m³, absolute water scarcity. It emphasizes the amount of freshwater resources available within a given territory relative to number of habitants of the country (amount of per capita availability of fresh water). It is easy to derive under availability of raw data. However, it fails to account the microscopic picture which narrates the differentiation between different climatic conditions and lifestyles and economies of the country (Ohlsson, 2000). Besides, the raw water extraction through desalinization was omitted from the consideration of water resource availability. Hence, it is considered as not suitable for measuring the water scarcity in local areas.

Jiang (2009) has figured out the status of water scarcity within China. In order to produce a measuring tool, he applied the Falkenmark Indicator for different regions of China. This is justifiable based on the magnitude of China and its States. He used the available statistics for Average annual water resources in two ways; surface water and ground water resources in million m³ per year.

Water balance mapping is a useful tool to prepare the spatial distribution of Falkenmark Indicator. In order to quantify the Falkenmark indicator, it is necessary

to measure the Water resources availability of the relevant spatial entity. Water resources availability is attributed to the Water balance of the region (Bastianssen., 2003).

Though, Falkenmark in 1997 expressed “blue water” availability as the water in aquifers and water courses and the interaction in crop production between soil moisture (referred to here as ‘green water’), surface water was only taken as the blue water component by van Beek (2011). He, however, selected to consider groundwater as a particular resource in order to identify regions that may experience dwindling availability in the future (Wada et al., 2011). Amid the consumption of world population is around 10% of the maximum available blue water in the form of river discharge on the global scale (Oki and Kanae, 2006), water stress occurs since water availability is highly variable over space and time. The objective of van Beek’s study is to quantify at a monthly time scale the seasonal and inter-annual variations in blue water stress on the global scale.

2.4.2. Other water stress indicators used

A review of water scarcity indices and methodologies has been carried out by Brown et al. (2011).

2.4.2.1 The Social Water Stress Index

The Social Water Stress Index has been built up with the integration of Building on the Falkenmark indicator and UNDP Human Development Index (HDI) by Ohlsson (2000) for integrating the “adaptive capacity” of a society to consider how economic, technological, or other means affect the overall freshwater availability status of a region. The UNDP Human Development Index (HDI) is a widely accepted indicator used to assess these societal variables. The HDI functions as a weighted measure of the Falkenmark indicator in order to account for the ability to adapt to water stress and is termed the Social Water Stress Index.

As per the research conducted by Ohlsson (2000), it was mentioned that the construction of water scarcity index by taking the equally widely used Falkenmark indicator of renewable fresh water, and dividing it with the HDI (and some arbitrary but common correction factor) will get a Social Water Scarcity Index (SWSI) which

not only would serve to highlight the importance of a society's social adaptive capacity facing the challenges of water scarcity, but also gets rid of some annoying anomalies discussed in that Falkenmark indicator.

2.4.2.2 The Index of Local Relative Water Use and Reuse

The Water Resources Vulnerability Index, sometimes referred to as the WTA ratio, was then developed as the ratio of total annual withdrawals to available water resources. The WTA ratio was used in a freshwater availability assessment that incorporated geospatial tools along with climate inputs (Vorosmarty et al., 2005). A defined area was divided into 8 km cells. An index of local relative water use as well as a water reuse index was calculated for each cell (n). Water use is the sum of the water withdrawals for the domestic (D), industrial (I), and agricultural (A) sectors. The locally generated discharge is the product of locally generated runoff and the area of the cell; the river corridor discharge is the sum of all local discharges (Q_c). To calculate the index of local relative water use, the cell water use is divided by the river corridor discharge (Eq. 3).

Water use index (WUI) can be expressed as:

$$WUI = (D + I + A_n)/Q_c \quad (3)$$

An index of local relative water uses greater than 40% is considered a high degree of stress.

2.4.2.3 The Watershed Sustainability Index

Chavez and Alipaz (2007) proposed the Watershed Sustainability Index (WSI) that involves hydrology, environment, life, and policy (Eq. 4). The WSI is built up based on watershed or basin specific and intended for a maximum area of 2,500 km²; larger areas would need to be broken down into smaller sections.

The Watershed Sustainability Index (WSI) can be expressed as;

$$WSI = (H + E + L + P)/4 \quad (4)$$

The WSI ranging from 0 to 1 is the average of four indicators; 1. Hydrologic indicator, H (0–1); 2. Environmental indicator, E (0–1); 3. Life (human) indicator L, (0–1); 4. Policy indicator, P (0–1). Each parameter is given a score of 0, 0.25, 0.50, 0.75, or 1.0. All indicators are equal in weight, although parameters may vary from basin to basin, and should be chosen by consensus among stakeholders (Chaves and Alipaz, 2007). However, the use of the model depends on available information specific to watersheds, which may not be available in many regions.

2.4.2.4 The Water Stress Indicator

A Water Stress Indicator (WSI) was built up by Smakhtin et al. (2005), which recognizes environmental water requirements as an important parameter of available freshwater. Mean annual runoff (MAR) was used as a representative figure of total water availability, and estimated environmental water requirements (EWR) were expressed as a fraction of long-term mean annual river runoff that should be reserved for environmental purposes (Eq. 5). Using global annual water withdrawal data from the FAO and the IWMI for industrial, agricultural, and domestic sectors, global water resources incorporating environmental water requirements were evaluated (Table 2.3). These results were compared to the previous assessment of a commonly used water stress indicator (Eq. 5) that neglects EWRs. The authors applied this index in their global water resources assessment analysis using the WaterGAP 2 tool. By inclusion of Environmental water demand, the water stress area was enlarged, thus providing a more accurate assessment of regional water resource supplies.

$$WSI = Withdrawal/MAR \quad (5)$$

$$WSI_{Env} = Withdrawal/(MAR - EWR) \quad (6)$$

Table 2.3 Categorization of Water Scarcity as per Smartchin’s WSI

WSI (proportion)	Degrees of Environmental Water Scarcity of River Basins
WSI > 1	Overexploited (current water use is tapping into EWR) - environmentally water scarce basins.
$0.6 \leq \text{WSI} < 1$	Heavily exploited (0 to 40% of the utilizable water is still available in a basin before EWR are in conflict with other uses) – environmentally water stressed basins.
$0.3 \leq \text{WSI} < 0.6$	Moderately exploited
WSI < 0.3	Slightly exploited

2.4.2.5 Water Foot-printing

Hoekstra (2003) explained the water footprint concept as an index of freshwater use. The indicator parameters include both direct water use by consumer and producers, as well as indirect water use. The water footprint of a product is defined as “the volume of freshwater used to produce the product, measured over the full supply chain.” Recently Hoekstra et al. (2009) developed a method of calculating water scarcity by incorporating green, blue and grey water footprints. Water scarcity is evaluated in terms of green water scarcity and blue water scarcity as well as grey water production. The green water scarcity in a region is calculated as the ratio of the green water footprint in the region and the green water availability. Likewise, the blue water scarcity is the ratio or the blue water footprint to the blue water availability. The new concept of “water pollution level” is an indicator of the magnitude of water flow pollution using grey water. Polluted water is considered unusable water and is not included when calculating water resource availability.

Sharshard et al. (2019) has conducted a research to validate the applicability of a numerical model in interpreting the water demand. They built up an integrated nonlinear daily water demand forecast model (case study: City of Guelph, Canada).

The tripling of the human population in the past 70 years has been accompanied by a six-fold increase in water withdrawals (Gleick, 1993).

CHAPTER 3

METHODOLOGY

This chapter, it is intended to present the theoretical foundations behind the approach that have been applied to solve the prioritization order of water supply need of Southern province, Sri Lanka.

3.1. Methodology Overview

Though, several approaches to solve MCDA cases have been explained in the literature survey, the selected major methodology plan of the GIS-based MCDA decision-making platform for prioritization of water supply need applied in this thesis is shown in Figure 3-1.

In the context of the case study, only one objective was considered; prioritization of water supply needs. This objective was operationalized by assigning four criteria. The alternatives are modelled as raster cells. After selecting criteria, three components are sequentially implemented as follows:

1. Preparation of datasets of Spatial Distribution of Population density, Equivalent Water Quality Index, Relative Water balance and Population Index for New Developments to describe the criteria pertaining to the prioritization status in real case shown in Chapter 4.
2. Standardization of above criteria. With this process, since all factors are measured quantitatively, the alternatives are reclassified/ranked order on one common interval scale (Voogd, 1983).
3. Weights are assigned to the suitability maps. The weights are derived using the Analytic hierarchy process (AHP) which is based on pairwise comparisons (Saaty 1987; Saaty 2008)
4. Addition of above criteria with the use of GIS technology and weighted linear combination (WLC) (Carver 1991).With WLC, the

final suitability map S is derived by multiplying each factor by its relative weight followed by summation of the results.,

$$S = \sum w_i x_i \tag{7}$$

Given w_i as weight of factor I, where $w_i \in [0,1]$ and x_i as the standardized score of factor I where in our case $x_i \in [0,1]$ (Eastman et al., 1995).The MCDA was fully implemented based on 500m * 500 m cell size advanced raster analysis, in ArcGIS 10.2.1 Esri Software. The intention is to create visual maps of the study results to provide recommendations for NWSDB management about the real requirement in public perspective.

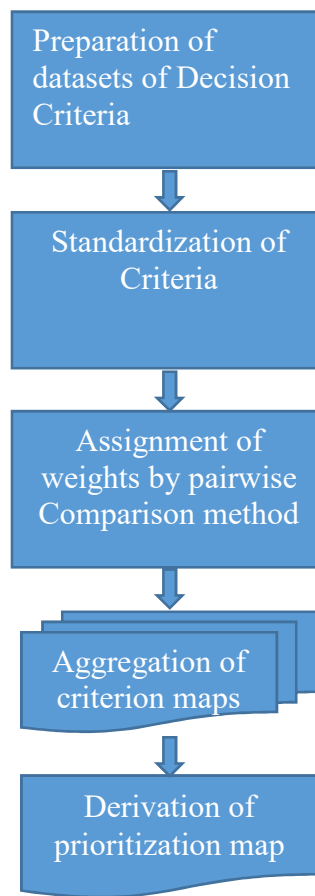


Figure 3.1 Overview of the proposed approach of prioritization Model

3.2. Preparation of datasets

3.2.1 Population Density

This factor specifies the localization of water demand by the concentration of demography. To figure out the spatial distribution of population density, the distribution of domestic buildings was taken into the consideration. The base demographic data selected for the research area was Census data published in 2012 on Grama Niladhari Divisional (GND) basis.

First and foremost, the GNDwise population was projected up to present as follows;

$$pop_{2020} = pop_{2012}(1 + n)^8 \quad (8)$$

Where , Pop_{2020} = projected GND-wise population in 2020

Pop_{2012} = Census GND-wise population in 2012

n = Natural growth rate derived from census 2001 and 2012

Projected population was, then, distributed among the domestic buildings proportionately to the respective building area;

$$pop_i = A_i pop_{2020} / \sum A_i \quad (9)$$

Where , Pop_i = projected population equivalent of respective building

Pop_{2020} = Census GND-wise population in 2020

A_i = Area of the respective building

In the ArcGIS platform, this result was obtained by using the Spatial join tool available in Analysis toolset. The updated building layer produced by the Survey Department was spatially joined with the GND shapefile to derive the projected population equivalent of the respective building.

Using the summary statistics tool available with Analysis toolset, the total floor area ($\sum A_i$) of each GND was calculated.

Kernel density tool was used to produce the spatial distribution of demographic agglomeration. Kernel Density calculates the density of point features around each output raster cell. Conceptually, a smoothly curved surface is fitted over each point. The surface value is highest at the location of the point and diminishes with increasing distance from the point, reaching zero at the Search radius distance from the point. Only a circular neighbourhood is possible. The volume under the surface equals the Population field value for the point, or one if none is specified. The density at each output raster cell is calculated by adding the values of all the kernel surfaces where they overlay the raster cell centre. The kernel function is based on the quadratic kernel function described in Silverman, 1986.

The selected cell size was 500 m \times 500 m. It was understood that the building layer produced by the survey department, is incomplete. Hence, digitizing the buildings shown in Google earth was used to update the building layer. Sequence of preparation of spatial distribution of demographic agglomeration was automated using model builder facility provided by ArcGIS as below;

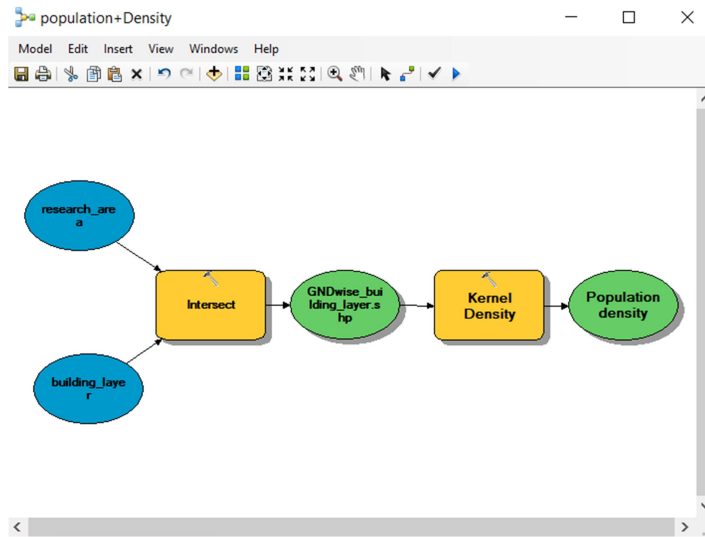


Figure 3.2 Model Builder tool to automate the plotting of Population Density

3.2.2 Water Quality Index

Water Quality Index for the research area was derived using 8 Water Quality parameters namely; 1. Total dissolved solids 2. Hardness 3. Nitrate 4. Nitrite 5. Total iron 6. Flouride 7. Chloride 8.Manganese.To build up a representative figure for the water quality status of the given area, an amalgamation of the treated Water quality of NWSDB fed customers and other water users was required. Hence following data model was preliminarily fitted with the above requirement;

$$WQI_e = (WQI_{OTHER} * N_{NOTHER} + WQI_{NWSDB} * N_{NWSDB}) / N_{Tot} \quad (10)$$

- WQI_e = Equivalent Water Quality Index
- WQI_{NWSDB} = Water Quality Index of respective NWSDB Water supply scheme
- WQI_{Other} = Water Quality Index of Sources other than NWSDB fed sources
- N_{NWSDB} = Number of NWSDB customers
- N_{Other} = Number of users other than NWSDB customers
- N_{Tot} = Number of total habitants of the area

As per the census and Statistics published in 2012, the percentage of well users and NWSDB users of Galle, Matara and Hambantota districts are 83.21 %,93.51% and 78.2% respectively. Hence, the number of users belonging to other water practices is quite significant; especially in the Hambantota district. However, the most dominant component of the remainder; the beneficiaries of rural water supply frequently suffer from low-quality water supply (NWSDB water quality reports,2019). Hence, it was assumed that the water quality of produced water from RWS is equal to the respective groundwater quality parameters of the area.

To derive the WQI for NWSDB fed areas, first, the area supplied by respective WSS was demarcated. Since the spatial distribution of pipe network for each WSS was not available; the minimum size of the area was taken as GND level.

As the next step, data about treated water quality were collected from regional chemists of three districts for the last year (2019) and tabulated with the GND database available. As mentioned earlier, 8 water quality parameters were listed against each GND to calculate the WQI.

Calculation of WQI was made using Weighed Arithmetic Index Method (Brown et al., 1972).

Accordingly,

$$1. \quad \text{Quality rating for } n\text{th parameter} = q_n;$$

$$q_n = 100(v_n - v_i)/(v_s - v_i) \quad (11)$$

were.

V_n	= Observed value
V_i	= Ideal value
V_s	=Standard Value

Preparation of relative weight was calculated using the method introduced by Rawat et al. (2008).

2. Unit weight for nth parameter = w_n ;

$$w_n = K/s_n \quad (12)$$

were.

K = Proportionality constant

S_n = Standard permissible value for n^{th}

parameter

As per the equation 12, following table was tabulated to calculate w_n of each parameter;

Table 3.1 Unit Weight of n^{th} parameter

Parameter	SLS 614 :2013	1/ S_n	$W_n=(k/V_s)$
TDS	500	0.002	0.0001
Total Hardness	250	0.004	0.0003
Nitrate	50	0.020	0.0014
Nitrite	3	0.333	0.0227
Total Iron	0.3	3.333	0.2268
Fluoride	1	1.000	0.0680
Chloride	250	0.004	0.0003
Manganese	0.1	10.000	0.6804
	$\sum(1/S_n) =$	14.697	
	$1/\sum(1/S_n) =$	0.068	

With aid of above calculation, Water Quality Index of groundwater and NWSDB federation for each GND was calculated based on following equation;

$$WQI = \frac{\sum q_n w_n}{\sum w_n} \quad (13)$$

3.2.2.1 Preparation of WQI for groundwater sources

Spatial distribution of groundwater quality was required to build up the GNDwise WQI of the project area. A comprehensive Groundwater quality was conducted by Dissanayake et al. (1985). They prepared a Hydrogeochemical atlas for the entire country. The above mentioned 8 parameters were considered to build up WQI using the maps prepared by Dissanayake.

Following sequence was adopted to create WQI for Groundwater resources within research area;



Geo-referenced 8 maps were annexed as Appendix A1-A8.

3.2.2.2 Preparation of WQI for NWSDB fed habitants

Data was obtained from the Chief Chemist (S/E) and his staff regarding the Treated Water Quality of the respective Water treatment plants (WTP).

First, the WTP wise coverage area was demarcated to identify the influence zone of NWSDB fed systems. The demarcation was based on the administrative boundaries, since the data is not available on finer scale. Though, the distribution of Water Supply Schemes is available for most of the schemes, the platform for distributing number of connections should be fair for the entire set of schemes. Hence, the area was selected as the GN divisions covered by NWSDB fed schemes.

GN divisions fed by NWSDB is shown as Appendix B. Then, GN division wise population covered by WSS was tabulated based on repository database of NWSDB.

NWSDB covered population is shown as Appendix C. Following sequence was adopted to create WQI for NWSDB fed component within research area;



Figure 3.3 Sequence of Formulating WQI

Finally, the weighted (by population of the water practice) WQI are summed up to figure out the equivalent WQI.

3.2.3 Relative Water balance

After considering the data available monolithically within research area, it was decided to measure the local Water scarcity as a function of water resource availability. To figure out the Water scarcity, Water Stress indicator was derived for an area of $500\text{m} \times 500\text{m}$ cell. First, the local water balance of the respective area was built up. In order to figure out the local water balance, Precipitation, Evaporation and inflow to research boundary was considered. Following simplified model was used to derive the water balance of the region;

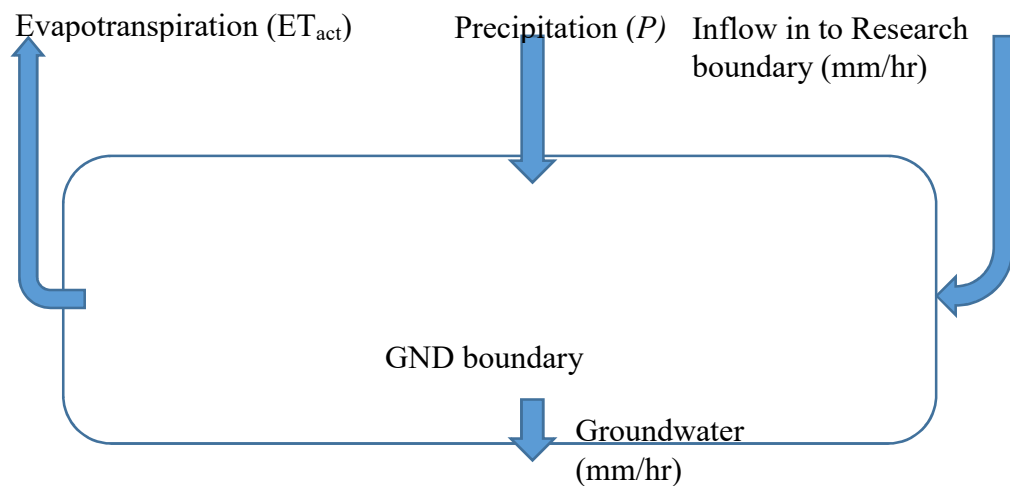


Figure 3.4 Simplified model of water balance

Evaporation figures in this calculation are based on the actual evaporation statistics documented by Chandrapala and Wimalasuriya (2003). The computation of evaporation are relied on NOAA-AVHRR satellite data using the Surface energy Balance Algorithm for land (SEBAL). Spatial Distribution of Evaporation is shown as Appendix D.

The rainfall surplus (S_p , mm) for every pixel is obtained as the difference between rainfall P and actual evaporation, ET_{act} :

$$S_p = P - ET_{act} \quad (14)$$

Apart from the rainfall surplus (S_p), the given GN divisional boundary is blessed with water inflow from river flow in to research are. Following simplified model can be used to illustrate the computation pertained to river inflow;

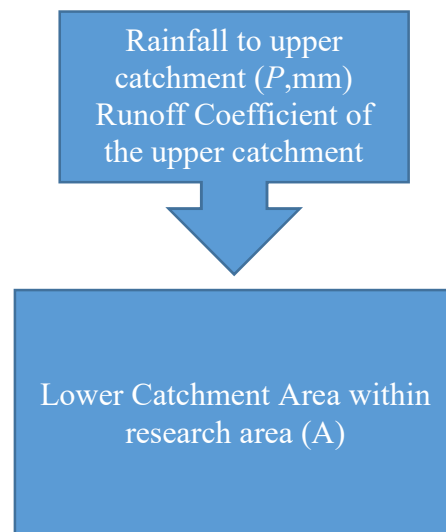


Figure 3.5 River Inflow to the Study area

Run off coefficient of the upper river basin was computed based on the results produced by Bastiaannsen (2003).

Total rainfall of the upper catchment is calculated as below;

Using the average rainfall (∂P_{avg}) of the pixel (cell size 500 m* 500m) and rainfall coefficient of the upper catchment (C),

$$P = \partial P_{avg} C \quad (15)$$

Amount of inflow at the boundary of the research area (Q_{in}) was calculated using the area of upper catchment (A_u) as follows;

$$Q_{in} = P A_u \quad (16)$$

As such, it is assumed that the above inflow (Q_{in}) is evenly distributed among the total downstream area as follows;

$$Q_{GN} = Q_{in}/A_d \quad (17)$$

Withdrawal for each cell was derived as below;

Agricultural Demand (D_A) was calculated using the land use pattern demarcated by Survey Department and the Evaporation rates (E_c) stipulated for each crop type by actual evaporation statistics documented by Chandrapala and Wimalasuriya (2003).

After assigning demand for each type of crop, the summation of demand for all crops fallen in to cell was taken using polygon to raster tool.

$$D_A = \sum E_c A_e \quad (18)$$

Domestic Water Demand (D_D) was calculated based on the adjusted building distribution of study area. Number of domestic units fallen in to each cell was normalized on projected population in 2020 (pop2020) and allocated 100lpcd as per capita consumption. Industrial water demand was taken as 30% of the Domestic water demand.

After assigning demand for each building, the summation of demand for all housing units fallen in to cell was taken using point Density tool.

$$D_D = 100 * 1.3 * N_{pop} \quad (19)$$

Total water withdrawal is summed up as;

$$D_{tot} = \sum E_c A_e + 0.1 * 1.3 * N_{pop} \quad (20)$$

Water balance for each cell is calculated by dividing the population (Pop) as follows;

Relative Water Balance;

$$WB_R = S_P + Q_{in} - D_{tot} \quad (21)$$

3.2.4 New Development Index

Possible agglomeration of population thrust owing to new development is computed based on the projections and plans stipulated by National Physical Planning Department.

Two national physical plans have been crafted during last decade projecting up to 2030 and 2050 respectively.

In order to figure out the population thrust of respective possible areas, the projected year is taken as 2030. The population increment rate of respective area is projected by National Physical Plan -2050.

Expected development zones and development corridor are demarcated in National Physical Plan - 2050

Development corridors are shown as Appendix E.

Apart from the development corridors, the demarcation of metro regions and its impact zones are demarcated based on the policies stated by National Physical Plan stated below;

1. Metro Region' shall be an indication of an area with a minimum population of 500,000, and net residential population density between 1,000 - 5,000 persons per square kilometer
2. Population Projection of Southern Corridor is as below;

Table 3. 2 Expected population growth rate of metro regions

Metro Region	Expected population Growth rate (%)
Galle	0.6
Matara	1.1
Hambantota	1.9
Ambilipitiya	1.3
Tangalle-Beliaththa	1.5
Thissa-Katargama	0.4

- i) The spatial extent of this corridor is defined approximately as the area within the first 10 kilometers (highest concentration), and 10-20 kilometers (medium concentration) and 20-30 kilometers (moderate concentration).
- ii) Additional population poured in to the research area on 2030 (Pop_{2030}) is calculated based on the population growth rates mentioned as b) by following equation;

$$Pop_{2030} = Pop_{2012}(1 + n)^{18} \quad (22)$$

3.3. Standardization

As per the raster procedures stipulated by Eastman (1995) and Voogd (1983), it is essential to standardize before proceeding with weighting and combination, since the built up criteria are quantified in different scales. Though the criteria have been evolved as a ratio, it is yet incomparable due to the presence of their units. In order to compare various criterion scores, it is essential to transform them in to one common measurement unit, for instance, transforming each criterion value to receive a range of 0-1. this type of alteration is called Standardization.

In order to prepare a standardized score, following equation is considered;

$$\text{Standardized Score, } X_i = \frac{(\text{Raw score} - \text{Minimum Raw Score})}{(\text{Maximum Raw Score} - \text{Minimum Raw Score})}$$

Thus,

$$X_i = (R_i - R_{min}) / (R_{max} - R_{min}) \quad (23)$$

However, the scale for equivalent water Quality Index (EWQI) indicate best to worst in a vice versa manner. The minimum value of EWQI gives the best Water Quality and Maximum value of EWQI gives the worse Water Quality. Hence, to represent such change, following equation was adopted;

$$X_i = (R_{max} - R_i) / (R_{max} - R_{min}) \quad (24)$$

In GIS platform, the standardization is carried out with the aid of “Raster Calculator” tool available under map algebra of ArcGIS 10.2.1 version.

3.4. Assignment of Weights

Each and every evaluation criterion considered in this research is explicitly correlated with the objective of the study; prioritizing the order of Water Supply Need. However, it will be impossible to optimize the entire set of criterions. Thus, a

compromise solution is an alarming requirement. To attain a compromise, trade-offs among the criteria are achieved by the use of weighting (Eastman et al., 1995).

Amid the number of weighting methods, we select the pairwise comparison method which is known as the Analytical Hierarchy Process (AHP). The evaluations against each criterion are relied on the relative importance of each pair of criteria on the fundamental nine-point scale (Eastman et al., 1995).

The, weights from these two levels are developed by adding each row and dividing by their total.

Following comparison matrix was developed to carry out the relative importance of each criterion with the participation of decision makers. In this process, decision makers were identified as two groups namely; 1. experts in the water supply field and the General public. To identify the most suitable criterion to symbolize the four sectors, only experts were consulted. Further, the relative importance of the criterion was figured out with the aid of all participants. The detailed survey results are shown in appendix M, and Results of the averaged responses can be summarised as below;

Table 3.3 Relative Importance of criterion

	Population Density	EWQI	Relative Water Bal.	New Development	Weights
Population Density	1	1/7	1/9	1	0.07
EWQI	7	1	1	7	0.39
Relative Water Bal.	9	7/9	1	9	0.47
New Development	1	1/7	1/9	1	0.07

3.5. Compensatory aggregation

The last segment of the GIS based MCDA analysis is evaluating suitability maps that has been produced in the previous steps. In order to evaluate the above factored final output, it is derived by simply multiplying each map by its weight and adding up the results to produce one single map (Eastman et al., 1995). Amid the numerous

ways available for the aggregation, weighted linear combination (WLC); also known as simple additive weighting is selected. This approach multiplies normalized criteria scores by relative criteria weights for each alternative (Greene 2011). With WLC, the final suitability map S is derived by multiplying each factor by its relative weight followed by summation of the results.,

$$S = \sum w_i x_i \quad (7)$$

Given w_i as weight of factor I, where $w_i \in [0,1]$ and x_i as the standardized score of factor I where in our case $x_i \in [0,1]$ (Eastman et al., 1995).

This computation work is carried out with the aid of weighted overlay function of ArcGIS.

CHAPTER 4

CASE STUDY

4.1. Defining Study area

In a bid to bind the research scope, the research boundary is required to be demarcated. As a preliminary tentative measure, the administrative boundary consisting of Southern province and Katharagama Divisional secretariat which comes under the purview of Southern regional support centre, NWSDB is taken to demarcate the boundary.

Grama Niladari Division wise Shapefile prepared by Survey Department is used in line with the research scope. GND wise coverage of the southern region is shown in Appendix B.

Unarguably, the water supply need is aroused from the habitable areas. Hence, the deduction of inhabitable areas i.e. Reserved forest and Water bodies are essential from the project area. To figure out the forest cover, the Survey department detail is extracted and shown as Appendix F1. Further, the spatial distribution of Water bodies is considered, and habitable areas are demarcated to finalize the research area as Appendix F2 and F3. Derivation of the habitable area is shown as below;

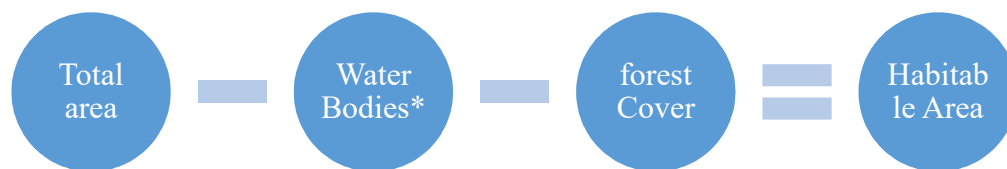


Figure 4.1 Derivation of habitable area

*: In this case, water bodies larger than 1 ha are taken in to consideration.

Final research area is shown as below;

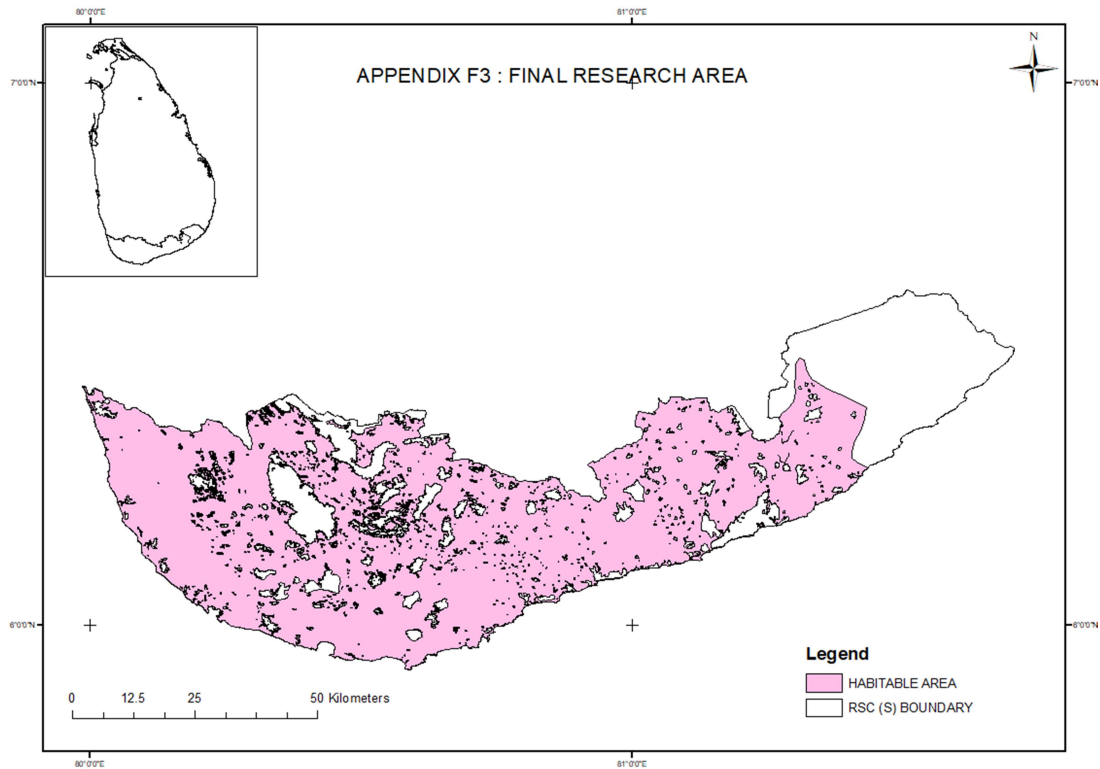


Figure 4.2 Final research area

4.2. Data Collection and Preparation of Datasets

4.2.1 Population Density

In this study, all spatial data regarding the demographic agglomeration is adopted from Survey data produced by Survey Department (SD). Since the building layer prepared by SD is older (constructed in 2008), it is updated with the open street map facility. Three demographic features are considered in this thesis as follows: GN Divisional Boundaries, GN division wise population and Spatial Distribution of

Buildings. Since a larger set of data is aggregated, input data is shown by as follows;

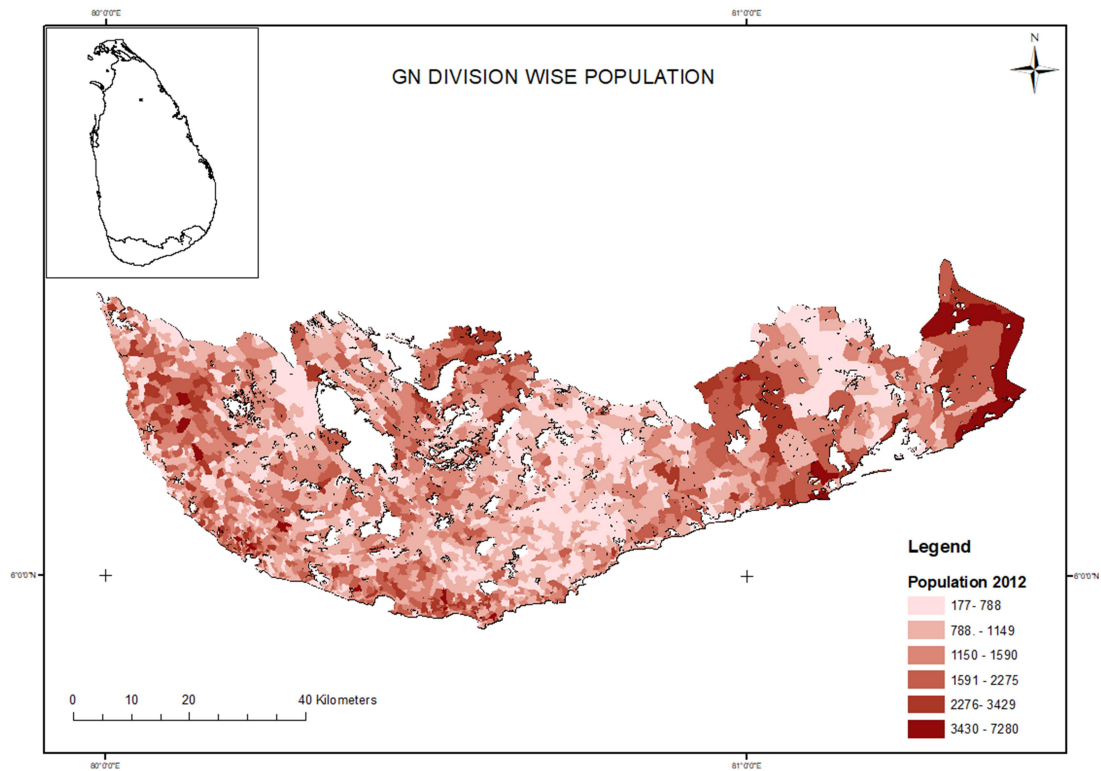


Figure 4.3 GN Division Wise Population

Secondary data (Population in 2020) was derived from the Census data (the base year 2012). Individual growth rates were obtained from the milestones established by Census and Statistics department as Galle-0.69%, Matara-0.59%, Hambantota-1.17% + migration 0.53% and Monaragala- 1.17%. Buildings within the study area were demarcated with the aid of a building layer prepared by the Department of Survey and updated by using the Open street map. The Spatial distribution of the building is shown as below;

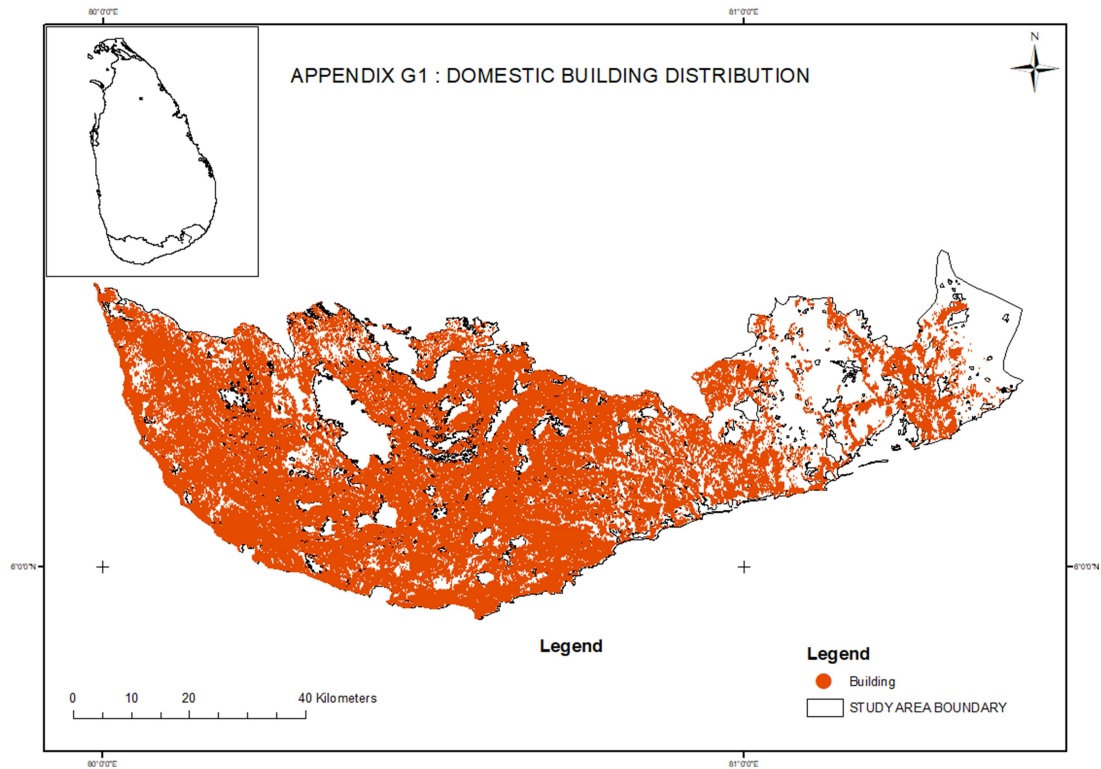


Figure 4.4 Domestic Building Distribution

It was noted that certain habitats were located within forest reserves. Such buildings were removed from the final building layer. Then, the population of the respective GN division was proportionately distributed among domestic buildings as per the floor area. The number of buildings recorded within the scope boundary is 540,239 which was distributed among 2,131 GN divisions.

In the GIS platform, the final output prepared was the household size of each housing unit. Finally, the population density was calculated with the aid of the point density tool by using the household size as the population field. The cell size used was 500m*500 m.

The final Demand density map is shown as below;

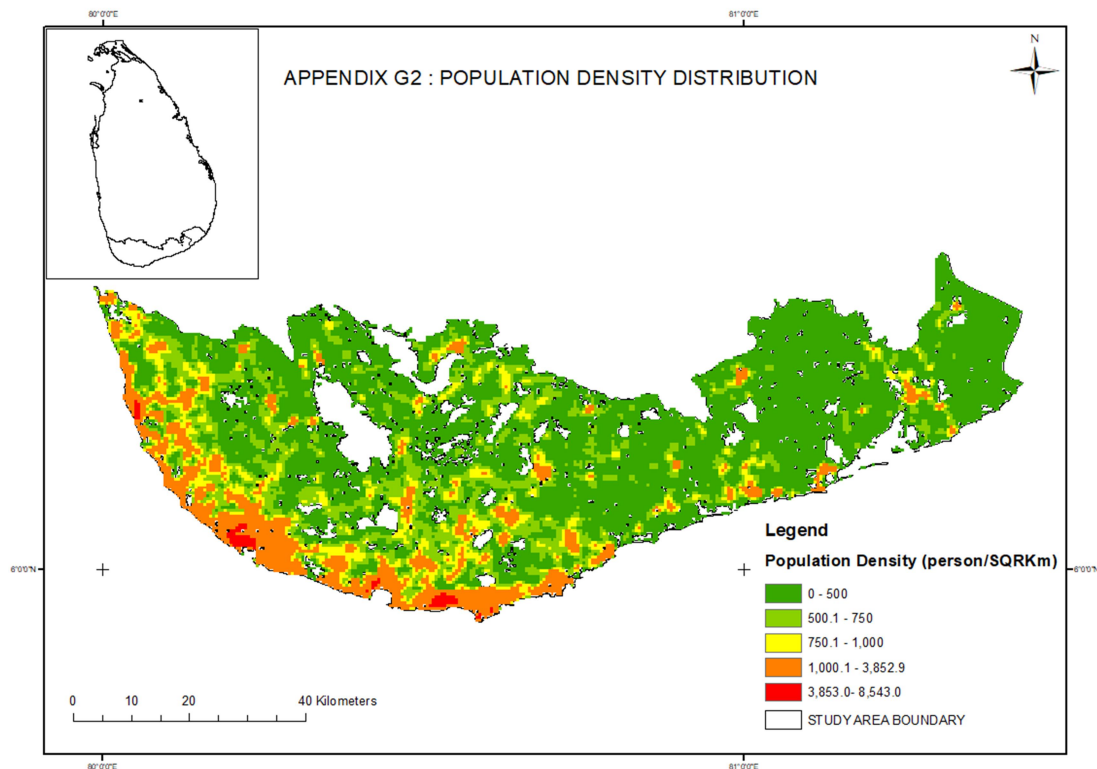


Figure 4.5 Population Density Distribution

4.2.2 Equivalent Water Quality Index

In this study, all monitored data regarding the water quality assessment of NWSDB fed systems are recorded by the staff attached to Chief Chemist (S/E) office. Nine water quality parameters are taken into account in this thesis as follows: Electrical Conductivity (EC), Total Dissolved Solids (TDS), Hardness, Nitrate Nitrogen (NO_3^-), Nitrite (NO_2^-), Total Iron, Fluoride (F1) and Manganese (Mn^{2+}). Since the reliable and monolithically unique water quality data for drinking water sources of groundwater and surface water is not available, it was decided to use Geochemical atlas prepared by Dissanayake et al. (1985). The monitoring data for heavy metals such as Cr (+6), Pb (II) and Zn (II) were lower than the maximum permitted by SLS 614 water quality standards and thus were not considered in this thesis. One set of valid monitoring data were obtained from multiple field sampling and analysis trips between January and December 2019 for NWSDB WSS. All 8 parameters were

sampled once per month. The detailed data collected is illustrated in Appendix H1. The summary of monitoring data details is shown in Table 4-1.

Table 4.1 The Summary of Monitored Water Quality data

Manager Office	Name - WSS	Hardness	TDS	Nitrate	Nitrite	T.Iron	Fluoride	Chloride	Mn
		250	500	50	3.000	0.30	1.00	250	0.1
Matara	Akuressa	23.64	42.58	0.12	0.00	0.09	0.01	12.55	0.00
	Hakmana	181.33	272.62	0.03	0.00	0.22	0.20	46.67	0.00
	Makandura	167.45	235.96	0.03	0.00	0.35	0.38	14.18	0.00
	Malimbada	32.08	50.69	0.11	0.00	0.06	0.01	11.33	0.00
	Nadugala	29.09	53.76	0.13	0.00	0.07	0.01	13.64	0.00
	Pitabeddara	158.17	208.09	0.02	0.00	0.31	0.22	14.00	0.00
	Radampola	151.27	253.08	0.05	0.03	1.18	0.29	36.91	0.00
	Thihagoda	81.00	173.82	0.24	0.00	0.18	0.20	45.20	0.00
	Urubokka	12.00	27.43	0.12	0.00	0.11	0.01	7.27	0.00
Weligama	35.86	56.09	0.13	0.00	0.08	0.02	15.14	0.00	
Hambantota	Ambalantota	140.33	282.70	0.05	0.01	0.06	0.41	31.25	0.00
	Angunukolapelessa	89.78	176.16	0.03	0.01	0.15	0.25	26.11	0.02
	Beliatta	223.00	390.33	0.02	0.01	0.17	0.30	51.50	0.00
	Bundala	215.00	473.85	0.07	0.01	1.71	0.51	66.17	0.09
	Kataragama	155.00	352.49	0.07	0.01	0.13	0.42	34.17	0.00
	Lunugamwehera	118.53	219.24	0.05	0.01	0.09	0.25	16.65	0.00
	Weeraketiya	38.67	71.84	0.05	0.01	0.11	0.17	15.25	0.00
	Walasmulla	38.67	71.84	0.05	0.01	0.11	0.17	15.25	0.00
	Ranna	135.83	301.58	0.05	0.01	0.08	0.44	39.83	0.02
	Hungama	135.83	301.58	0.05	0.01	0.08	0.44	39.83	0.02
	Ruhunupura	136.17	260.60	0.05	0.01	0.05	0.29	40.67	0.00
	Hambantota	136.17	260.60	0.05	0.01	0.05	0.29	40.67	0.00
	Tangalle	101.67	220.84	0.03	0.01	0.09	0.35	42.83	0.02
	Thissamaharama	236.67	508.94	0.06	0.01	0.45	0.57	57.83	0.04
Kirinda	236.67	508.94	0.06	0.01	0.45	0.57	57.83	0.04	
Wakamulla	102.00	189.13	0.05	0.01	0.11	0.29	24.33	0.00	
Galle	Baddegama	22.09	43.24	2.34	0.01	0.1	0.05	11.35	0
	Udugama	132.5	201.08	0.97	0.01	0.07	0.14	14.75	0
	Wakwella	20	48.71	3.3	0.01	0.18	0.04	15	0

As shown in equation 3.5 mentioned in chapter 3, Water quality rating (q) for individual water quality parameter NWSDB fed habitants are tabulated as below.

Table 4.2 Water Quality rating (q) for Water Quality parameter

O&M Manager Office	Name - WSS	q _{Hardness}	q _{TDS}	q _{Nitrate}	q _{Nitrite}	q _{T.Iron}	q _{Fluoride}	q _{Chloride}	q _{Mn}
		250	500	50	3.000	0.30	1.00	250	0.1
Matara	Akuressa	9.5	8.5	0.2	0.1	29.4	1.2	5.0	0.0
	Hakmana	72.5	54.5	0.1	0.1	73.7	20.4	18.7	0.0
	Makandura	67.0	47.2	0.1	0.1	117.3	38.4	5.7	0.0
	Malimbada	12.8	10.1	0.2	0.1	19.7	1.1	4.5	0.0
	Nadugala	11.6	10.8	0.3	0.1	23.3	1.4	5.5	0.0
	Pitabeddara	63.3	41.6	0.0	0.1	103.6	22.4	5.6	0.0
	Radampola	60.5	50.6	0.1	0.8	392.4	28.8	14.8	0.0
	Thihagoda	32.4	34.8	0.5	0.1	59.0	20.0	18.1	0.0
	Urubokka	4.8	5.5	0.2	0.1	36.1	1.2	2.9	0.0
	Weligama	14.3	11.2	0.3	0.1	26.7	1.5	6.1	0.0
Hambantota	Ambalantota	56.1	56.5	0.1	0.2	19.2	41.0	12.5	0.0
	Angunukolapelessa	35.9	35.2	0.1	0.3	49.4	25.4	10.4	22.8
	Beliatta	89.2	78.1	0.0	0.2	57.5	29.7	20.6	0.0
	Bundala	86.0	94.8	0.1	0.4	570.3	51.4	26.5	94.9
	Kataragama	62.0	70.5	0.1	0.2	42.5	42.0	13.7	0.0
	Lunugamwehera	47.4	43.8	0.1	0.2	30.2	25.4	6.7	0.0
	Weeraketiya	15.5	14.4	0.1	0.2	35.6	16.6	6.1	3.9
	Walasmulla	15.5	14.4	0.1	0.2	35.6	16.6	6.1	3.9
	Ranna	54.3	60.3	0.1	0.3	27.8	44.3	15.9	17.4
	Hungama	54.3	60.3	0.1	0.3	27.8	44.3	15.9	17.4
	Ruhunupura	54.5	52.1	0.1	0.3	17.2	28.7	16.3	0.0
	Hambantota	54.5	52.1	0.1	0.3	17.2	28.7	16.3	0.0
	Tangalle	40.7	44.2	0.1	0.3	28.3	34.8	17.1	21.0
	Thissamaharama	94.7	101.8	0.1	0.3	148.3	57.0	23.1	42.1
Kirinda	94.7	101.8	0.1	0.3	148.3	57.0	23.1	42.1	
Wakamulla	40.8	37.8	0.1	0.2	35.3	28.7	9.7	0.0	
Galle	Baddegama	8.8	8.6	4.7	0.3	33.3	5.0	4.5	0.0
	Udugama	53.0	40.2	1.9	0.3	23.3	14.0	5.9	0.0
	Wakwella	8.0	9.7	6.6	0.3	60.0	4.0	6.0	0.0

As shown in equation 3.7 mentioned in chapter 3, WQI for NWSDB fed habitants are tabulated as below.

Table 4.3 Water Quality Index of NWSDB fed Water

O&M Manager Office	Name - WSS	WQHardness	WQTDS	WQNitrate	WQNitrite	WQT.Iron	WQFluoride	WQChloride	WQMn	WQI
				0.0003	0.0001	0.0014	0.0227	0.2268	0.0680	0.0003
Matara	Akuressa	0.003	0.001	0.000	0.001	6.667	0.080	0.002	0.000	6.8
	Hakmana	0.022	0.005	0.000	0.002	16.716	1.390	0.006	0.000	18.1
	Makandura	0.020	0.005	0.000	0.001	26.597	2.609	0.002	0.000	29.2
	Malimbada	0.004	0.001	0.000	0.001	4.473	0.074	0.001	0.000	4.6
	Nadugala	0.003	0.001	0.000	0.001	5.292	0.093	0.002	0.000	5.4
	Pitabeddara	0.019	0.004	0.000	0.002	23.499	1.524	0.002	0.000	25.0
	Radampola	0.018	0.005	0.000	0.019	89.002	1.960	0.004	0.000	91.0
	Thihagoda	0.010	0.003	0.001	0.003	13.381	1.360	0.005	0.000	14.8
	Urubokka	0.001	0.001	0.000	0.001	8.179	0.080	0.001	0.000	8.3
	Weligama	0.004	0.001	0.000	0.002	6.048	0.102	0.002	0.000	6.2
Hambantota	Ambalantota	0.017	0.006	0.000	0.005	4.347	2.788	0.004	0.000	7.2
	Angunukolapelessa	0.011	0.004	0.000	0.008	11.214	1.730	0.003	15.498	28.5
	Beliatta	0.027	0.008	0.000	0.004	13.041	2.017	0.006	0.000	15.1
	Bundala	0.026	0.009	0.000	0.008	129.339	3.496	0.008	64.581	197.5
	Kataragama	0.019	0.007	0.000	0.004	9.639	2.856	0.004	0.000	12.5
	Lunugamwehera	0.014	0.004	0.000	0.005	6.848	1.730	0.002	0.000	8.6
	Weeraketiya	0.005	0.001	0.000	0.006	8.064	1.128	0.002	2.665	11.9
	Walasmulla	0.005	0.001	0.000	0.006	8.064	1.128	0.002	2.665	11.9
	Ranna	0.016	0.006	0.000	0.007	6.300	3.009	0.005	11.850	21.2
	Hungama	0.016	0.006	0.000	0.007	6.300	3.009	0.005	11.850	21.2
	Ruhunupura	0.016	0.005	0.000	0.006	3.906	1.949	0.005	0.000	5.9
	Hambantota	0.016	0.005	0.000	0.006	3.906	1.949	0.005	0.000	5.9
	Tangalle	0.012	0.004	0.000	0.007	6.426	2.369	0.005	14.288	23.1
	Thissamaharama	0.028	0.010	0.000	0.006	33.642	3.876	0.007	28.634	66.2
	Kirinda	0.028	0.010	0.000	0.006	33.642	3.876	0.007	28.634	66.2
Wakamulla	0.012	0.004	0.000	0.005	8.001	1.949	0.003	0.000	10.0	
Galle	Baddegama	0.003	0.001	0.007	0.008	7.560	0.340	0.001	0.000	7.9
	Udugama	0.016	0.004	0.003	0.008	5.292	0.952	0.002	0.000	6.3
	Wakwella	0.002	0.001	0.009	0.008	13.608	0.272	0.002	0.000	13.9

WQI for the NWSDB fed zones were demarcated as below.

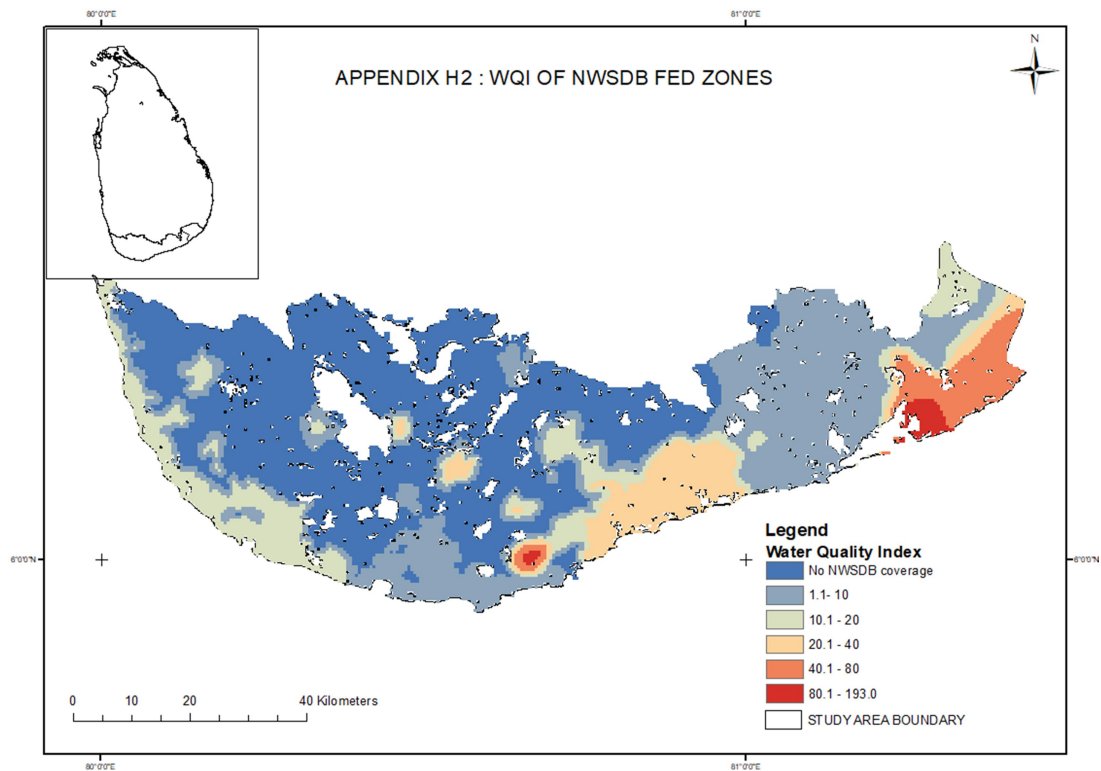


Figure 4.6 WQI of NWSDB fed Zones

Apart from the NWSDB supply, the rest of the water use practice is dominated by groundwater usage in the southern province. As such, the above-mentioned groundwater quality maps were regenerated using a geochemical atlas prepared by C.B.Dissanayake in 1985. The maps were digitized by the point layer which represents the centre of the respective GN division. Then, the raster file for each water quality parameter was generated using Topo to raster tool available under the 3D analyst toolset. Finally, the map was clipped to match the study area boundary. The prepared maps are shown as below;

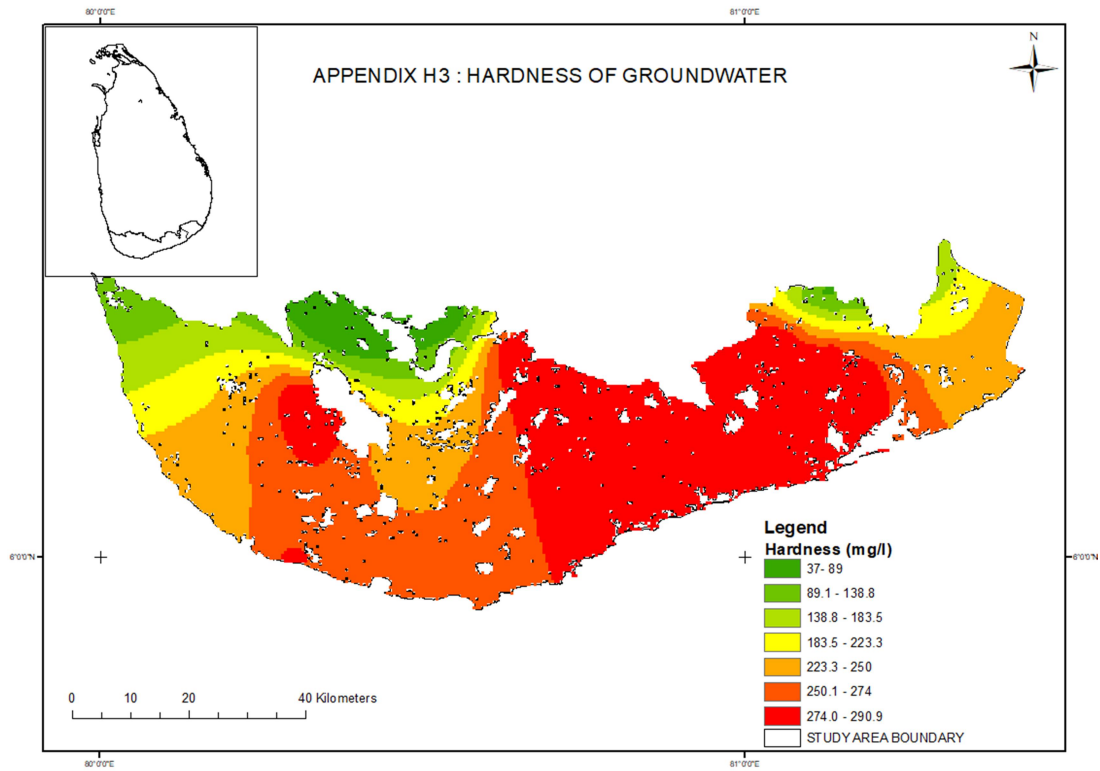


Figure 4. 7 Hardness of Groundwater

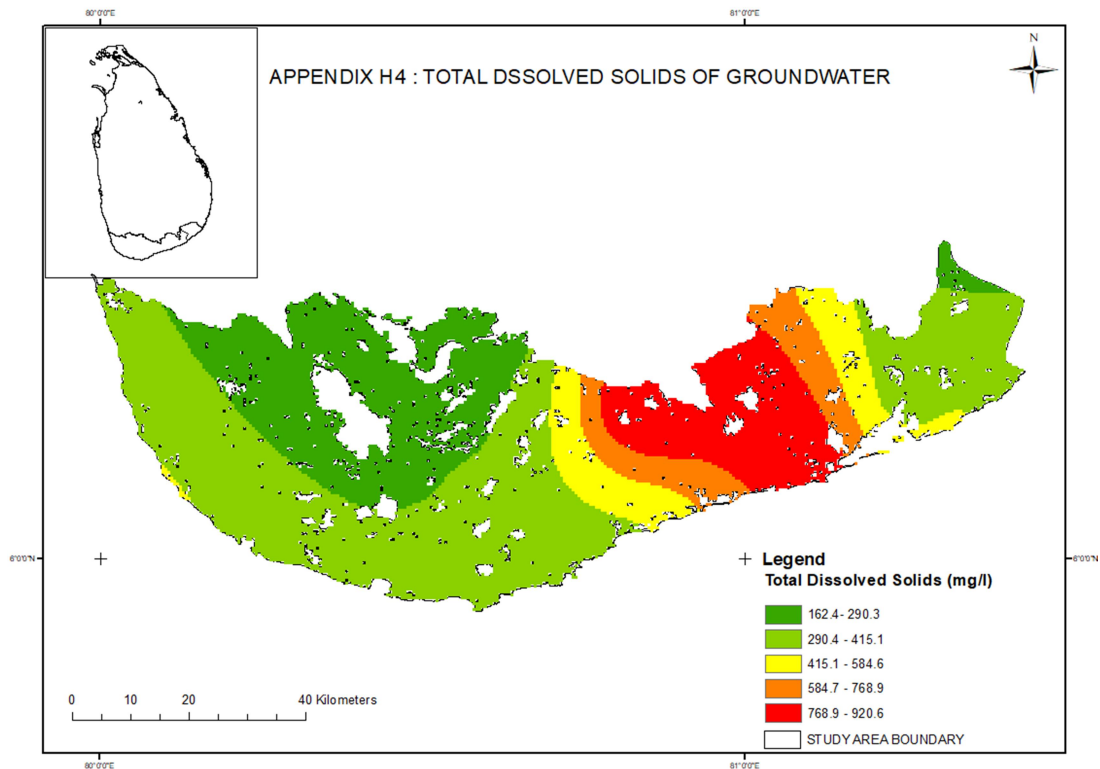


Figure 4. 8 Total Dissolved Solids of Groundwater

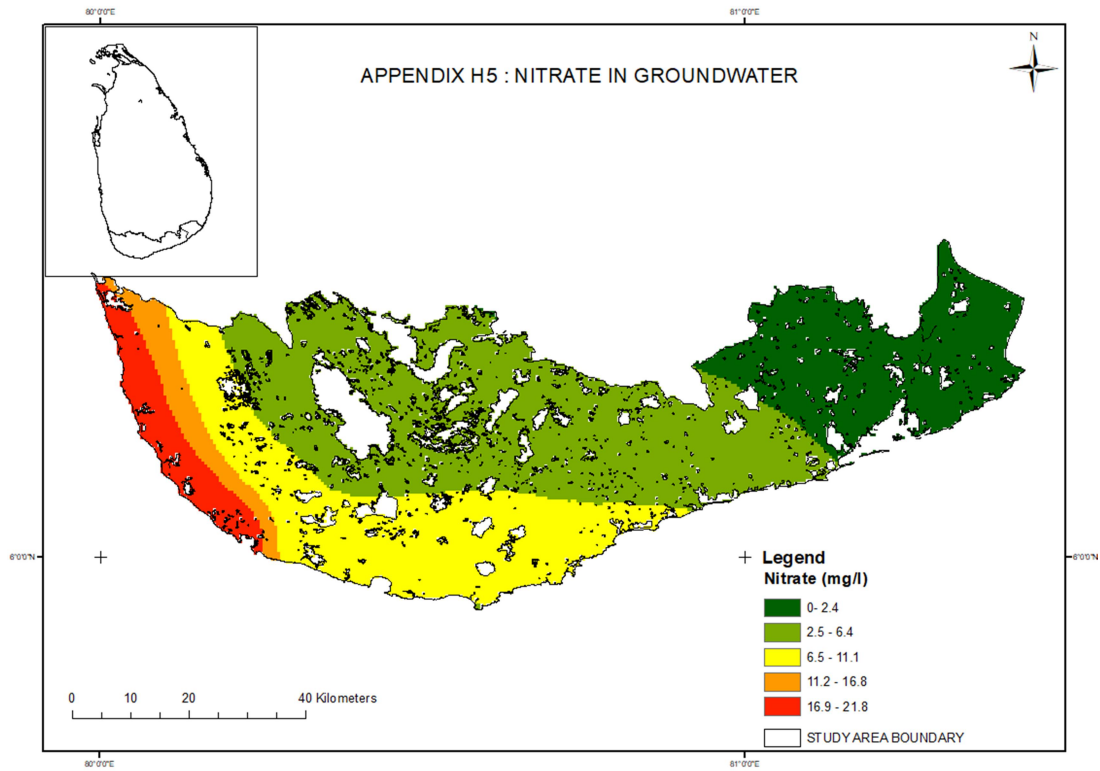


Figure 4.9 Nitrate in Groundwater

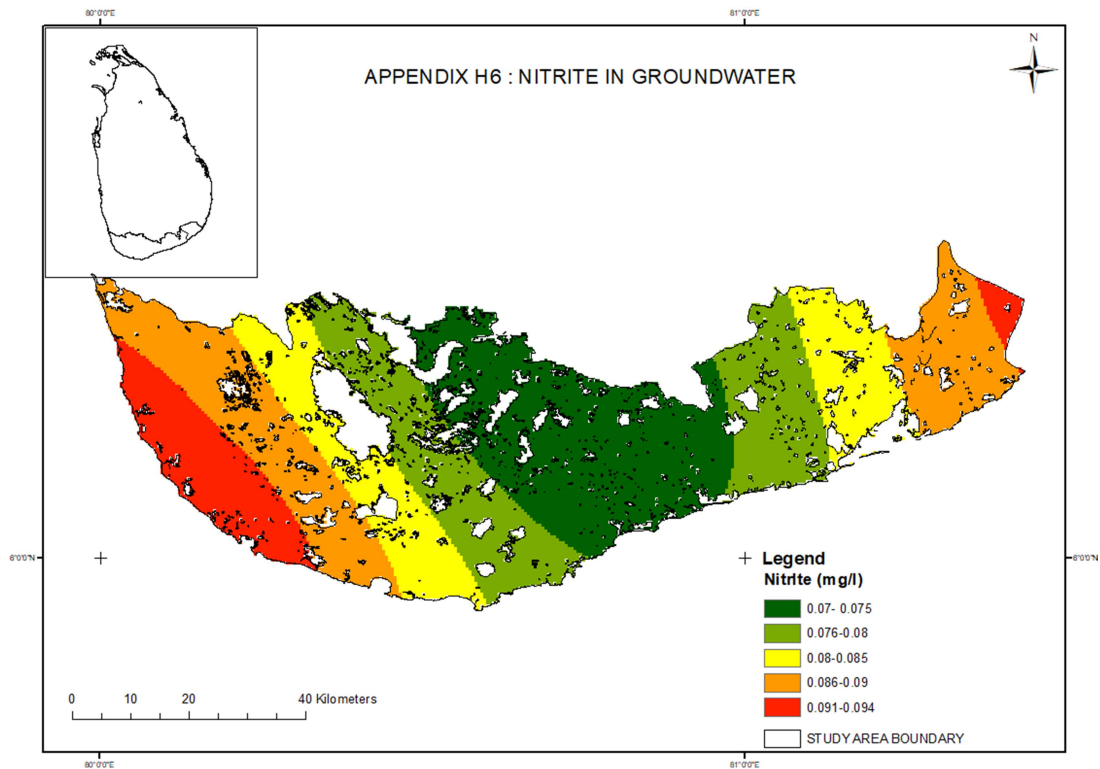


Figure 4.10 Nitrite in Groundwater

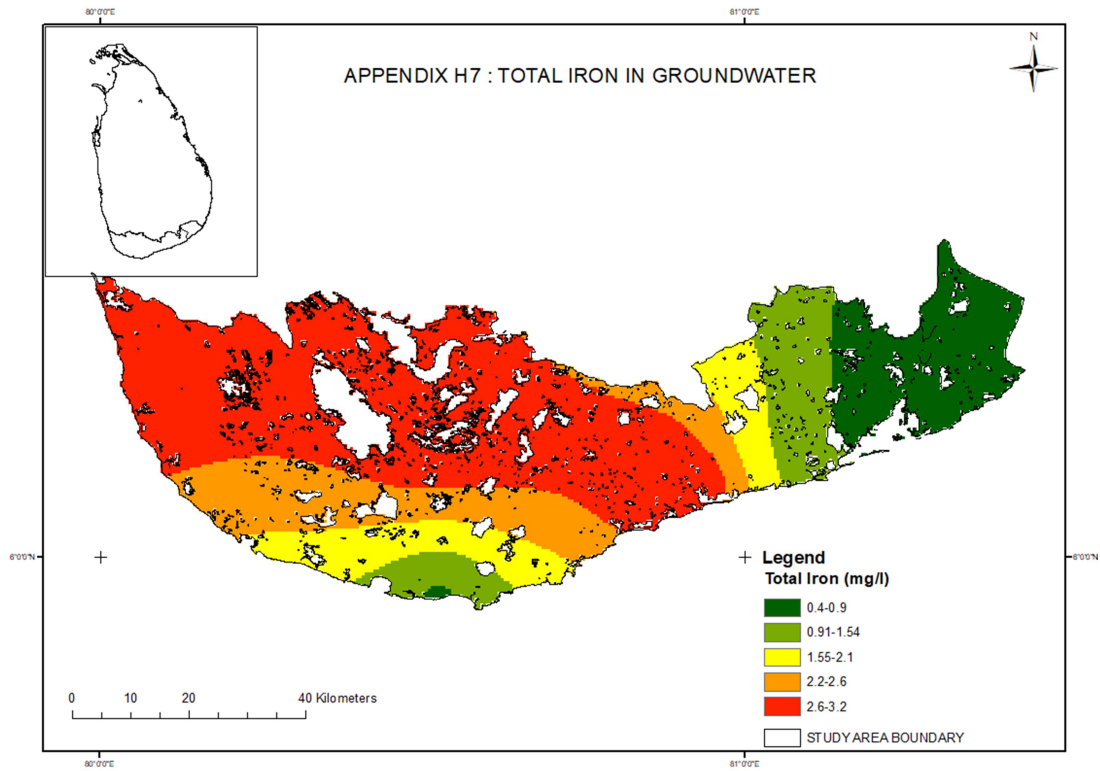


Figure 4.11 Total iron in Groundwater

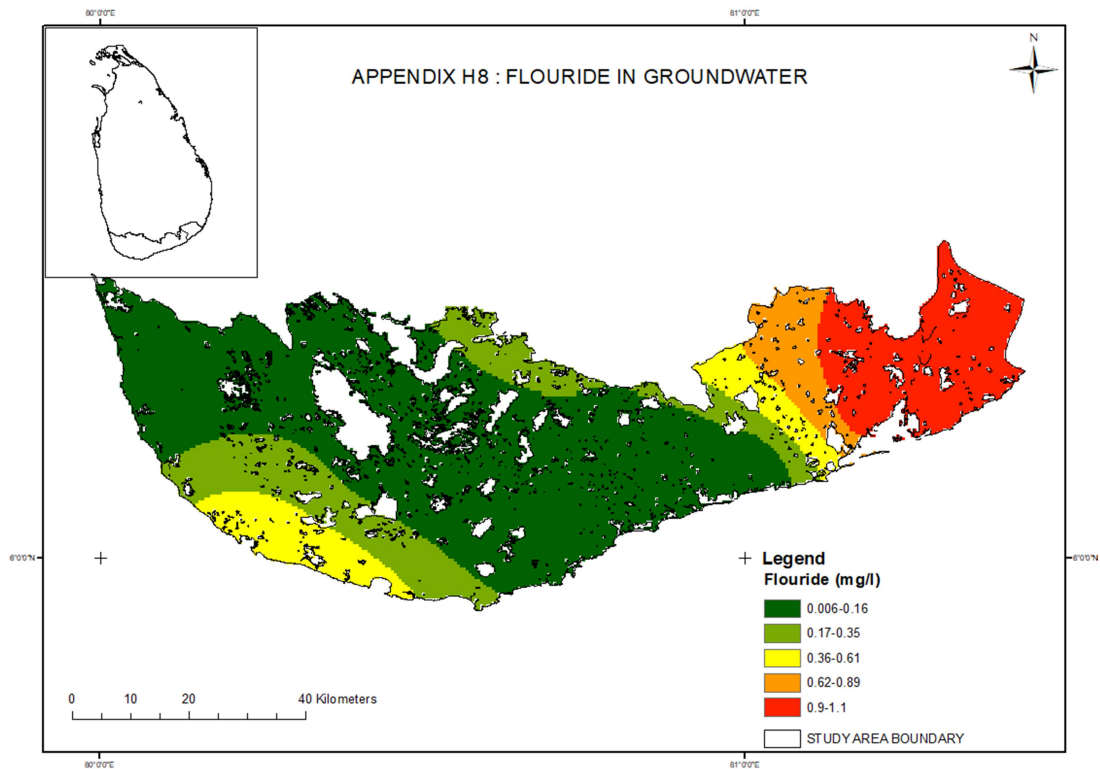


Figure 4.12 Fluoride in Groundwater

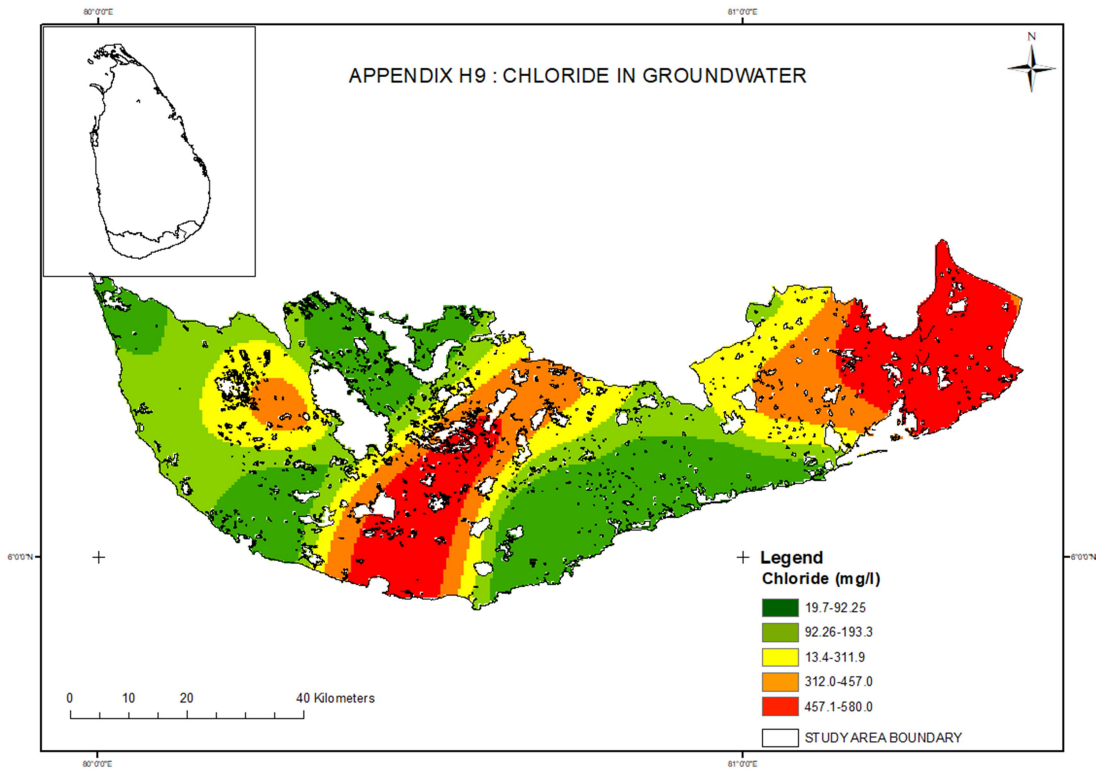


Figure 4. 13 Chloride in Groundwater

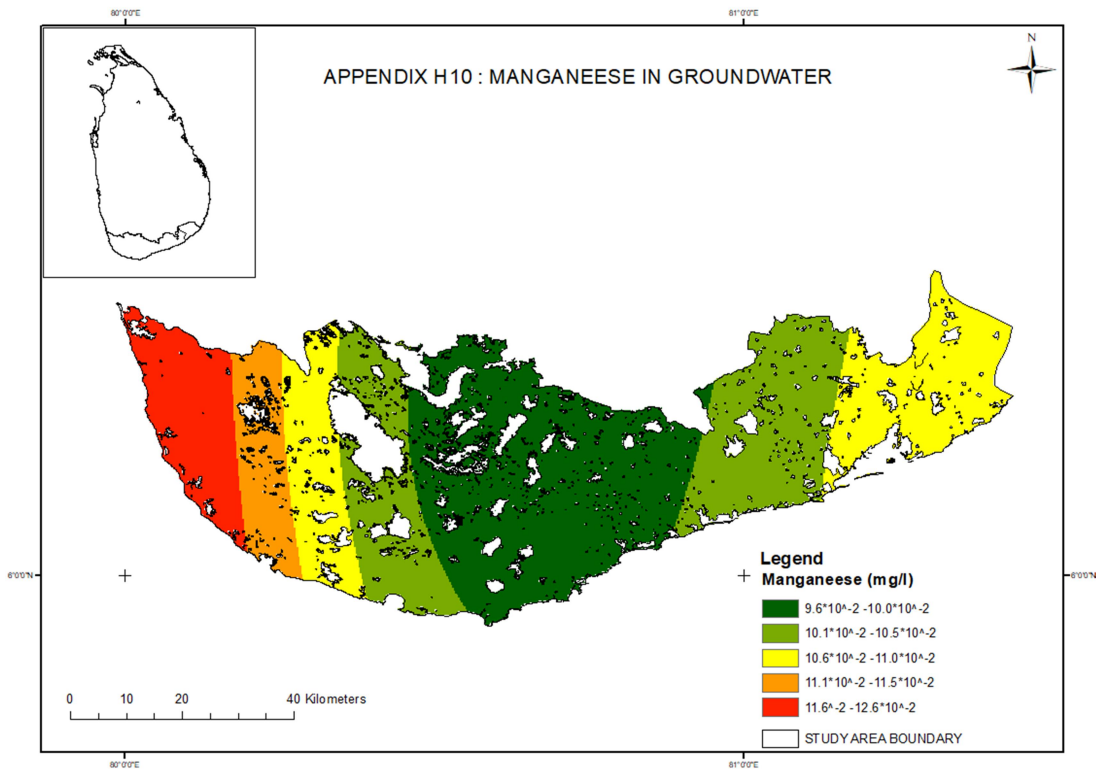


Figure 4. 14 Manganese in groundwater

As in equations 3.5 and 3.6, water quality rating and weightage for each parameter were tabulated in the attribute table in ArcGIS and prepared WQI for non-NWSDB fed habitants are tabulated and shown as Appendix H11. WQI prepared based on Groundwater quality of the region is shown as below.

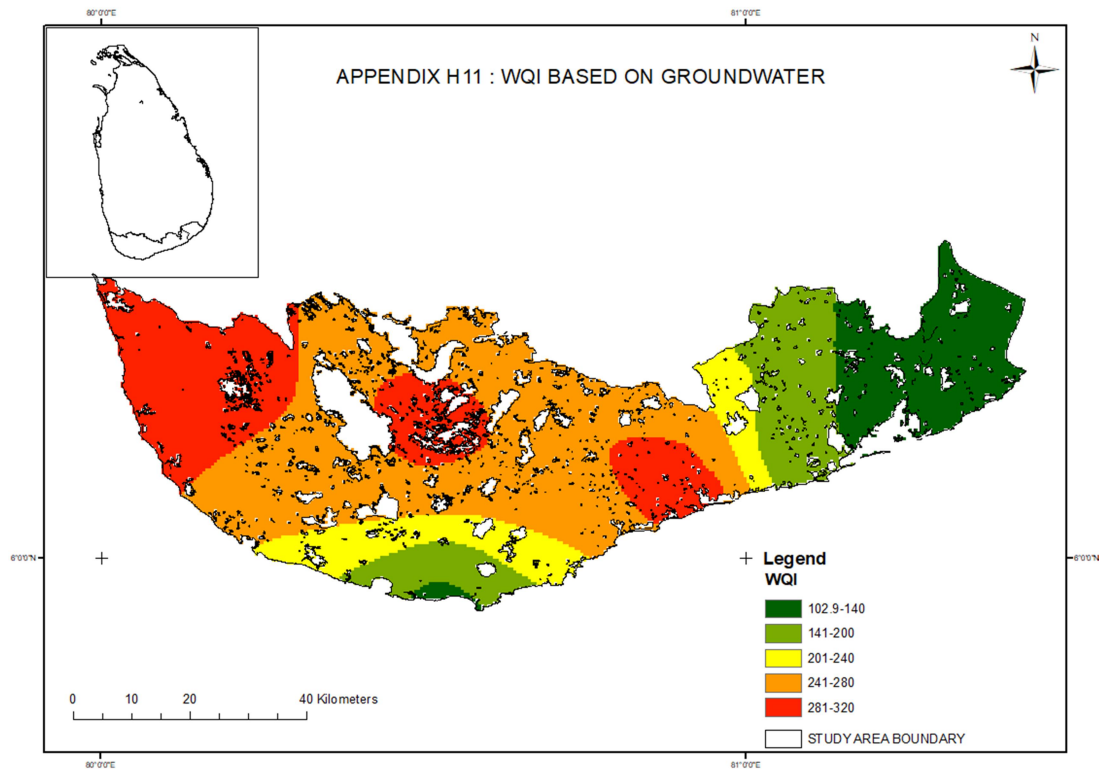


Figure 4.15 WQI based on Groundwater

Finally, the population equivalent for each water-use practice was prepared on a GN division basis. The equivalent WQI was prepared as the following equation. The calculation for each GN division is shown in Appendix H12.

$$WQI_e = (WQI_{OTHER} * N_{OTHER} + WQI_{NWSDB} * N_{NWSDB}) / N_{Tot} \quad (10)$$

The calculation for each GN division is shown in Appendix H12.

Based on above equation, equivalent water quality Index for Southern region was demarcated as below;

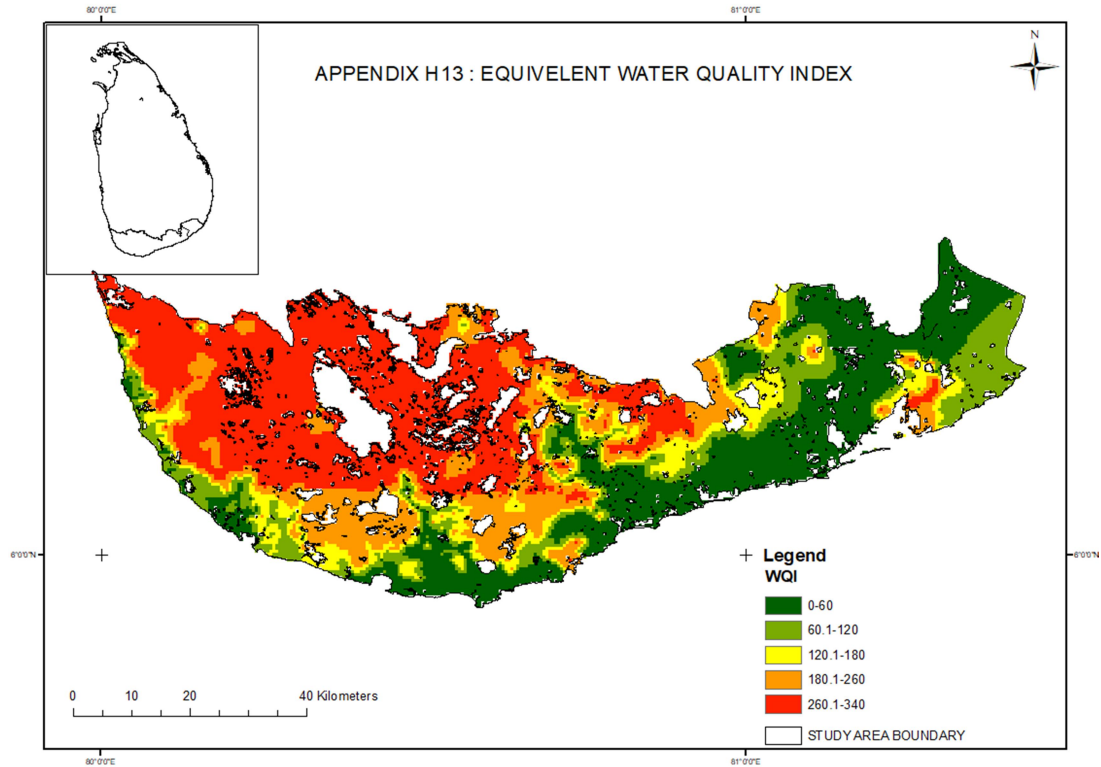


Figure 4.16 Equivalent WQI

4.2.3 Relative Water Balance (RWB)

To prepare an indicator for water resource availability, first and foremost, Rainfall surplus (S_p) was required to be calculated as per equation 3.8. To figure out the spatial distribution of rainfall surplus. Following datasets are required to be prepared; 1. Average annual rainfall 2. Evapotranspiration.

$$S_p = P - ET_{act} \quad (14)$$

4.2.3.1 Average Annual rainfall (P)

In Sri Lankan Context, the rainfall data is recorded by the Meteorological Department with the aid of data collected by 487 No of rainfall gauging stations located with island-wide coverage. The data is recorded daily and the data is stored

within their national database. Rainfall is measured daily at 08.30 hours at these stations and the daily rainfall report is obtained by the Department at the end of the month for processing. Data from 210 stations selected island-wide are obtained daily by telephone to be used for weather forecasting 20 telemeter rain gauges are deployed at rural and rainy areas. Half-hourly data are received via SMS. Based on the data produced by rainfall stations, the MD prepared the spatial distribution of Average annual rainfall as below;

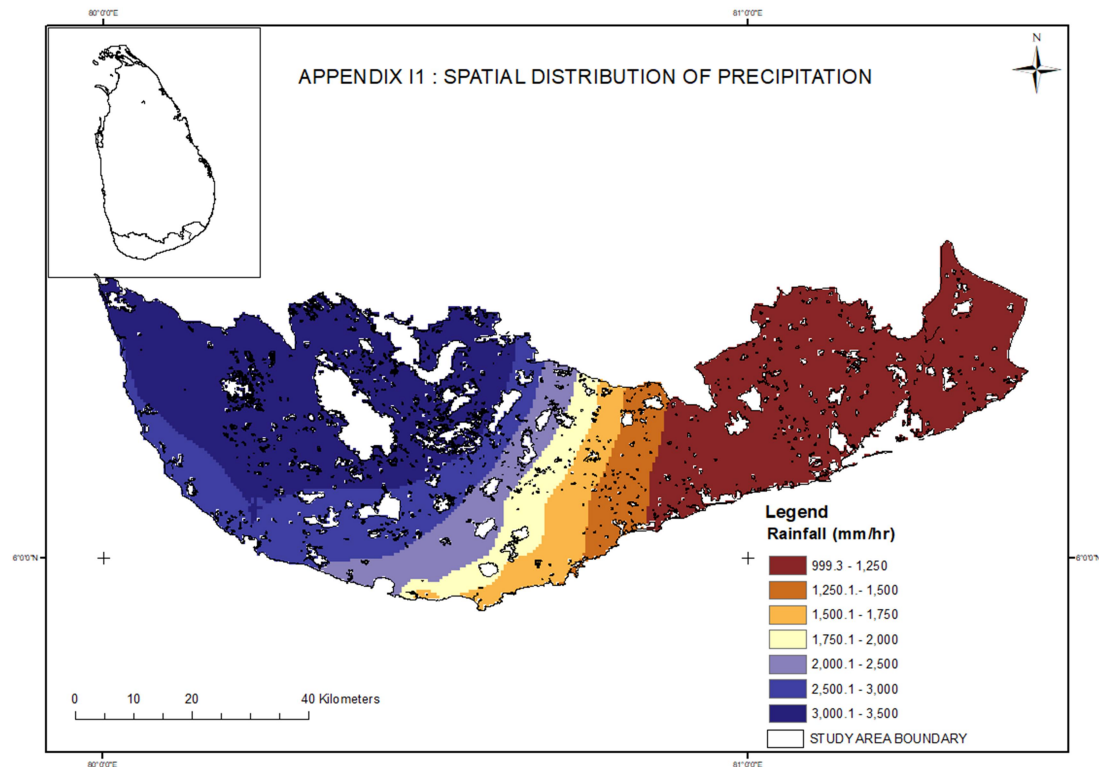


Figure 4.17 Spatial Distribution of Precipitation

4.2.3.2 Evapotranspiration (ETact)

Evaporation figures in this calculation are based on the actual evaporation statistics documented by Chandrapala and Wimalasuriya (2003). The computation of evaporation is relied on NOAA-AVHRR satellite data using the Surface energy Balance Algorithm for land (SEBAL). Spatial Distribution of Evaporation is shown in Appendix D and reconstructed for the research scope as per Appendix I2.

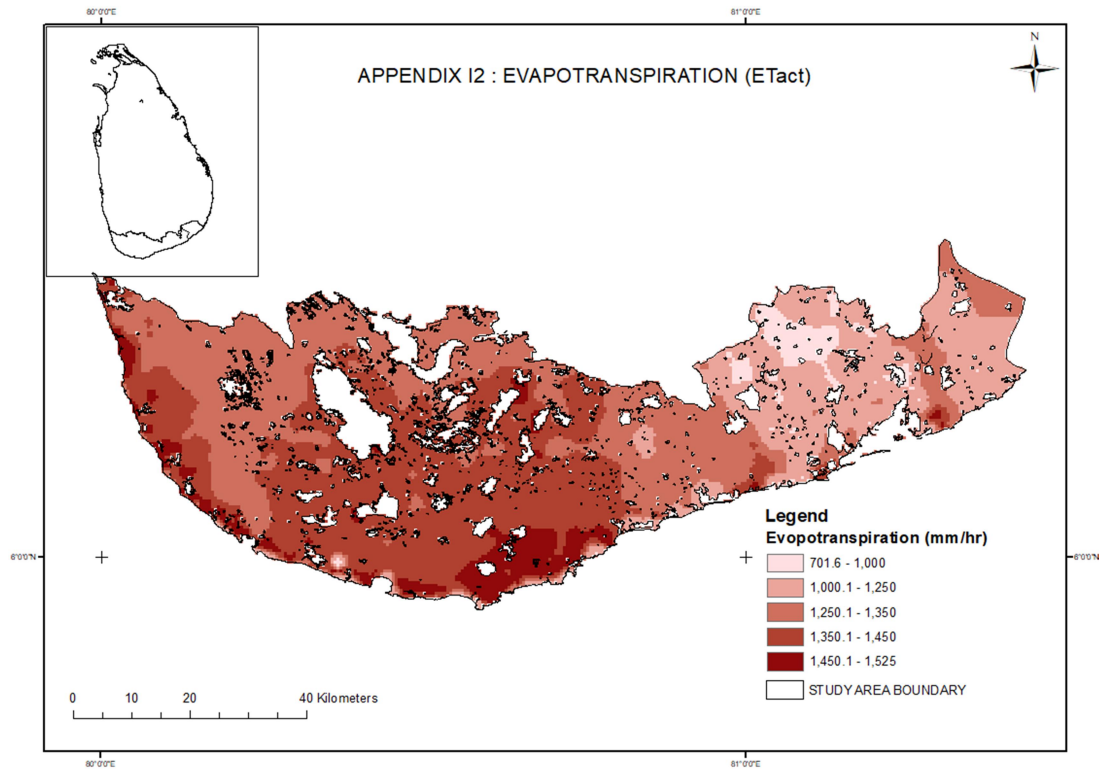


Figure 4.18 Evapotranspiration (ETact)

By using the above two layers (datasets): Average Annual rainfall and Evapotranspiration, Rainfall surplus for the study area was calculated using a raster calculator.

The output of the raster calculator tool available with the ArcGIS facility is as below;

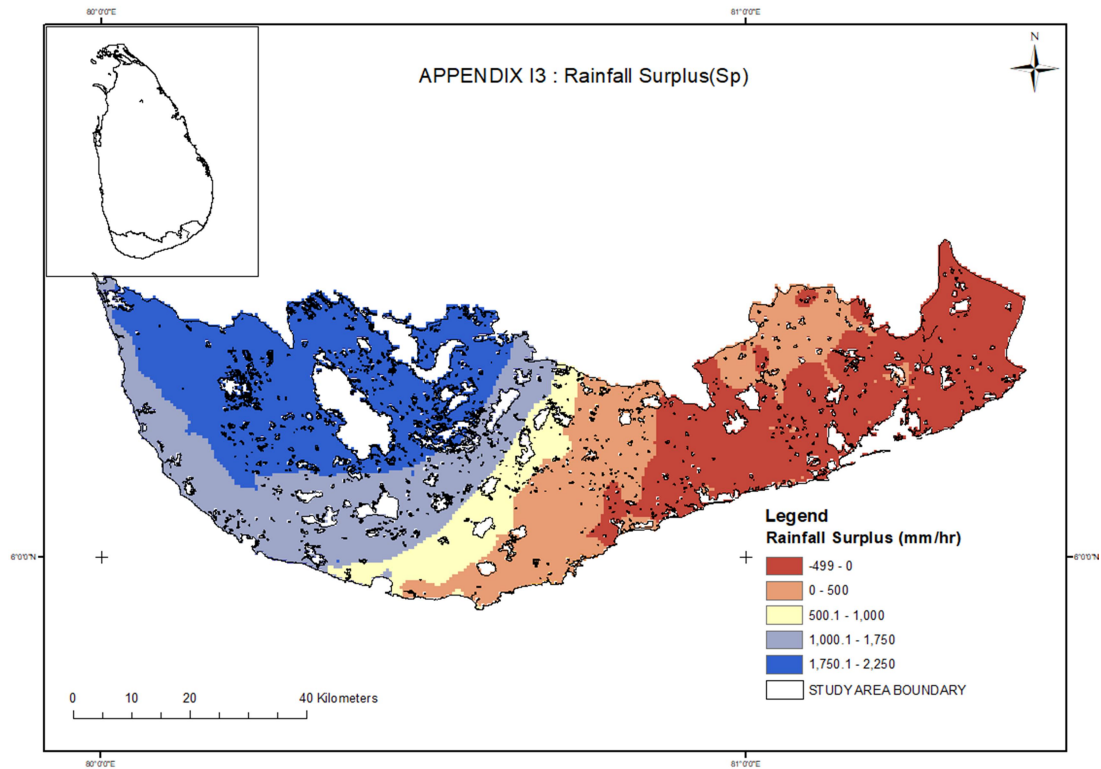


Figure 4.19 Rainfall Surplus

4.2.3.3 River Inflow in to Study area

Whilst the consideration of Water balances of the Study area, there are three river inflows across the scope boundary. These rivers can be identified as Walawe Ganga, Kirindi Oya and Manik Ganga. The respective pour points of 3 rivers are Embilipitiya, Thanamalvila and Kataragama. Surface runoff coefficients of respective catchments were obtained from the research work carried out by Bastiensen et al. (2003). Q_{in} at each point is calculated as below;

Table 4.4 River inflow in to Study area

River	Pour point	Upper Catchment (A,Km ²)	Avg. Pre(mm)	Surface runoff Coefficient	Q_{in} (MCM/Year)	Downstream area (Km ²)	Equivalent precipitation (mm)
Manik	Kataragama	770.7	1558	22.3	267.7	432.9	618
Walawe	Embilipitiya	2207.1	1861	28.6	1174.7	305.4	3847
Kirindi Oya	Thanamalwila	868.9	1587	23.2	319.9	210.4	1520

Accordingly, the equivalent water volume stemming from the Upper catchment river flow is equally distributed among the downstream area. The spatial distribution of river inflow is shown as below;

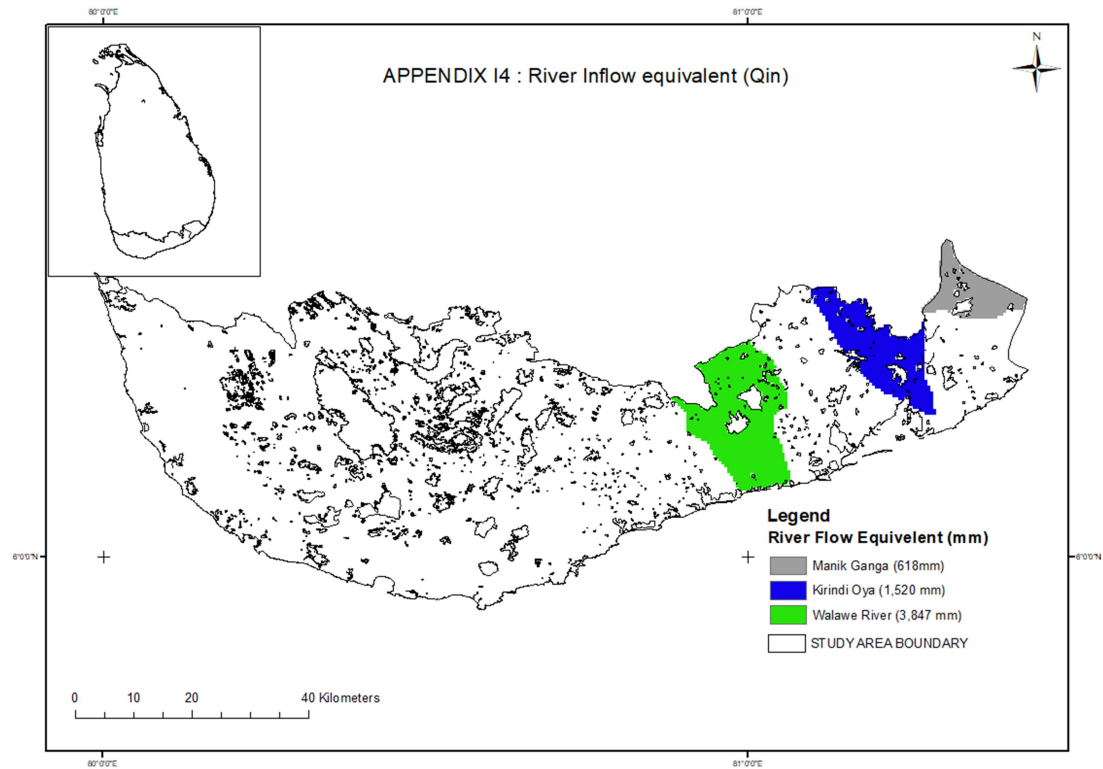


Figure 4. 20 River flow equivalent (Q_{in})

4.2.3.4 Water balance of the Study area

Water balance of the study area was computed by summing Rainfall surplus and Equivalent river inflow as below;

$$Q_{\text{total}} = (S_p + Q_{\text{IN}})$$

Two prepared raster; Rainfall surplus and Equivalent River inflow were added using raster calculator as below;

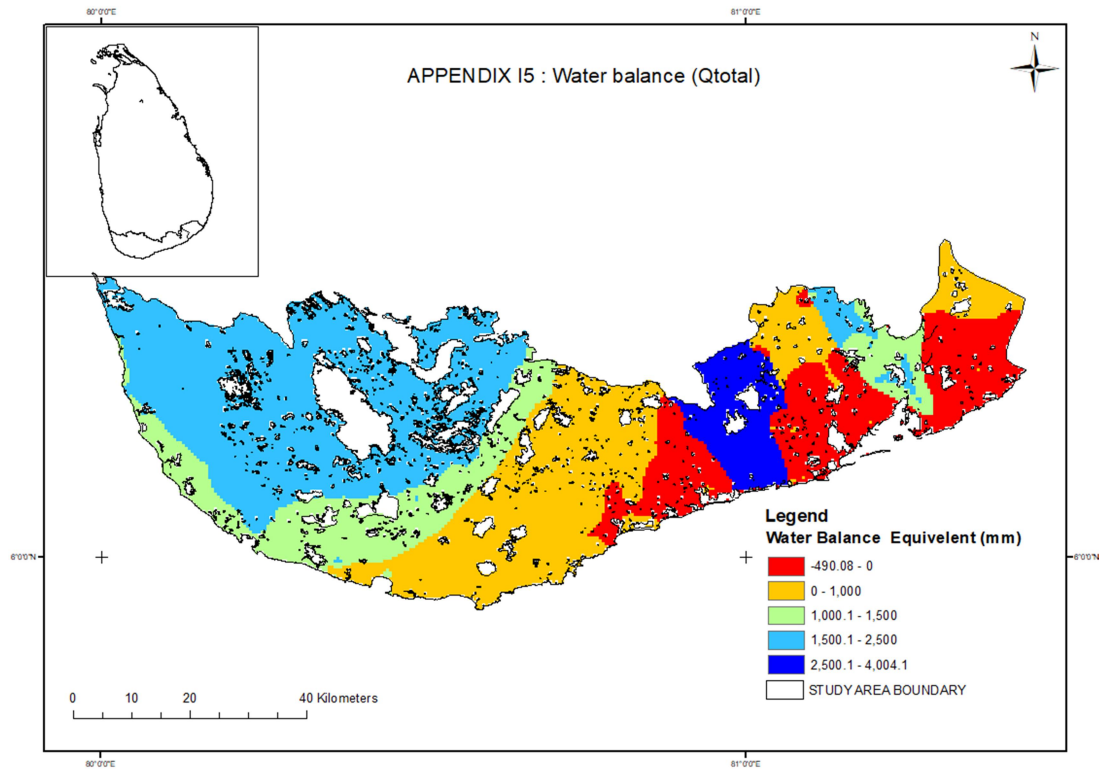


Figure 4.21 Water balance equivalent

4.2.3.5 Agricultural Water Demand (D_A)

The crop water demand of the region is interpreted in terms of evaporation rate. The major type of crops available within the study area can be identified as Paddy, Rubber, Tea, Coconut and mixed crops such as chena cultivation. The spatial distribution of such land use has been demarcated as land parcels by the Department of Survey. Crop water requirement in terms of evaporation is interpreted by Chandrapala and Wimalasuriya (2003), and the figures published by them are used in this research to figure out the Crop water demand. Before the modelling of Agricultural water demand, the spatial distribution of crops was demarcated as follows;

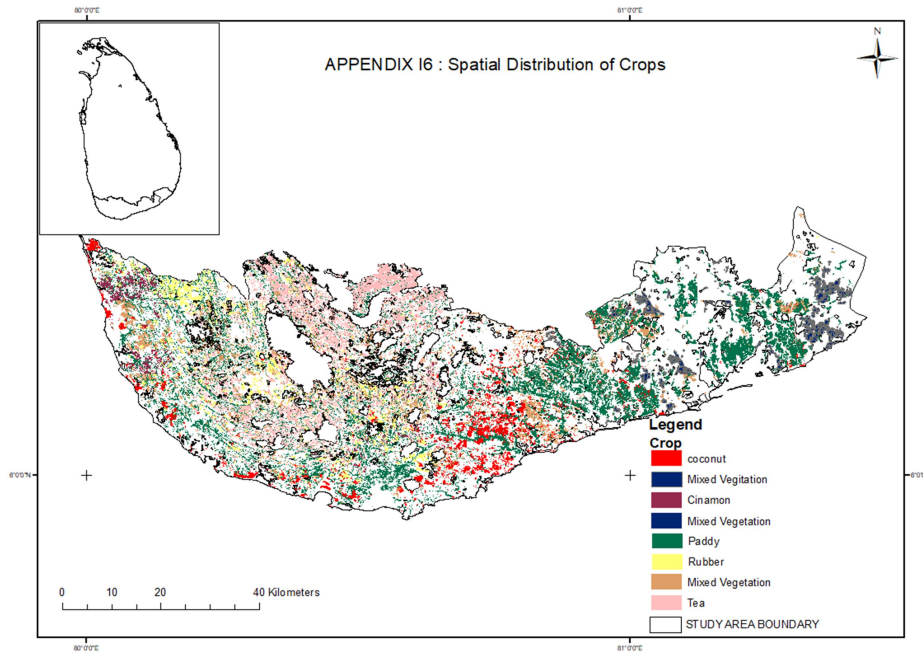


Figure 4.22 Spatial Distribution of Crops

Based on the evaporation rates, the crop water demand is projected (500m *500 m) as below;

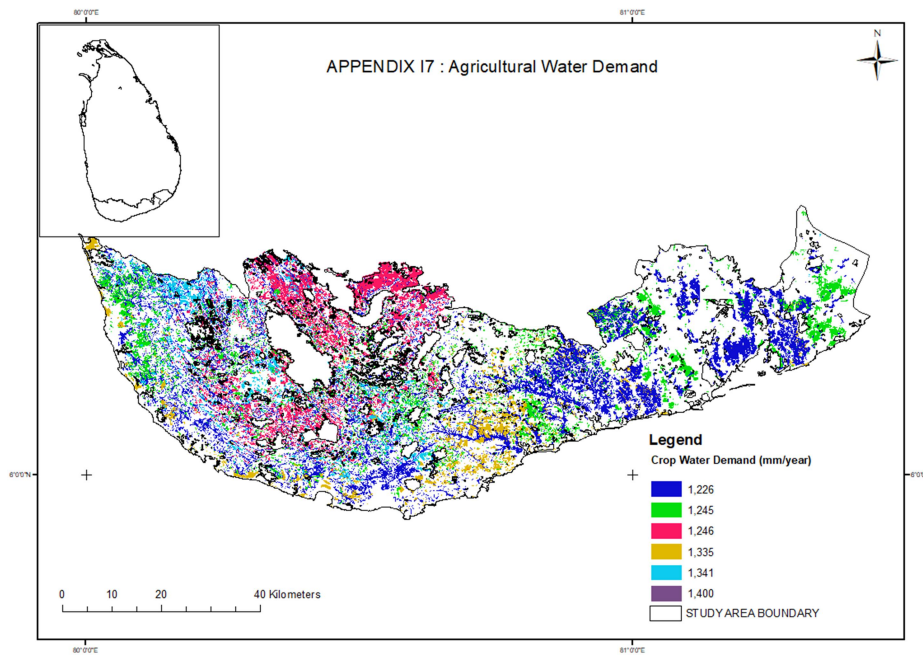


Figure 4.23 Domestic and Industrial Demand

4.2.3.6 Domestic and Industrial Water Demand

Domestic demand of the study area in the mesh with a cell size 500 m* 500 m was prepared based on the previously prepared Population density map with the same grid. To prepare the demand, the per capita consumption was taken as 100 litres per person per day to simplify the process. Accordingly, the domestic demand was built up to sum the annual demand. It was assumed that the industrial demand is 30% of total demand. By using a raster calculator, the domestic and Industrial demand was demarcated as below;

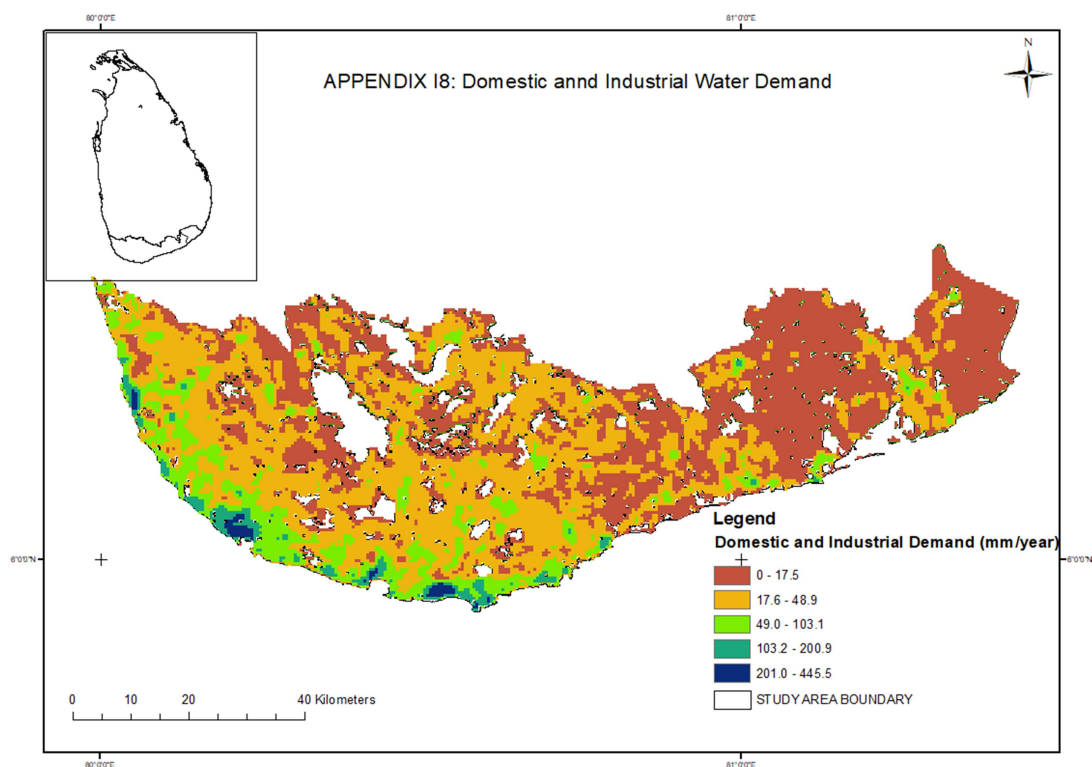


Figure 4. 24 Domestic and Industrial Demand

Withdrawals = Domestic and Industrial Water Demand + Agricultural water Demand

The total extraction value for each cell with a magnitude of (500 × 500) was demarcated by adding two rasters.

1. Domestic and Industrial Demand (mm/year)
2. Agricultural Demand (mm/Year)

The total Water Extraction map is as below;

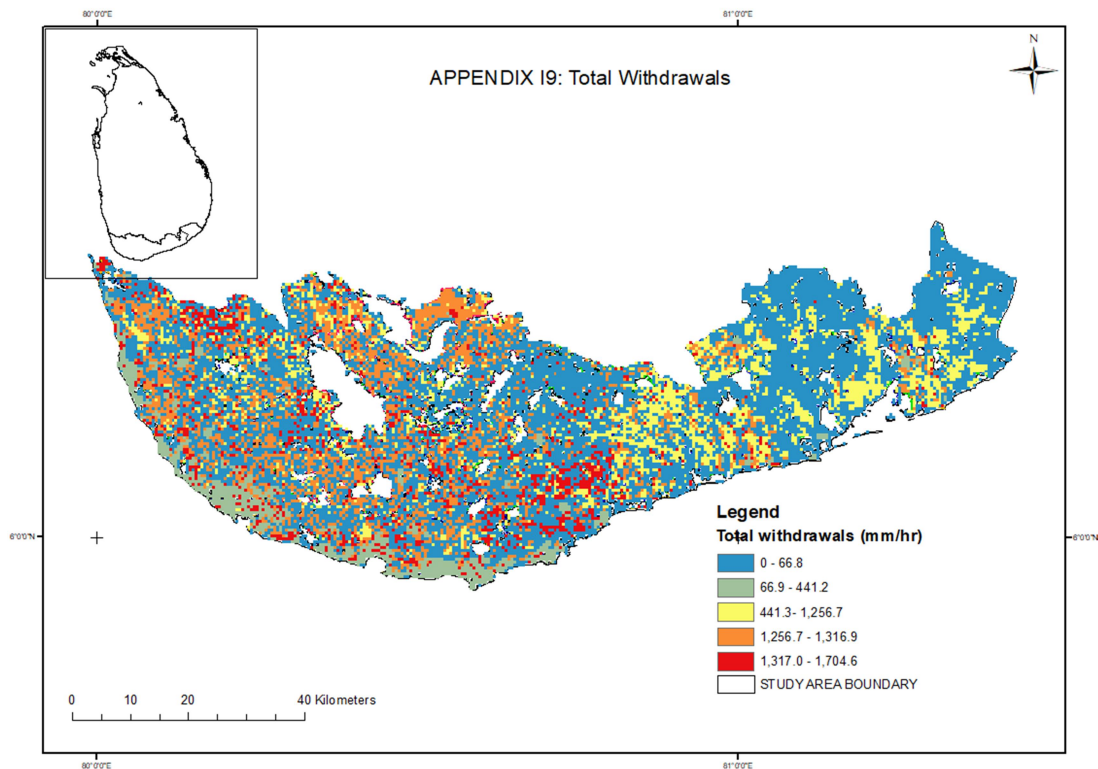


Figure 4.25 Total Withdrawals

Relative Water Balance = Rainfall surplus + River Inflow – Total Withdrawals

Relative Water balance (RWB) was used to quantify the degree of Water resources availability .Hence by using raster calculator tool, above equation was built up and RWB map is shown as below;

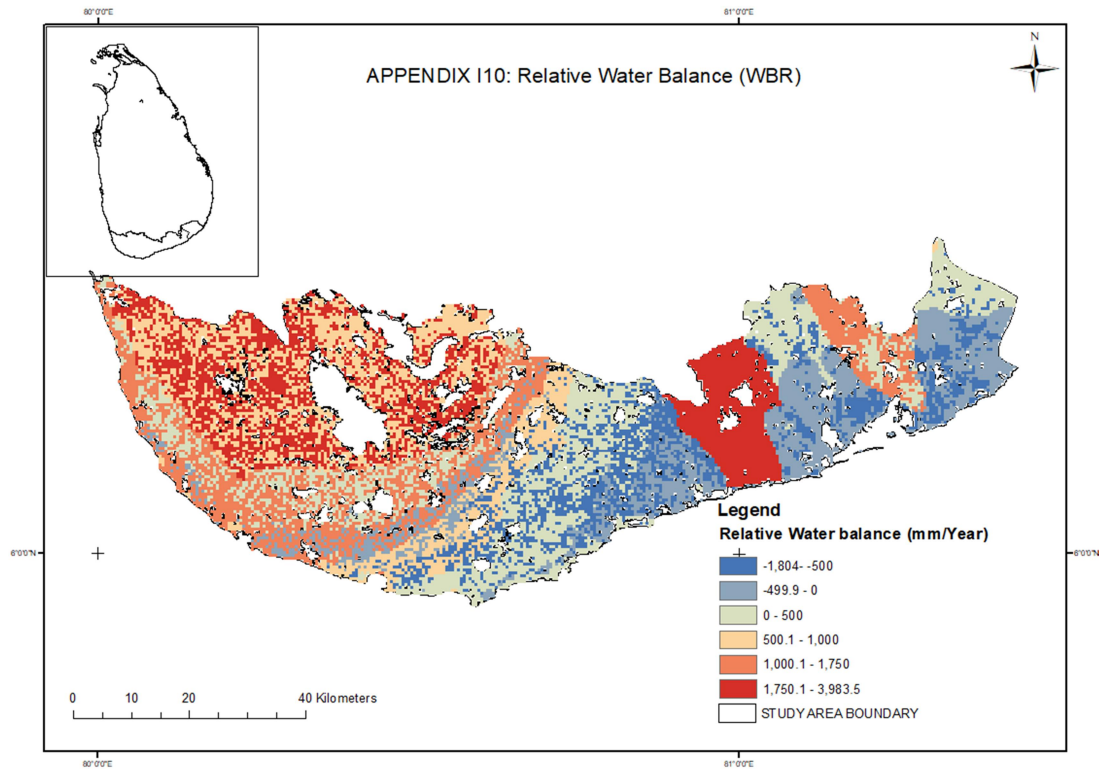


Figure 4.26 Relative water Balance

4.2.4 New Development

New development viable within scope area is projected by National Physical Planning Department by its National Physical Plan - 2050. As per the direction provided by the said plan, the population pressure owing to new development was taken as the indicator of the spatial distribution of the impact of new development. As mentioned in section 3.2.4, the growth rates attributed to each development corridor and metro region are mentioned as below;

Metro Region	Expected population Growth rate (%)
Galle	0.6
Matara	1.1
Hambantota	1.9
Ambilipitiya	1.3
Tangalle-Beliaththa	1.5
Thissa-Katargama	0.4

The affected zones of such developments are mapped in Appendix D. Additional population pressure induced from upcoming development is shown as below.

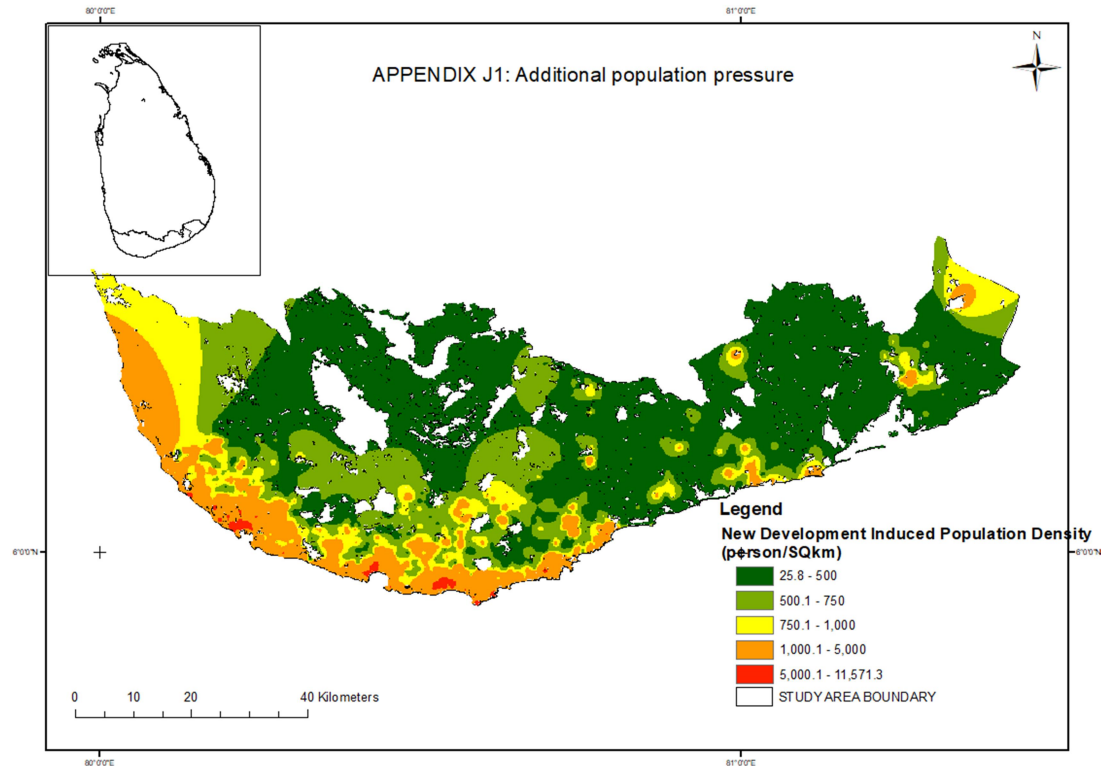


Figure 4.27 Additional Population Pressure

4.3. Standardized Index result visualization based on GIS

As stated in Section 3.4, Standardization was carried out for all criteria to scale into a common measurable and comparable state. Scores were allocated based on the degree of impact on the prioritization of Water Supply need. Hence, all four criteria are standardized by giving a Standardized score between 0 to 1 as follows.

4.3.1 Population Density

Since, the impact of population density towards prioritization rises with the magnitude of Population Density. Hence, highly dense areas were given high standardized score as follows;

$$\text{Standardized Score, } X_i = \frac{(\text{Raw score} - \text{Minimum Pop Density})}{(\text{Maximum pop Density} - \text{Minimum pop Density})}$$

Thus,

$$X_i = (R_i - pd_{min}) / (pd_{max} - pd_{min}) \quad (25)$$

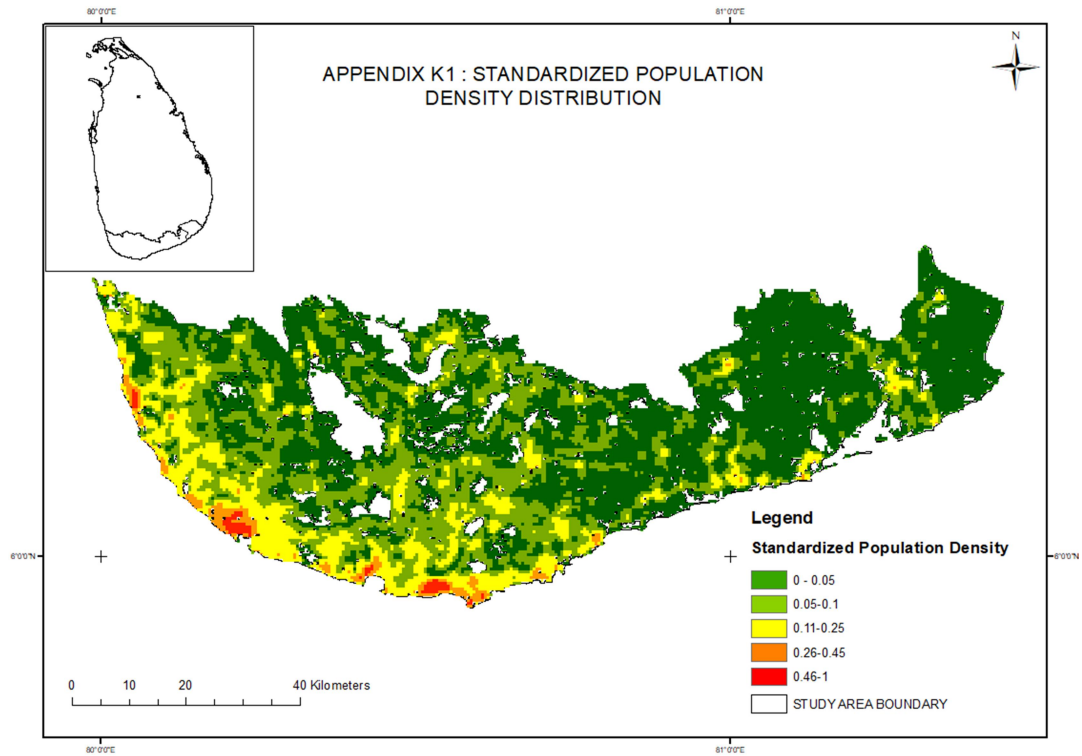


Figure 4.28 Standardized Population Density Distribution

4.3.2 Equivalent Water Quality Index

The scale for equivalent water Quality Index (EWQI) indicates best to worst in a vice versa manner. The minimum value of EWQI gives the best Water Quality and the Maximum value of EWQI gives the worse Water Quality. In other terms, Low water quality indicating high WQI values should offer high value in prioritization.

Hence, to represent such change, the following equation was adopted;

$$X_{EWQI} = (R_{EWQI} - WQI_{min}) / (WQI_{max} - WQI_{min}) \quad (26)$$

Standardized maps are shown as below.

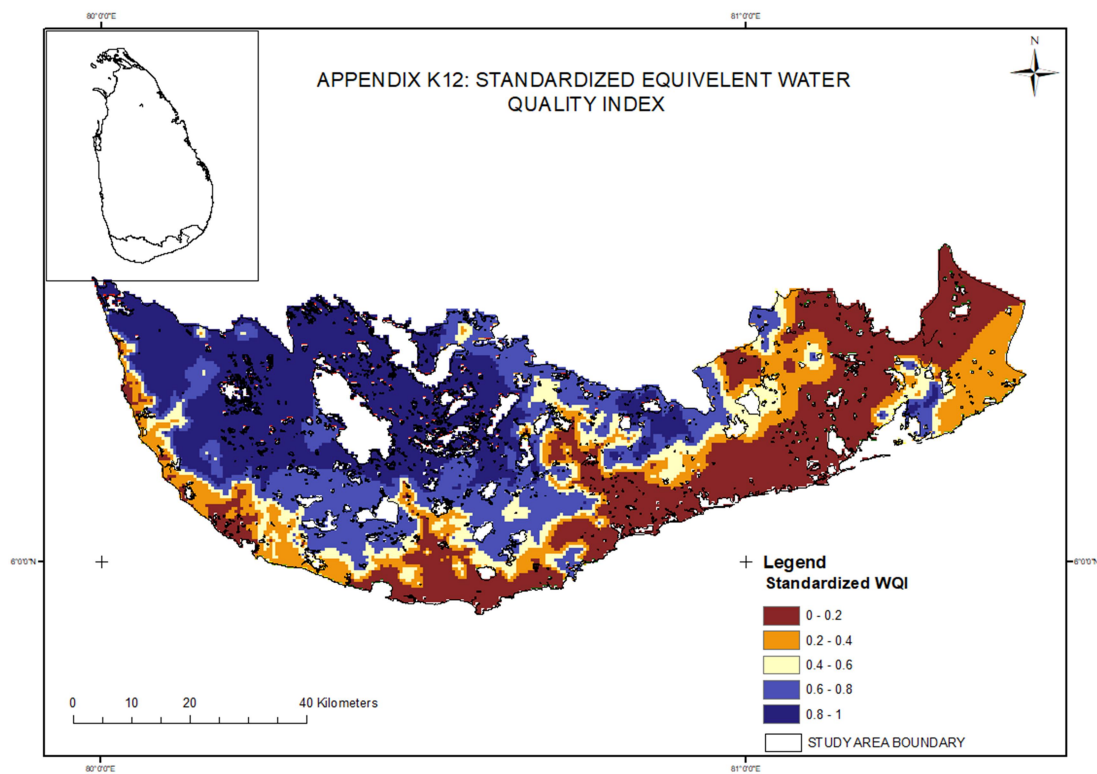


Figure 4. 29 Standardized Equivalent Water Quality Index

4.3.3 Relative Water Balance

Additional Surplus in relative water balance indicates less water stress level and a higher degree of water resources availability. Hence, the availability of higher RWB means less priority in ranking Water needs. The following equation was adopted to figure out the standardized scores for RWB;

$$X_{RWB} = (R_{RWB} - RWB_{min}) / (RWB_{max} - RWB_{min}) \quad (27)$$

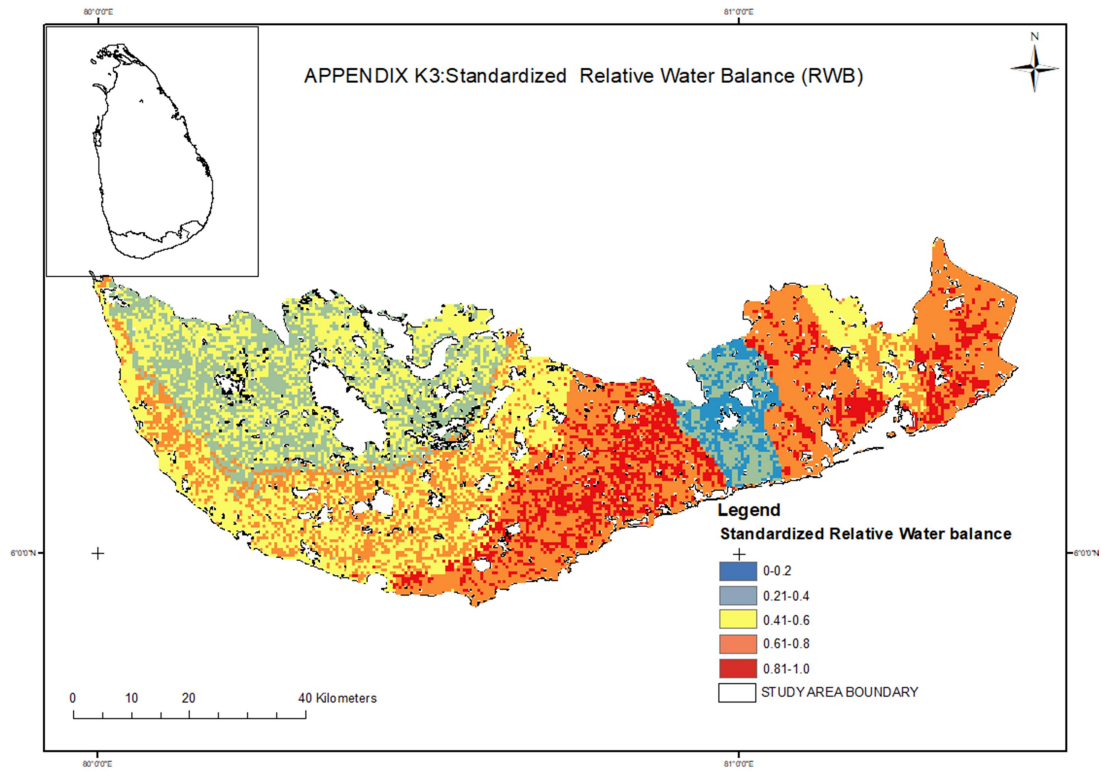


Figure 4.30 Standardized Relative Water balance (RWB)

4.3.4 New Development

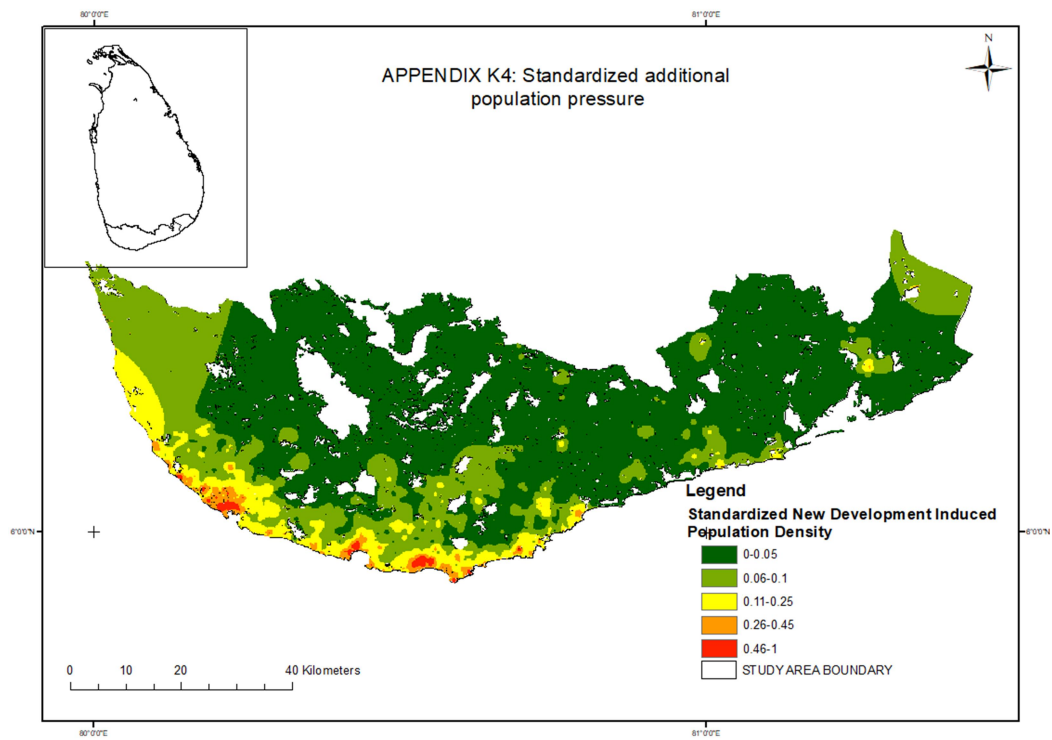


Figure 4.31 Standardized new Development induced Population Density

4.4 Results of GIS-MCDA Prioritization model

As stated in Section 3.4, the weighting of four criteria was carried out using pairwise comparison method. The nominated weightages are as below;

Table 4.5 Weightages assigned to criterions

	Population Density	EWQI	RWB	New Development	Weights
Population Density	1	1/7	1/9	1	0.07
EWQI	7	1	1	7	0.39
RWB	9	7/9	1	9	0.47
New Development	1	1/7	1/9	1	0.07

As stated in Section 3.4, weighted linear combination (WLC); also known as simple additive weighting is selected. This approach multiplies normalized criteria scores by relative criteria weights for each alternative (Greene 2011). With WLC, the final suitability map S is derived by multiplying each factor by its relative weight followed by the summation of the results.,

$$S = \sum w_i x_i \quad (7)$$

By using above mentioned weightages, 4 prepared rasters for each criterion were added using raster calculator tool.

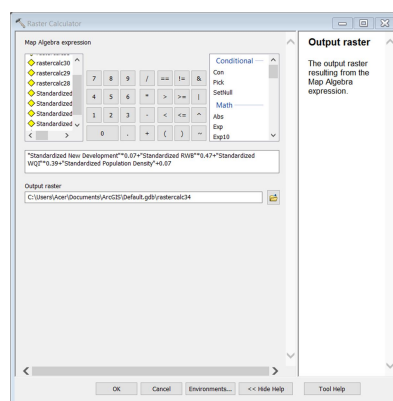


Figure 4.32 Raster calculator tool

The aggregated raster for the GIS-MCDA Prioritization model is as below;

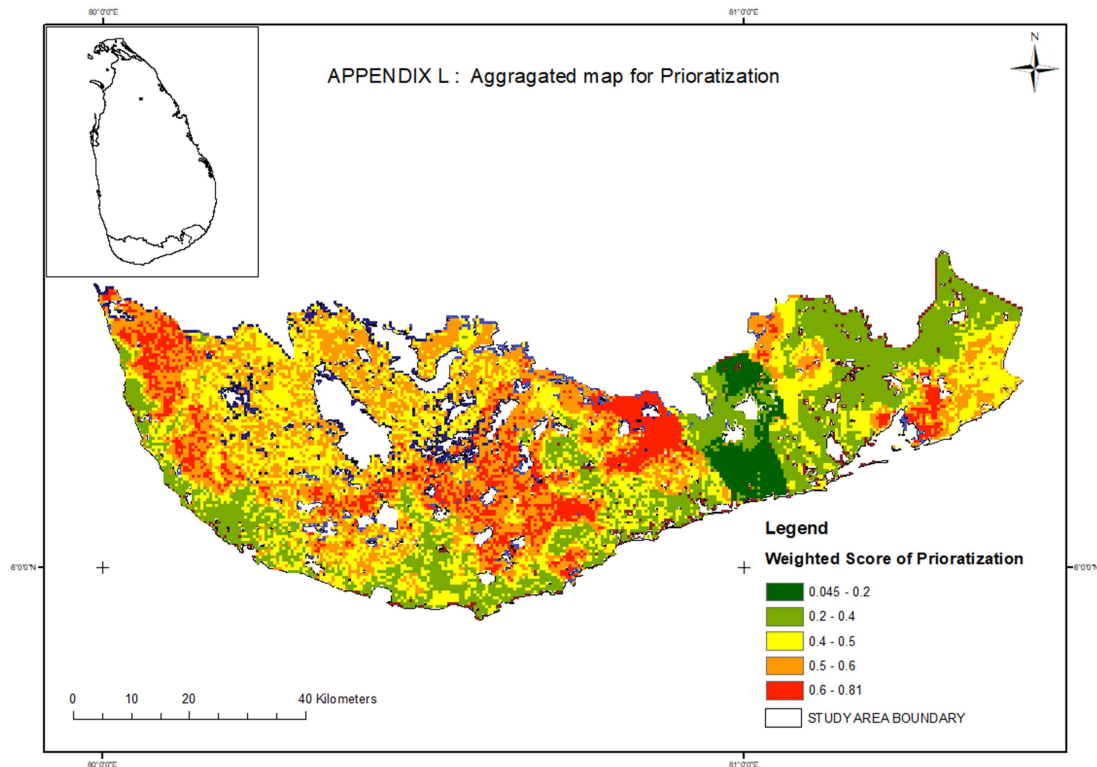


Figure 4.33 Weighted Score of Prioritization

4.5 Discussion

The 2,131 Grama Niladhari Divisions of Southern province and Katharagama DS division (divided into 16,977 number of 500 m × 500 m cells) were selected to determine the degree of Water supply need. We developed GIS tools to aid decision-makers throughout the Water Supply sector in identifying the prioritized areas to target new water supply schemes/extensions. Cells with higher aggregated prioritization value may be relatively suitable for the provision of Drinking Water Supply. This is an example to apply at any condition when a large number of sites need to be evaluated. We identified the top prioritized cells fallen into an aggregated weighted score of 0.6 - 0.81 (2235 of 16,777 potential cells) that could be attended first for supplying Drinking Water facilities (Appendix K). Further, standardized parameter scores could be compared among already proposed water supply project areas to identify the prioritization order of the projects.

Histogram of Prioritization index is shown as below;

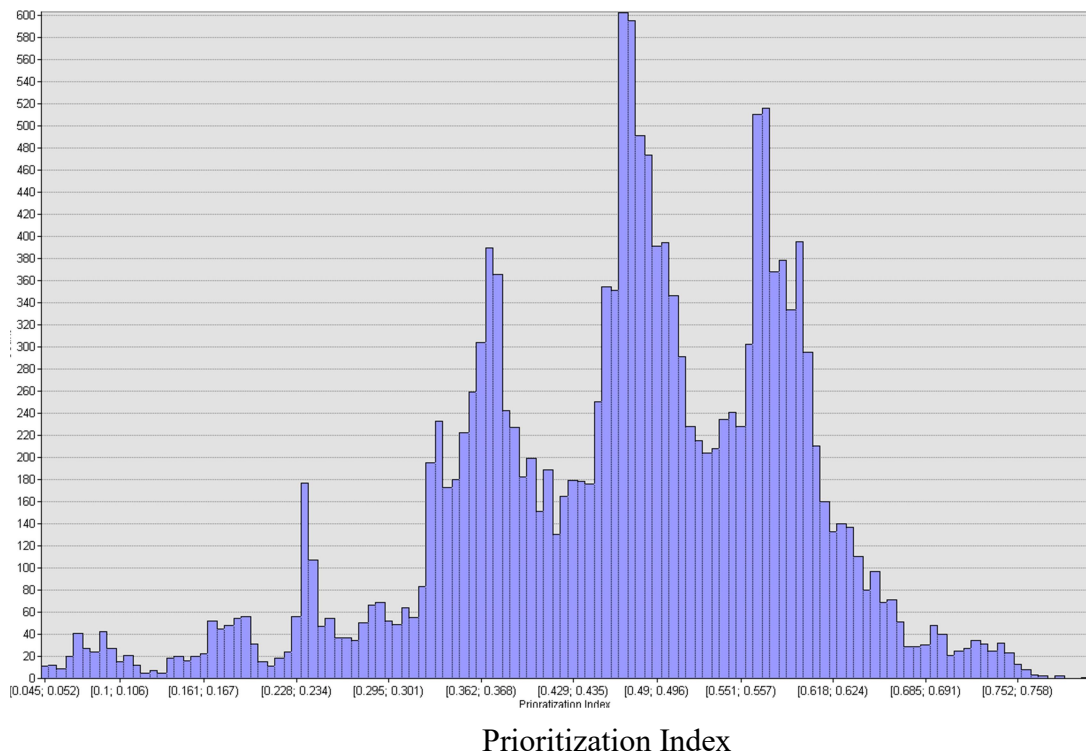


Figure 4.34 Prioritized rankings of 16,777 cells.

Cell ranks were determined by applying a weighted summation of standardized parameter scores. Ranks range from 0.045 to 0.81 on a scale of 0 to 1. The top and bottom-ranked 10% of prioritized cells are shown in pink and red colours respectively in figure 4.34.

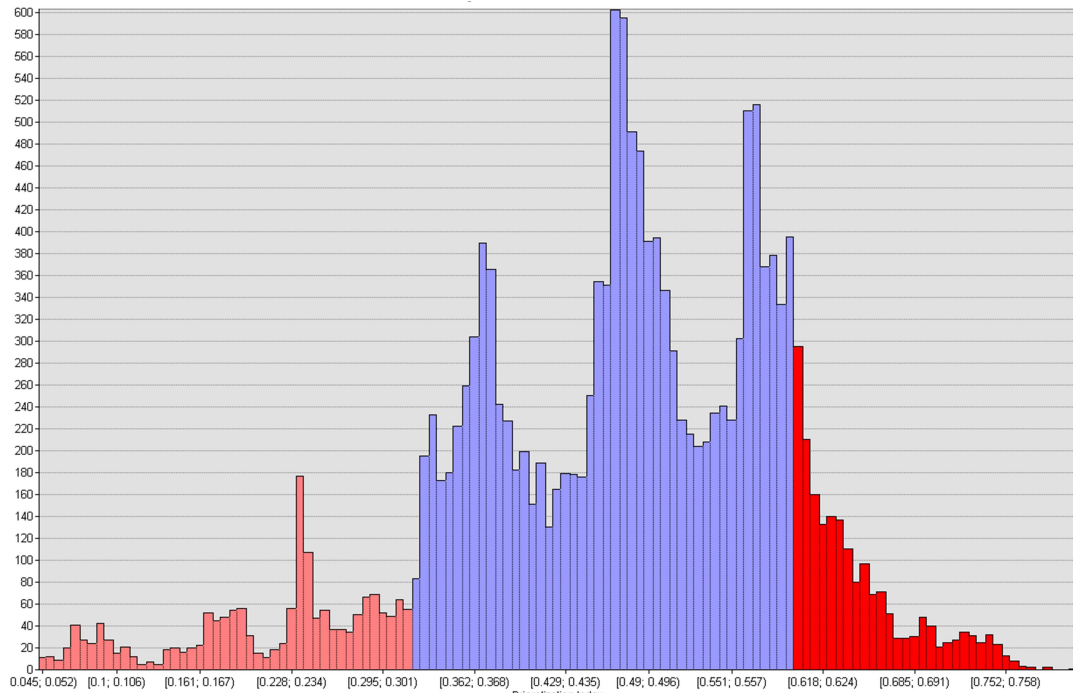


Figure 4.35 Bottom and Top deciles of the distribution

Rankings represent relative levels of Water Supply need. Higher scores indicate higher Water Supply need.

It is remarkably noted that the existing NWSDB fed areas are fallen into less prioritized zones in terms of existing Water needs. These zones are holding the prioritization value varying from 0.045 to 0.758 with a standard deviation of 0.117 and the mean value of the data set is 0.39. Hence, it indicates that the degree of prioritization has been lessened in NWSDB fed areas. Amid the ever-rising population density and possible new development, NWSDB has been achieved a good level of service to quench the dire demand within their coverage area.

Histogram pertained to Prioritization ranking of NWSDB fed areas is as below;

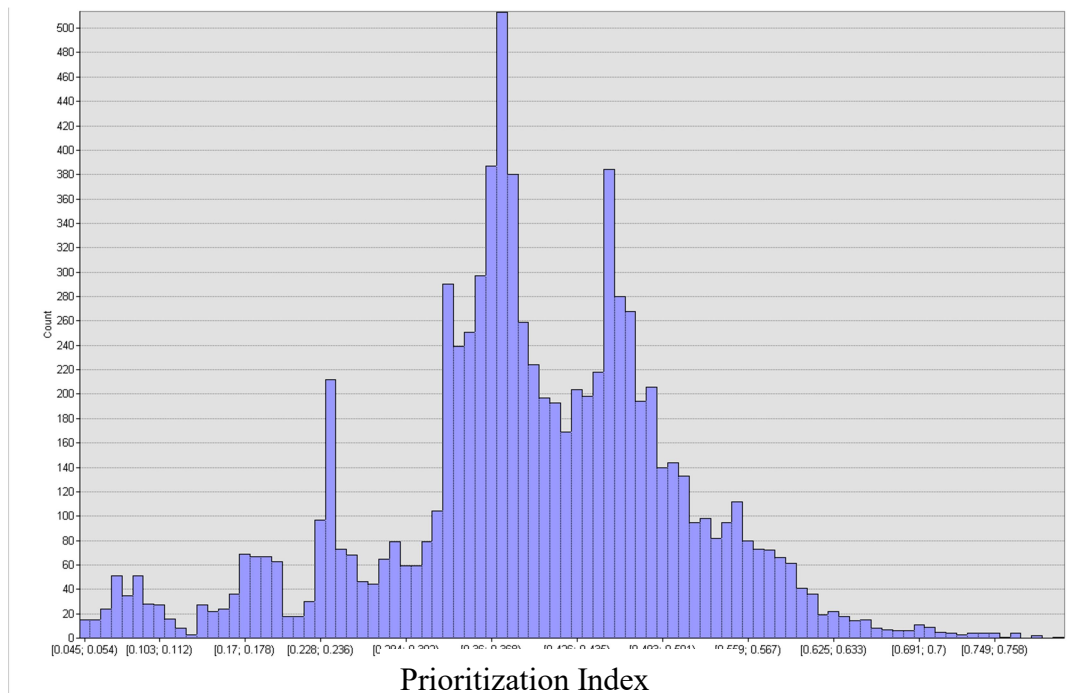


Figure 4.36 Prioritization Index Distribution of NWSDB fed areas

However, the number of cells (NWSDB fed) higher than 0.6 is 245 which is 1.44% of the total number of cells of the study area. It can be found that the most of above outliers are located as clusters namely; Kirinda, Bundala, Thissamaharama, Urubokka and Agunukolapalassa. The significant common attribute of all the above patches is the seasonally degraded water quality provided. Hence, the urgent improvement required in water quality improvement can be recognized through the clustered high prioritized zones. Further, the rest of the high prioritized NWSDB fed areas are located at the boundary of each scheme. Under the shade of other water use practices, the prioritization of such cells has been increased. To mitigate such a situation, the extension of NWSDB distribution is hereby proposed. Hence, the urgent extension requirements can be identified by filtering these isolated high prioritized patches.

While introspecting the criteria, it is observed that the highest population density slab is covered by NWSDB. The 1,362,673 of the population is covered by NWSDB which is 55.6% of the total population. However, the weightage on population

density (0.07) does not impact the final prioritization value compared to other criteria. Correlation of criteria.

Table 4. 6 Covariance and Correlation Matrix of criterions

Layer	MEAN	STD
Standardized Population density	0.0625	0.0723
Standardized Water Quality Index	0.5136	0.3036
Standardized Relative water balance	0.5685	0.2009
Standardized new Developments	0.0536	0.0583

COVARIANCE MATRIX				
Layer	1	2	3	4
1	0.00236	-0.00110	-0.00042	0.00158
2	-0.00110	0.04152	-0.00798	-0.00124
3	-0.00042	-0.00798	0.01723	-0.00013
4	0.00158	-0.00124	-0.00013	0.00152

CORRELATION MATRIX				
Layer	1	2	3	4
1	1.00000	-0.11158	-0.06597	0.83574
2	-0.11158	1.00000	-0.29851	-0.15650
3	-0.06597	-0.29851	1.00000	-0.02492
4	0.83574	-0.15650	-0.02492	1.00000

As per the visual representation of Standardized population density (Appendix K1), it is noted that the population density of the research area is not correlated with existing water quality entertained. By using the band collection statistics tools, the

received correlation coefficient is 0.11. In other words, the agglomeration of the population does not show a strong relationship with the spatial distribution of Standardized WQI.

Population pressure has been incurred due to the internal migration, and the excess population within the specific regions such as Pitabeddara, Kotapola and Deniyaya (Along A24 road) were unable to meet up their palatable water requirement. Since the demand centres with more liveable conditions are located away from areas where good water quality is being entertained.

This situation has been created a new potential in supplying palatable water to agglomerated areas where new water supply projects are required in terms of high demand for good quality water.

Further, it is revealed by Appendix G2, the population from Aluthgama to Tangalle is concentrated in the coastal belt. The majority of the remainder have agglomerated along the major roads and the rest have settled over the study area in a scattered manner. Most of the dense areas are already covered by NWSDB except the isolated urban patches such as Middeniya, Kirinda Puhulwella and Deyyandara.

When it comes to the comparison with Relative Water balance, population density has no significant relationship with RWB (Correlation Coefficient = -0.0659). It indicates that the general public has given less priority to water resources availability to decide where to settle.

On the other hand, the new developments in the study area have a strong relationship with the existing population density. The correlation coefficient is 0.83574. The new development was considered as a secondary derivative of population density, and the placement of development hubs aligned with the present population density hotspots. Further, the gained results were evaluated against the already prepared norms by NWSDB; the guideline for prioritization of drinking water supply projects as shown in Appendix N.

The criteria of NWSDB guideline can be summarized as below;

Table 4.7 NWSDB prioritization criteria

NWSDB Guideline	Given marks	Relevant Research criteria	Relative importance as per	
			NWSDB Guideline	Research criteria
Population density	10	Population density	0.3	0.07
New Development	8	New Development	0.24	0.07
Quality of Water	5	Water Quality	0.15	0.39
Alternative Water Sources	5	Water resource	0.3	0.47
Average Annual Rainfall	5	Availability		

It is evident that the weights given by NWSDB are contradictory to the research output. Since the perspective of NWSDB is not limited to serving the nation as a welfare service, it is intended to gain some of the profit by addressing highly dense populated areas. Consequently, the weightage for population density and new development was the dominant parameter in NWSDB prioritization.

Model builder facility provides transparent and flexible GIS analysis methods. It will prepare the platform to build up prioritization zones for other regions of Sri Lanka. However, the facility is available for customising the weightage for each criterion to suit local conditions. The Automation techniques proposed through the model builder detail the workflow of spatial analysis and provide specific geoprocessing methods to perform the analysis. When models are accessed via the interactive flowchart (Fig.3.5), input datasets and explicit geoprocessing tasks are available for user review, modification, and editing. Setting model parameters allows for use of variable input datasets, setting user-defined thresholds such as buffer distances, and the ability to modify how an input dataset is evaluated. End users have the information needed to evaluate if an analysis is sufficient to meet their needs, the flexibility to make changes if desired, and automated execution of the calculations.

4.6 Summary

A real case study was conducted by deploying the GIS-MCDA approach in the prioritization of Water Supply need in Southern province. A comparison and analysis between the criteria showed that the water scarcity and the water quality are undoubtedly vital and significant due to impact on the existing level of service of habitats, especially towards the final view on water supply need. It revealed that both NWSDB fed areas and other areas excluding NWSDB supply demand for drinking water. In clustering the high prioritized areas, the identified clusters are Kirinda-Bundala, Angunukolapalassa-Middeniya, Hakmana-Beliaththa, Deyyandara -Kaburupitiya and Baddegama -Karandeniya- Benthota.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusions

This thesis was tabled to build up a methodology abbreviated as GIS-MCDA of prioritization of drinking water need which includes the assessment of demography, drinking water quality, Water scarcity and Future development to project actual drinking water requirements.

GIS-MCDA of prioritization of drinking water need was carried out with the aid of GIS and vivid array of databases namely; demography data of census conducted in 2012, GIS data of Survey Department, Periodical treated water quality data produced by NWSDB, Groundwater quality data, Annual rainfall data from Meteorological Department, Evapotranspiration data, River flow data of gauging stations from Irrigation department and Planning data from National Physical Planning Department.

The methodology was applied for 2131 Grama Niladhari divisions in Southern Province and Kataragama Divisional Secretariat where the habitable land extent of the region was divided into 16,977 cells with a magnitude of 500 m × 500 m.

In this context, research was equipped with five research objectives namely; building up spatial distribution of 1. Current population density 2. Equivalent Water Quality Index 3. Relative water Balance 4. Population Index from New Development and 5. Prioritized drinking water needs.

As the first segment of the research, the spatial distribution of current population density revealed following significant indicators.

1. Agglomerating through the coastal area

It was noticed that all cells of the standardized population density from 0.45-1 was located along the coastal belt of the southern province. Either the highest slab (0.45-1) or the second-highest slab (0.26-0.44) belonged to 3 km buffer zone from the coastal belt.

2. Agglomerating along the main roads

It was quite evident that the rest of the population which includes the third and fourth slabs were laid along the roads which connect the main cities. The significantly dense roads are Colombo-Galle-Samanthhurei (A2) road, Galle-Baddegama-Elpitiya (B128) road, Matara-Akuressa road (A24) road, Galle-Akuressa-Deniyaya road (A17), Matara- Hakmana road (B275) and Thihagoda-Pagoda Road (B415).

3. Agglomerating in the wet zone

It was, further, understood that the population is concentrated in to wet zone. Statistically, the percentage of the population within the wet zone is 75.2% whereas the area of the wet zone is 47.9%. This is a vital indicator that shows the importance of the availability of water sources in populated areas.

Considering the second step of the research, the preparation of the water quality index can be concluded. It is properly evident that the influence of Water supply by NWSDB has shown a tremendous positive impact on the total Water Quality Index. For all instances, except Bundala and Kirinda WSS, total WQI was improved dramatically due to NWSDB supply. All cells pertaining to slab (0-0.2) were included within NWSDB fed areas. On the other hand, it emphasises the urgency of improvement of Water quality of other sources. However, NWSDB has failed to provide safe drinking water complied with SLS 614 in Kirinda and Bundala WSS.

Further, it is noticeable that the WQI is fairly low in most of the densely populated areas. Spatially, along the coastal belt where NWSDB water supply is dominant, drinking water quality is way better than in other regions.

In this research, relative water balance was derived as the water scarcity indicator. As suggested by the indicator, the water is fairly available within the wet zone of the research area consisting of the Galle district and part of Matara district. It was noticed that the Relative Water balance was incrementally reduced towards the east direction. Especially, in the Hambantota and Kataragama DS division, water scarcity is highly dominant, resulting in dire demand for drinking water supply need. However, due to limited inflow from Walawe River, Kirindi Oya and Manik Ganga,

the water scarcity was reduced at the respective river downstream catchments. Hence, Angunukolapalassa and Sooriyawewa DS divisions can be identified as the most water-scarce zones of the research area.

As the final criterion, the spatial distribution of population thrust induced by New Development revealed that the agglomeration of population towards existing cities is the most dominant characteristic. Further, the additional population thrust will be dispersed between newly stipulated metro regions such as Thissa-Kataragama and Hambantota. However, the main current cities, namely, Galle, Matara and Tangalle will be benefitted mostly from the possible population pressure, resulting in a dense population of 5,000 to 11,500 pop/km². Allied to the above, the new development induced population will tend to agglomerate along the coastal belt. The final and most vital research component was to calculate the magnitude of the relative importance of the criterion. In this objective, the result was achieved with the aid of a pairwise comparison method conducted by different decision-makers who involve in the process of planning, design, operational and corporate management. Further, the research was compared with the already derived relative importance criteria for the prioritization of water supply projects by NWSDB. As per the results received; the most weighted parameter was Relative water balance with a weight of 0.47. The second most significant parameter was Equivalent Water Quality Index, and a weighted score of EWQI was 0.39.

Further, the population density and the Population thrust induced by the new development had lesser significance with 0.07 each. This illustrates the local importance of water resource availability to decide the degree of demand for drinking water. Though it was derived from local experts for indigenous conditions, it is still applicable globally.

In conclusion, the research work presented in this thesis demonstrated that it is useful to apply spatial information technology in effective water prioritization in drinking water supply need. The research results indicated that the GIS-based MCDA approach developed in this thesis provides theoretical support for trading off the impact of a vivid array of criteria to obtain the real need for drinking water

supply. The developed methodology and model builder tool can also be applied in the evaluation of other regions in the country.

5.2 Contributions

This thesis study contains the following contributions:

1. Developed four GIS-based models to simulate the Water resource availability (Relative Water balance), a representative figure of Water quality (Equivalent Water Quality Index), Population Density in a more spatially descriptive manner and population thrust induced by New Development
2. Proposed a GIS-MCDA based Prioritization method with the aid of ArcGIS and multi-criteria decision analysis techniques based on prepared databases for Water quality, population density, Population thrust due to new development and Water resource availability. Four criterions pertaining to the above four databases are examined and compared based on a real case study to provide reliable and intuitive results regarding the spatial distribution of drinking water needs. This provides the basis for selecting the most urgent areas to formulate water supply projects from the public perspective.
3. Prepared a model builder tool to automate the decision-making process of prioritizing Water supply need.

5.3 Limitation of the research and Recommendations for future works

1. In the process of preparation of EWQI, the limitation of the study was occurred due to the unavailability of data pertaining to biological parameters and water quality parameters of minority using surface water like lakes and rivers. It is obvious to notice that biological parameters such as E-coli count are a governing factor in the determination of the water quality status. In contrast, a monolithic water quality survey of microbial parameters has not been carried out

within rural water supply schemes or other water sources such as dug wells, springs etc. Hence, it is advisable to carry out a microbial water quality survey to build up a much more fitted EWQI.

2. Preparation of GIS model of Relative water balance was carried out without considering the transfer of inter-basin groundwater flows. This can be achieved by groundwater modelling which can be integrated into the RWB model prepared by this research work.
3. The entire research work was based on the General public perspective. However, the implementation of the Water Supply project has relied on many other stakeholders such as donor/funding agency, NWSDB and the Government. Owing to the different perspectives stemming from a vivid array of institutional objectives, criterions such as finance and economical parameters are required to be considered in prioritizing water supply projects. Hence, this research work can, further, be extended to prioritize the Water Supply Projects by considering perspectives of donor/funding agencies and Government entities.

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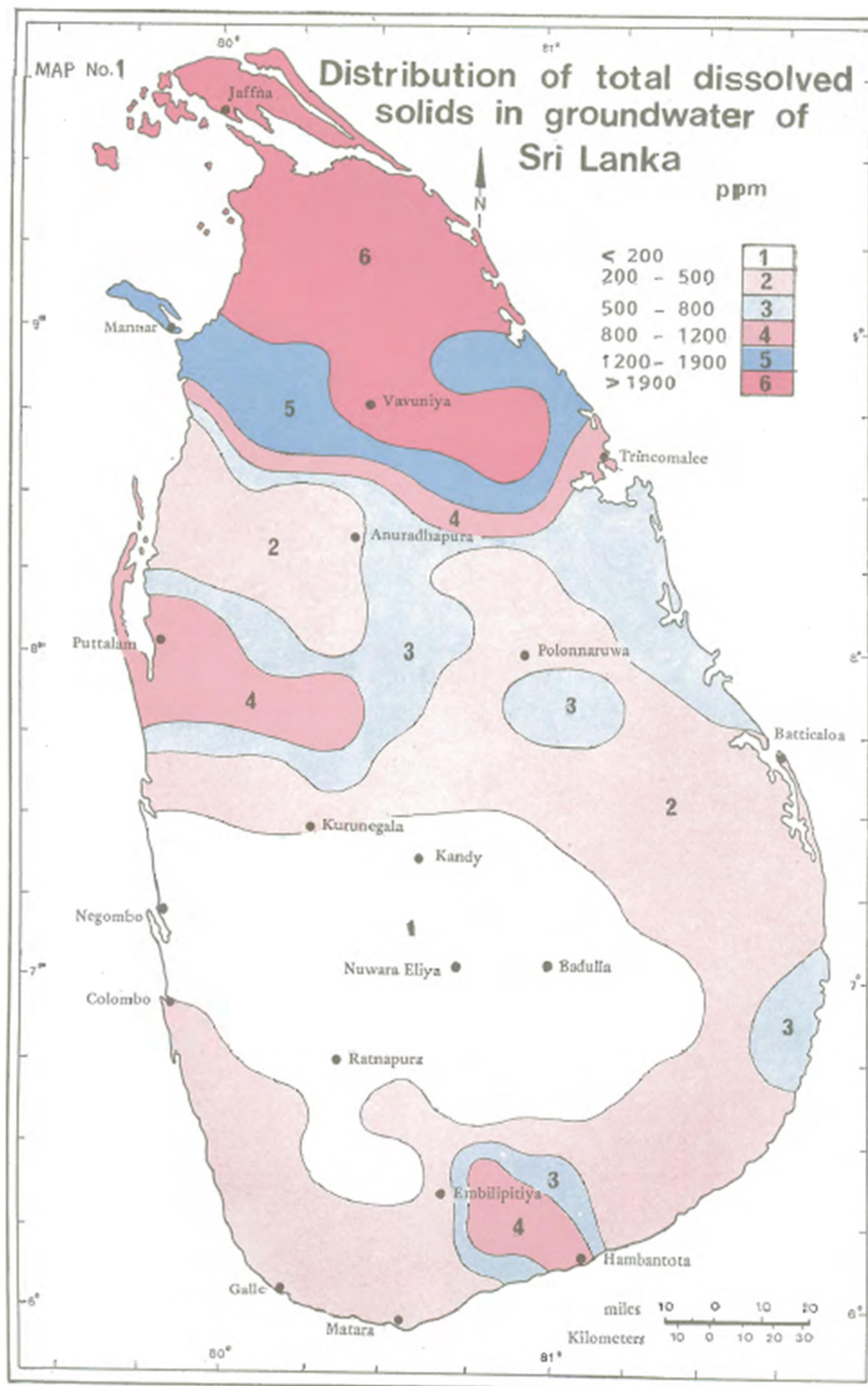
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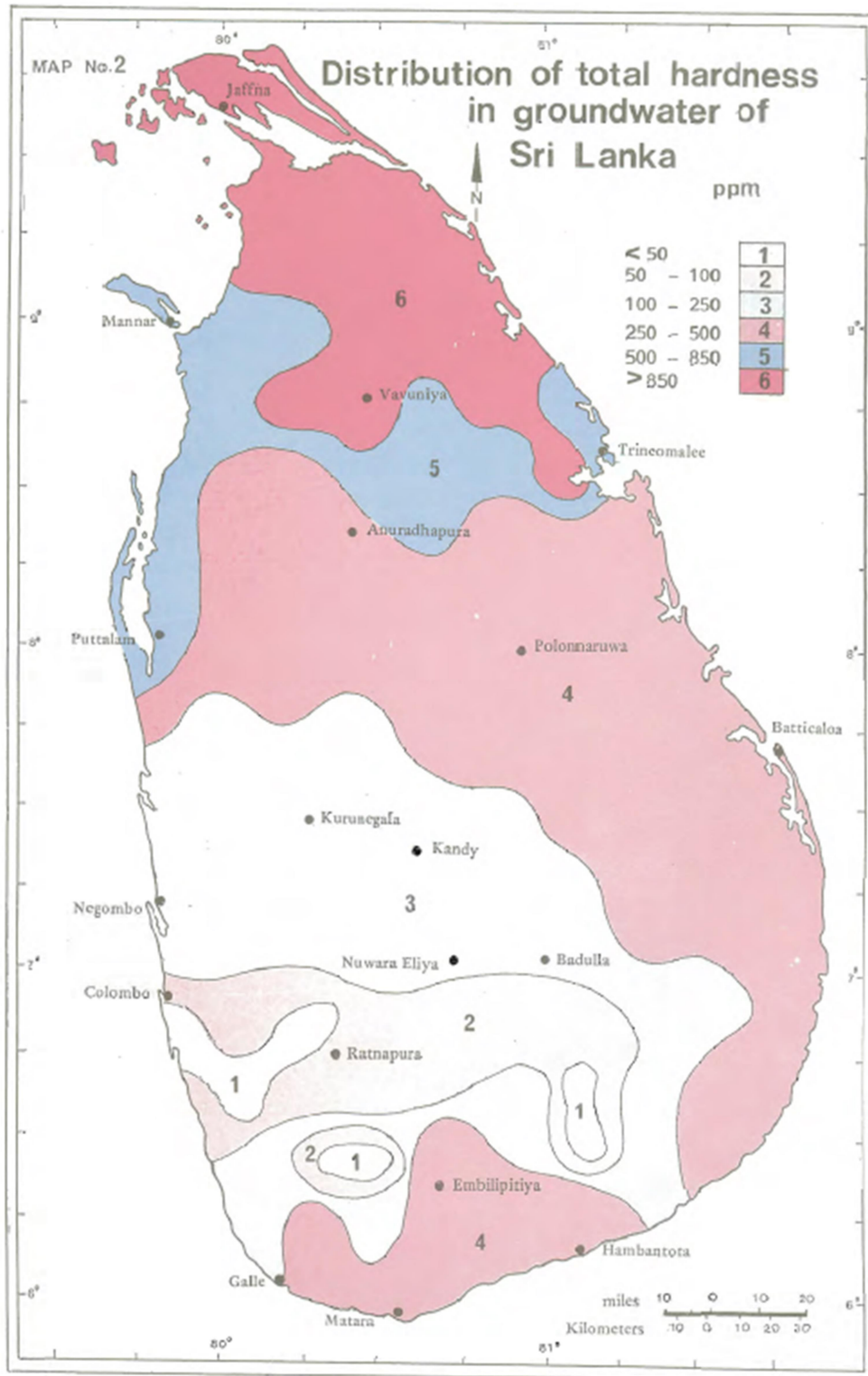
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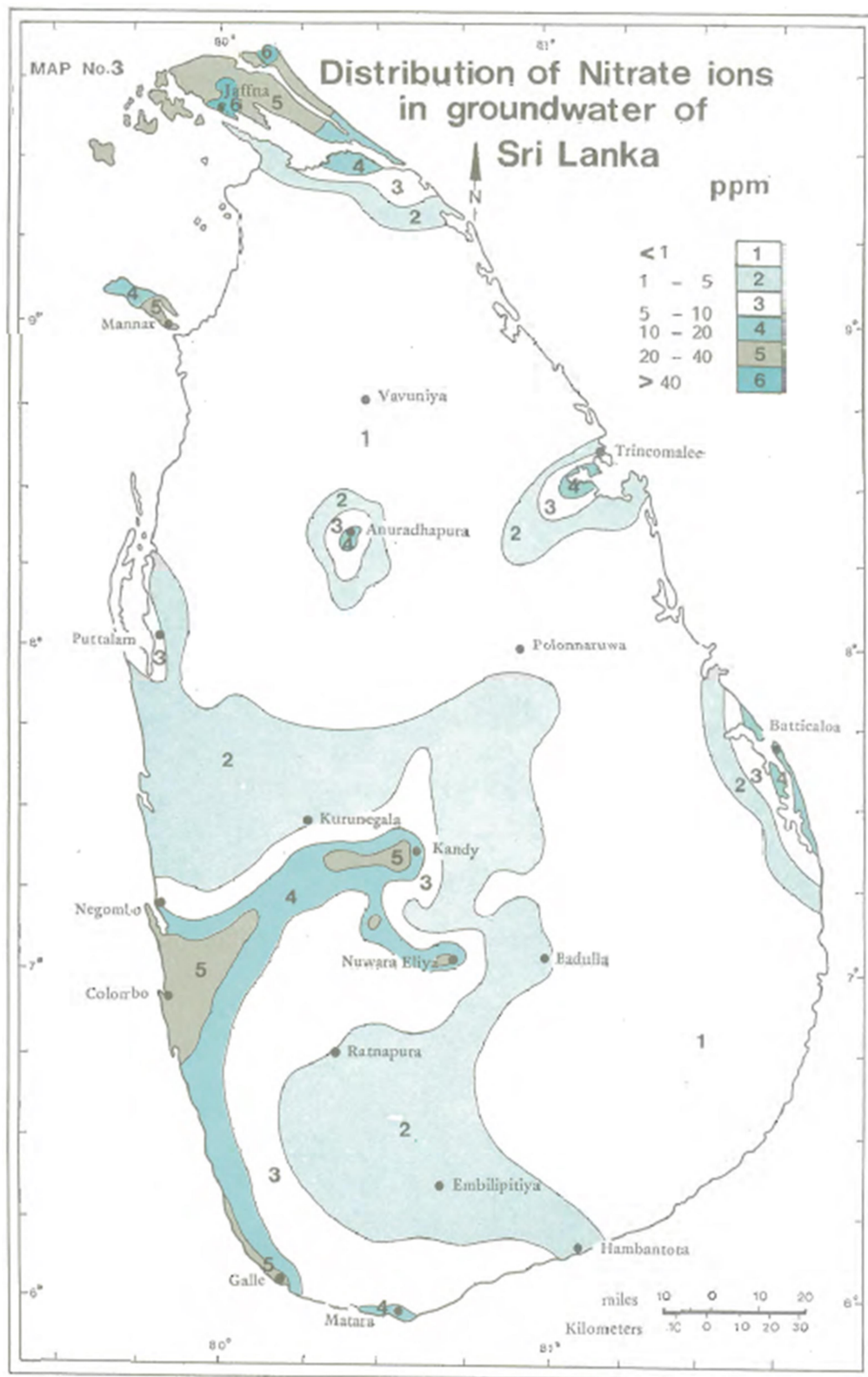
Appendix A1. – Spatial Distribution of TDS



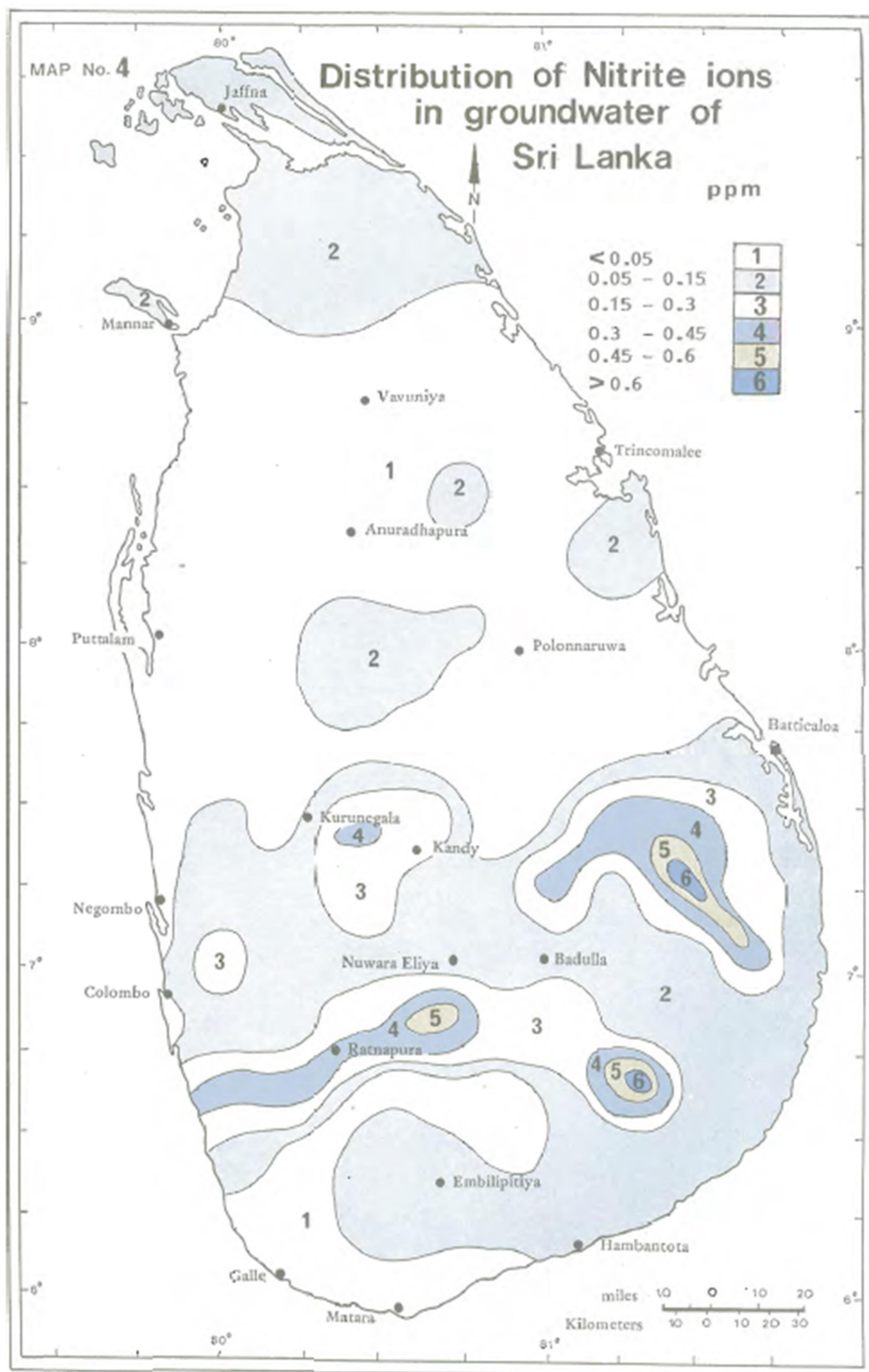
Appendix A2. – Spatial Distribution of Hardness



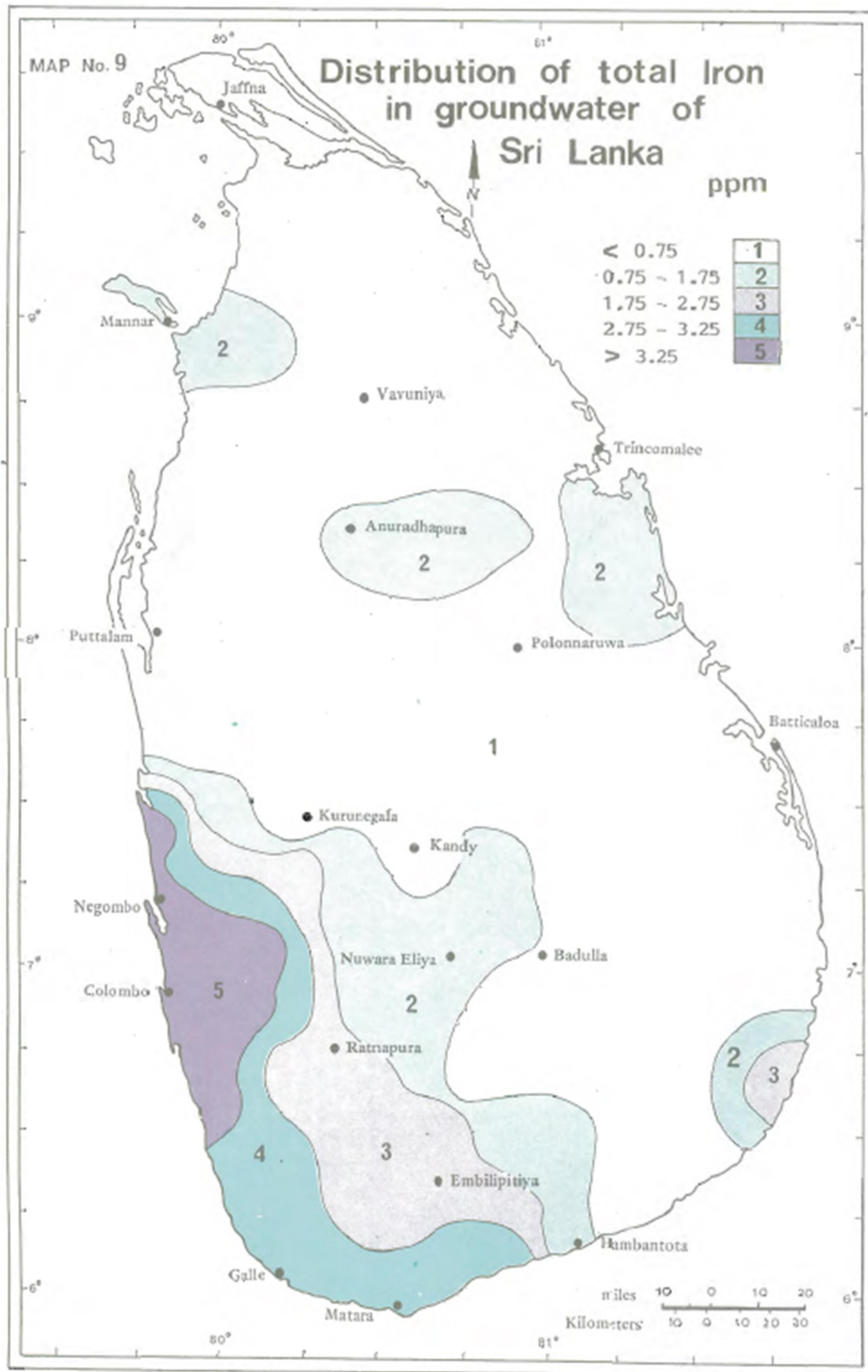
Appendix A3. – Spatial Distribution of Nitrate



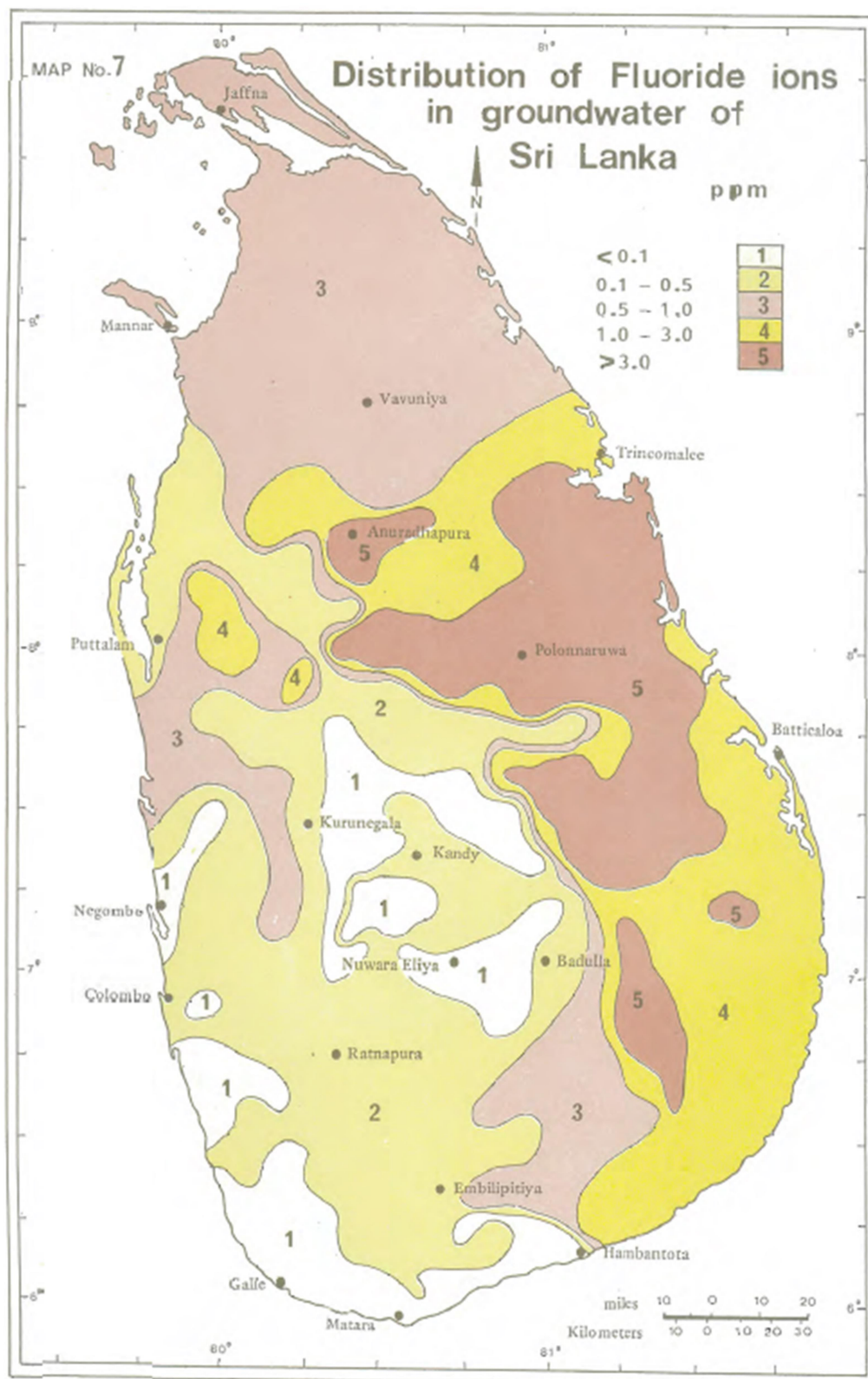
Appendix A4. – Spatial Distribution of Nitrite



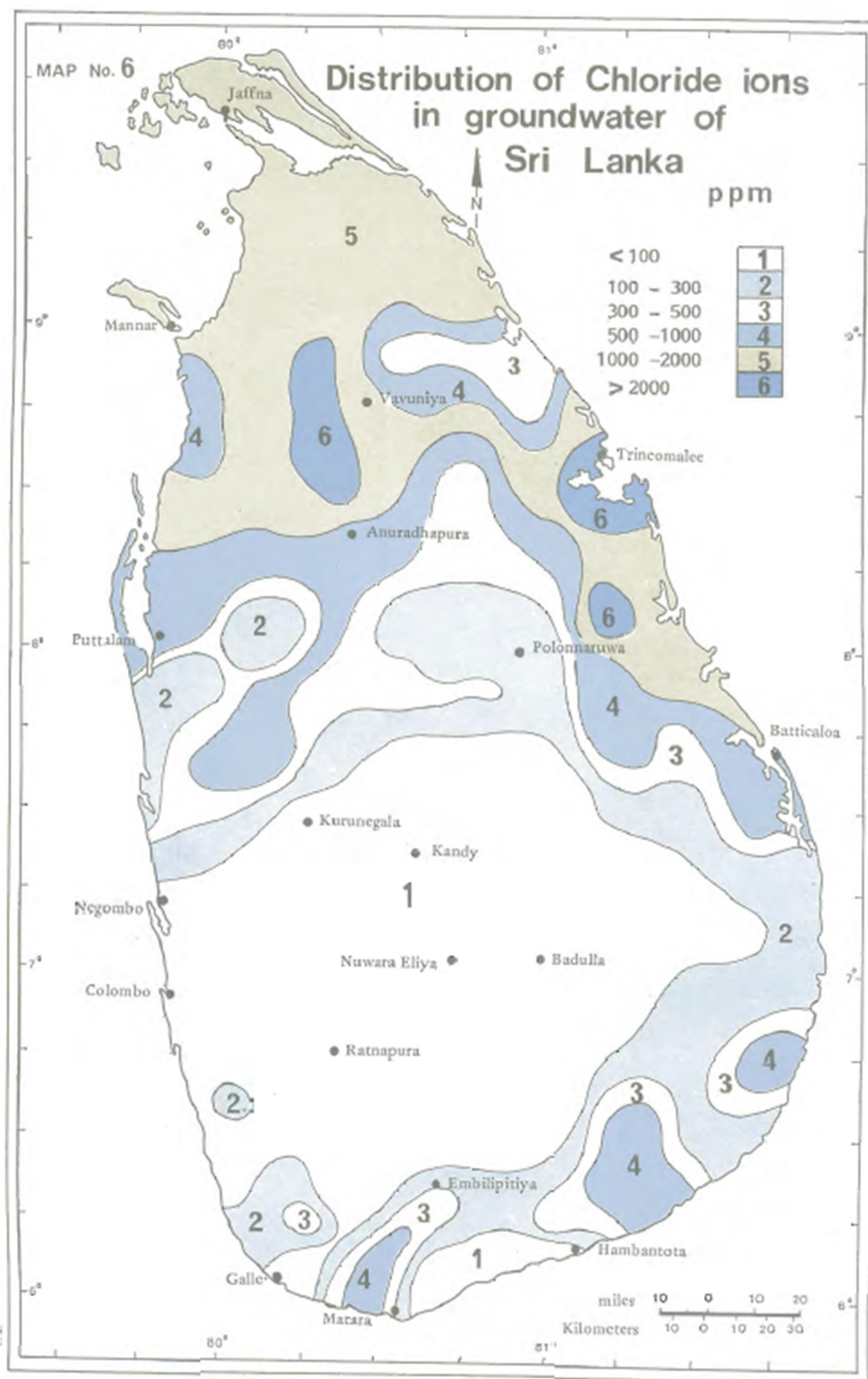
Appendix A5. – Spatial Distribution of Total Iron



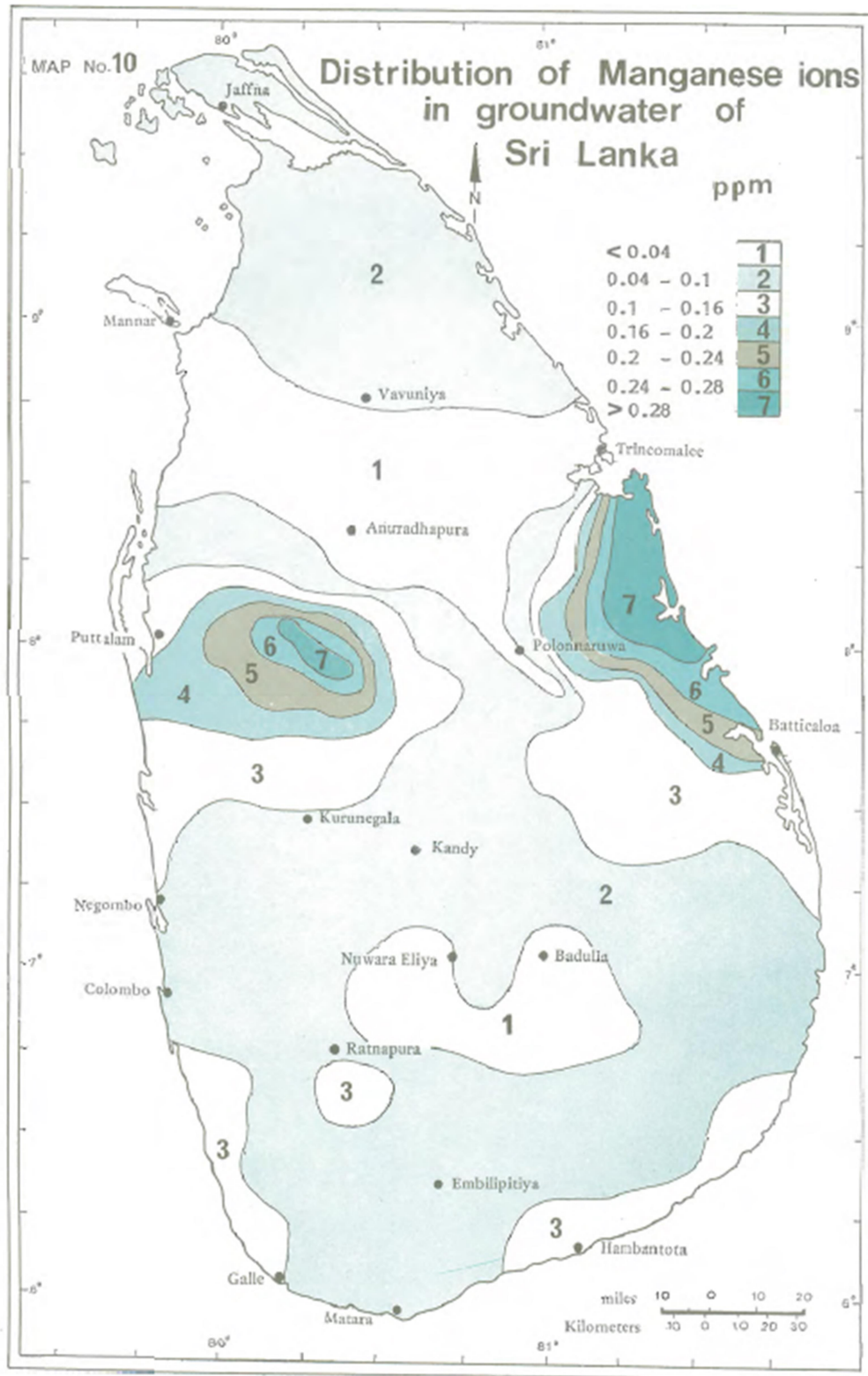
Appendix A6. – Spatial Distribution of Fluoride



Appendix A7. – Spatial Distribution of Chloride



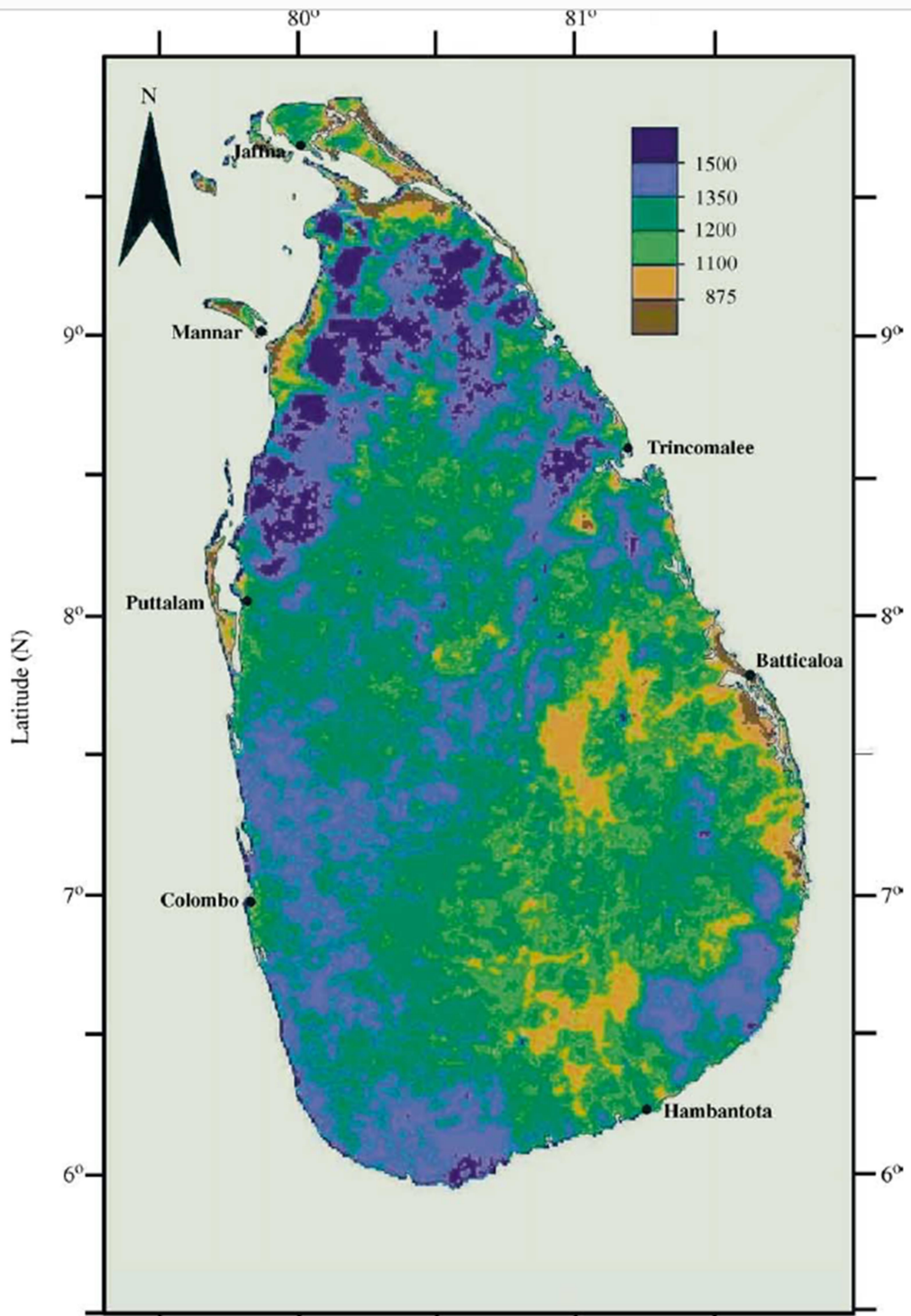
Appendix A8. – Spatial Distribution of Manganese



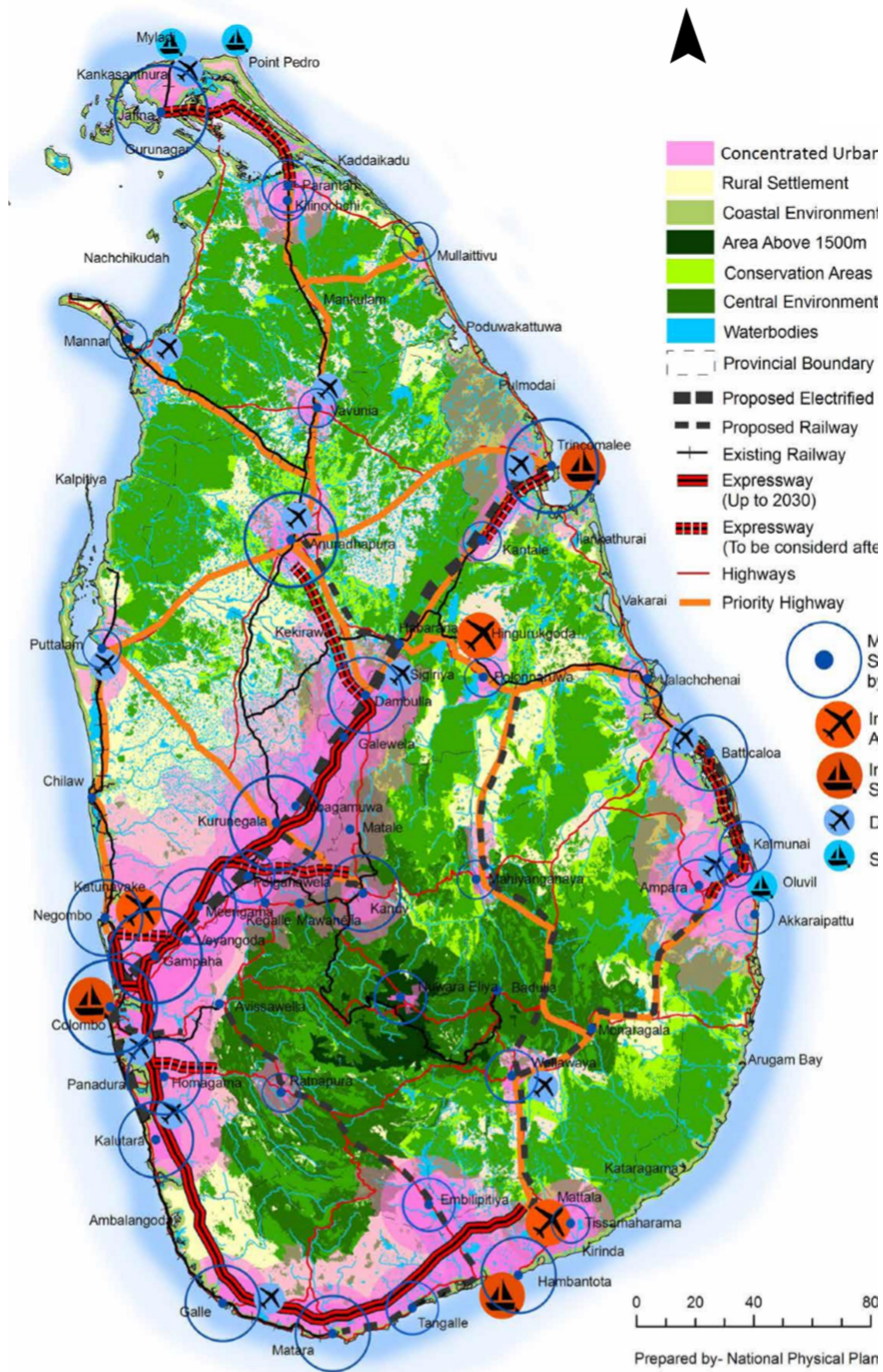
Appendix C. – Covered Population of NWSDB fed schemes in research area

Divisional Secretariat Name	Number of GNDs	Total Domestic units (2020)	Total NWSDB fed units (2020)	Coverage(%)
Akmeemana	63	20,346	9,134	45
Akuressa	46	12,987	1,217	9
Ambalangoda	36	15,838	8,071	51
Ambalantota	58	21,415	15,840	74
Angunukolapelessa	51	13,409	2,926	22
Athuraliya	28	7,934	1,227	15
Baddegama	70	22,699	2,577	11
Balapitiya	52	18,717	12,311	66
Beliatta	71	15,626	6,874	44
Bentota	51	12,216	212	2
Bope-Poddala	44	12,356	9,630	78
Devinuwara	41	11,836	8,646	73
Dickwella	48	13,414	13,414	100
Elpitiya	51	18,862	1,467	8
Galle Four Gravets	50	24,155	24,099	100
Gonapinuwala	18	6,196	0	0
Habaraduwa	59	17,088	9,024	53
Hakmana	34	7,734	1,040	13
Hambantota	30	15,842	14,434	91
Hikkaduwa	96	28,194	21,271	75
Imaduwa	43	12,497	1,512	12
Kamburupitiya	39	10,070	2,247	22
Karandeniya	40	19,107	218	1
Katharagama	5	3,297	2,537	77
Katuwana	56	12,881	1,219	9
Kirinda Puhulwella	25	4,968	0	0
Kotapola	37	15,882	847	5
Lunugamvehera	39	9,261	8,166	88
Malimbada	29	8,569	5,589	65
Matara Four Gravets	66	33,202	25,598	77
Mulatiyana	48	12,345	349	3
Nagoda	53	17,335	163	1
Neluwa	34	7,562	0	0
Niyagama	34	10,416	265	3
Okewela	27	5,255	0	0
Pasgoda	43	14,533	218	1
Pitabeddara	40	12,536	0	0
Sooriyawewa	21	11,954	6,721	56
Tangalle	72	19,999	16,523	83
Thawalama	36	9,443	0	0
Thihagoda	40	8,263	4,201	51
Tissamaharama	45	20,050	13,394	67
Walasmulla	53	11,741	4,242	36
Weeraketiya	60	11,509	4,544	39
Weligama	48	17,966	13,669	76
Welipitiya	38	12,684	3,638	29
Welivitiya-Divithura	20	9,001	65	1
Yakkalamulla	44	13,291	0	0

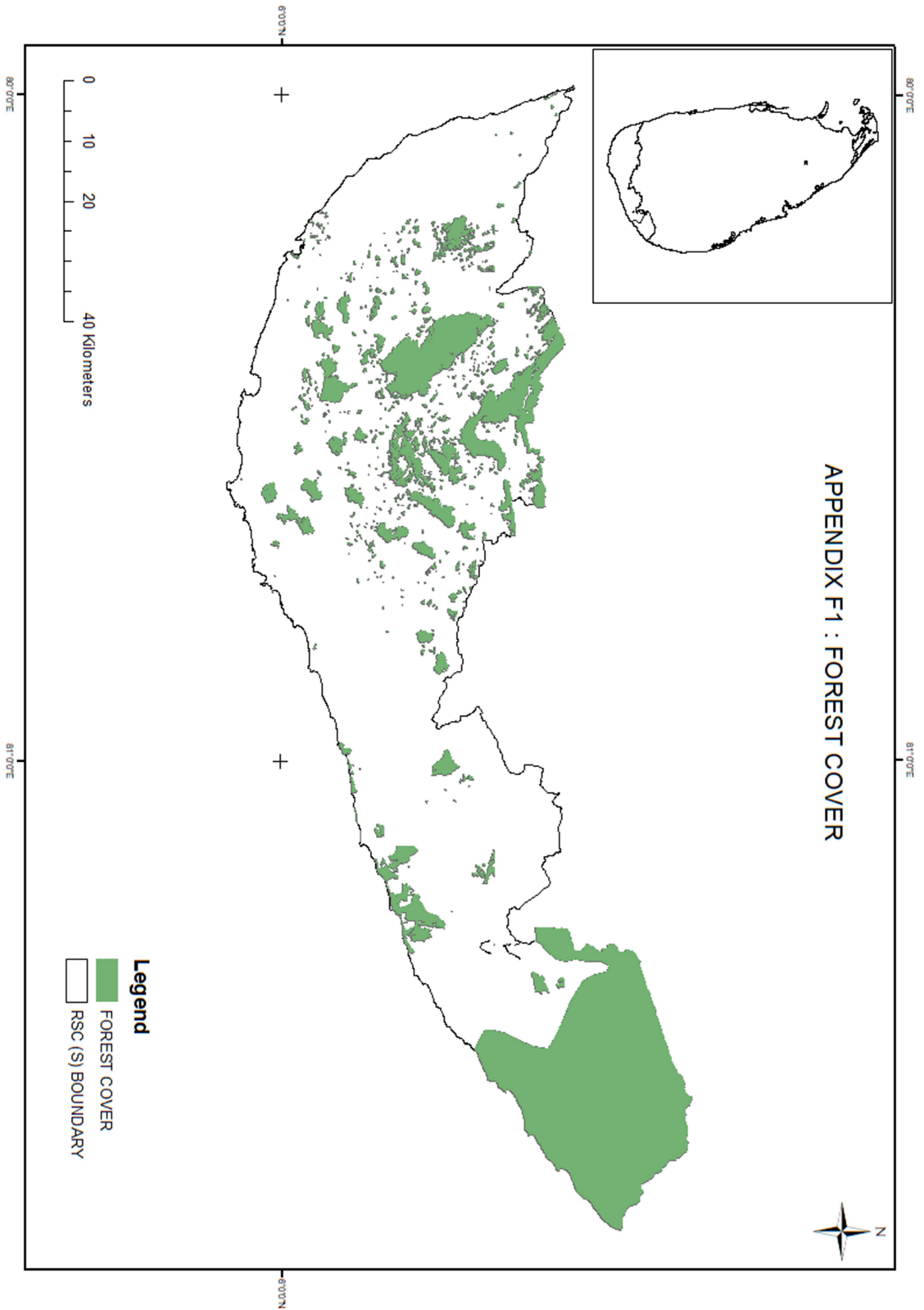
Appendix D. – Evaporation data



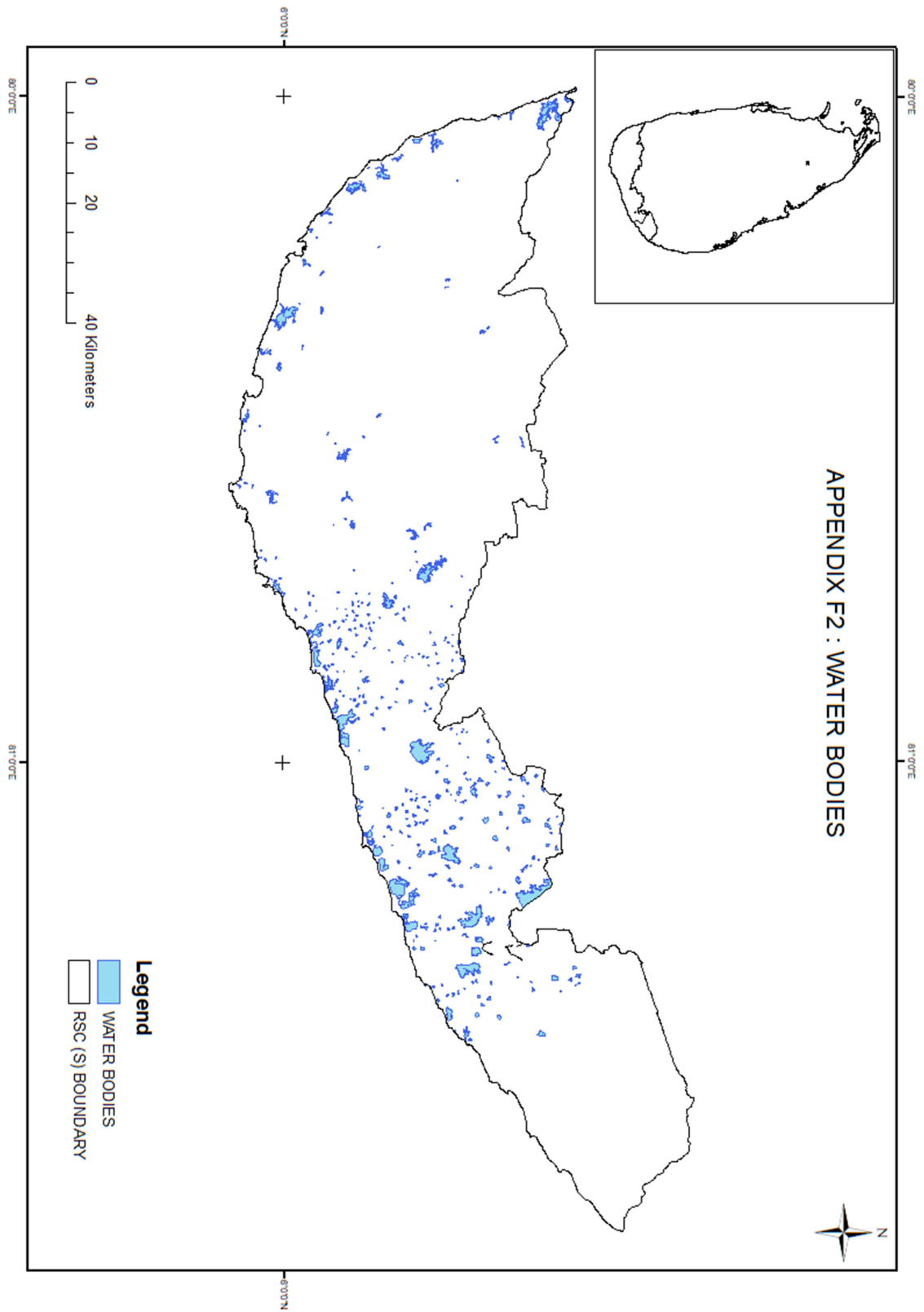
Appendix E. – Development Corridors



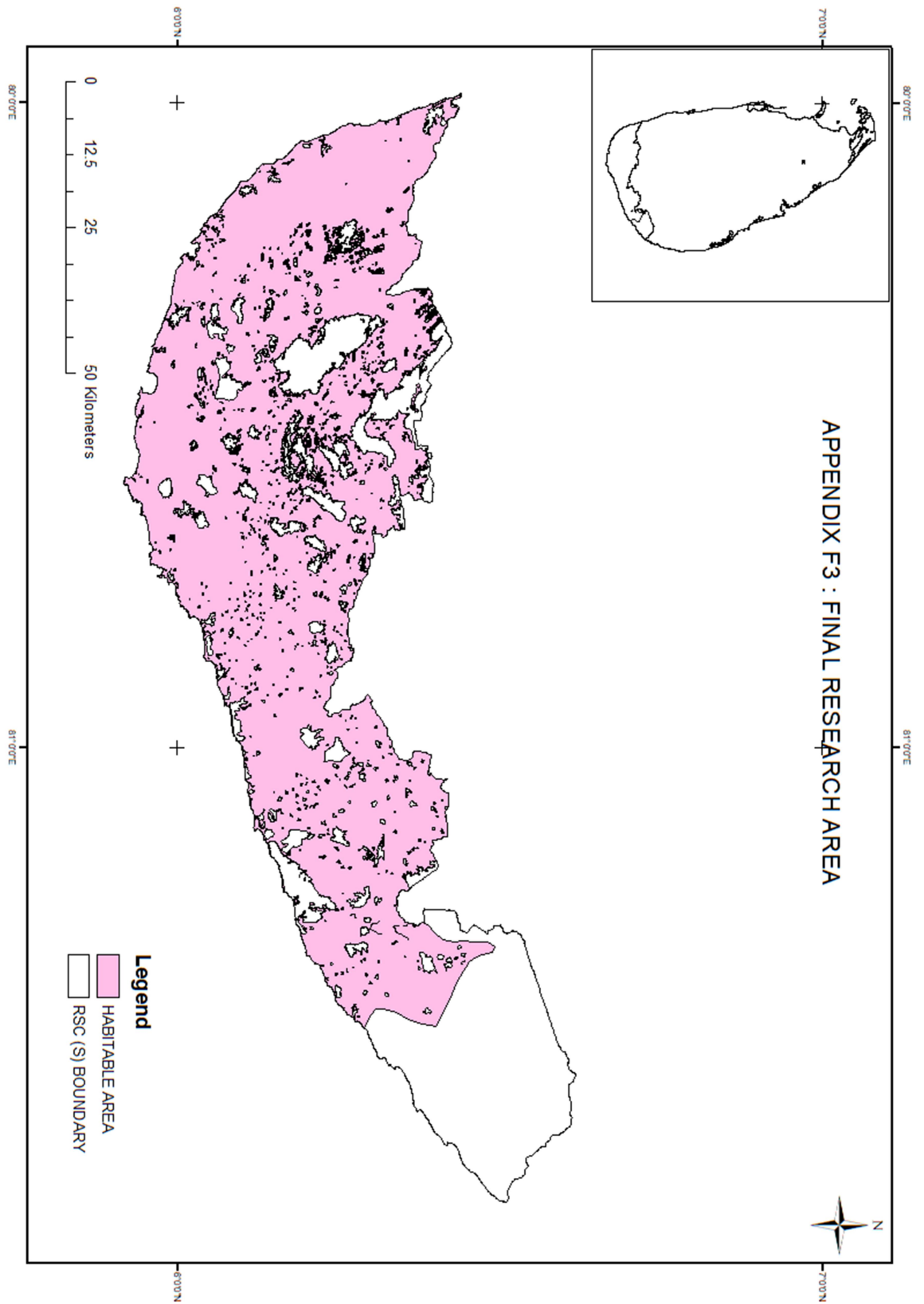
Appendix F1. – Forest Cover



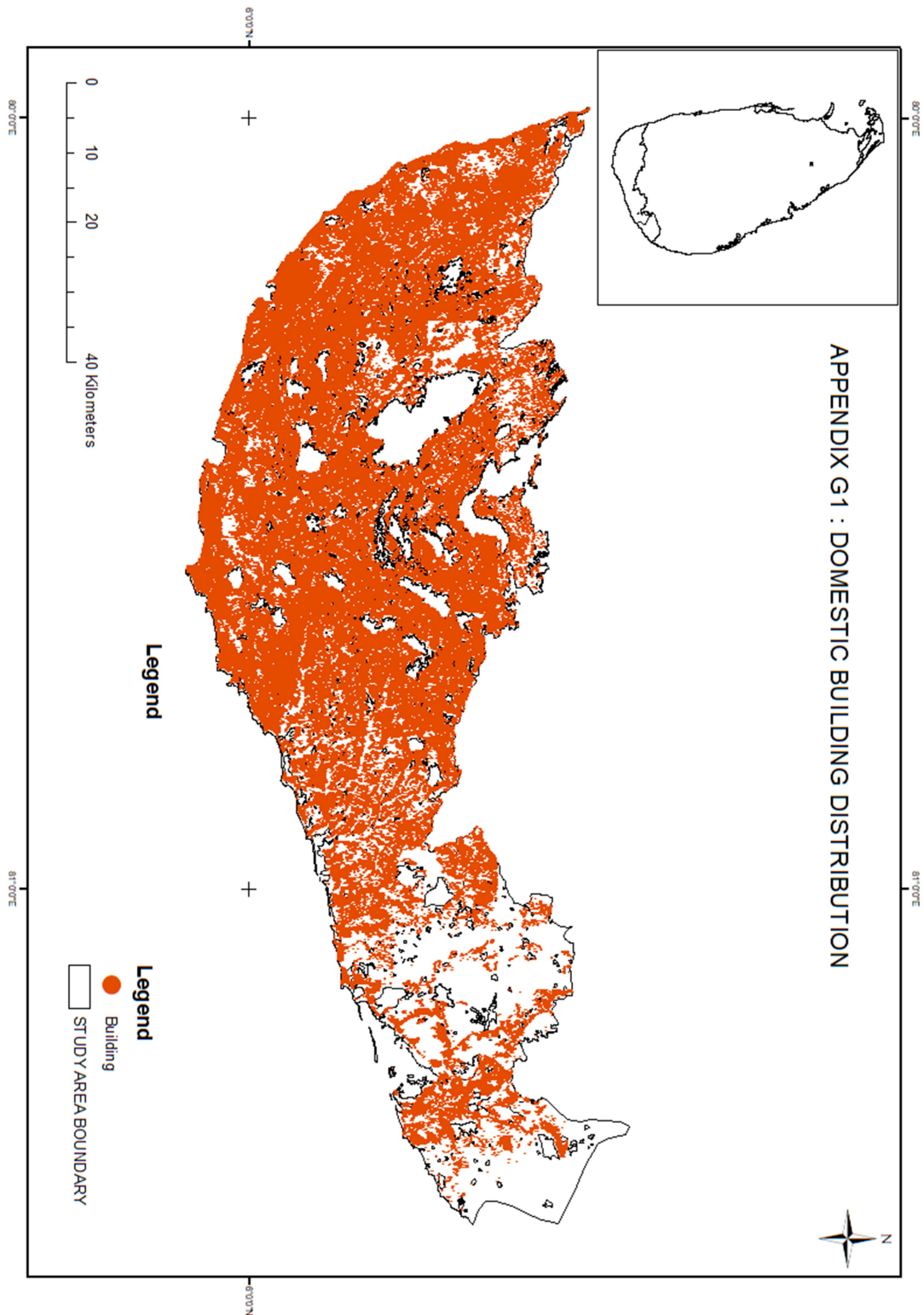
Appendix F2. – Water Bodies



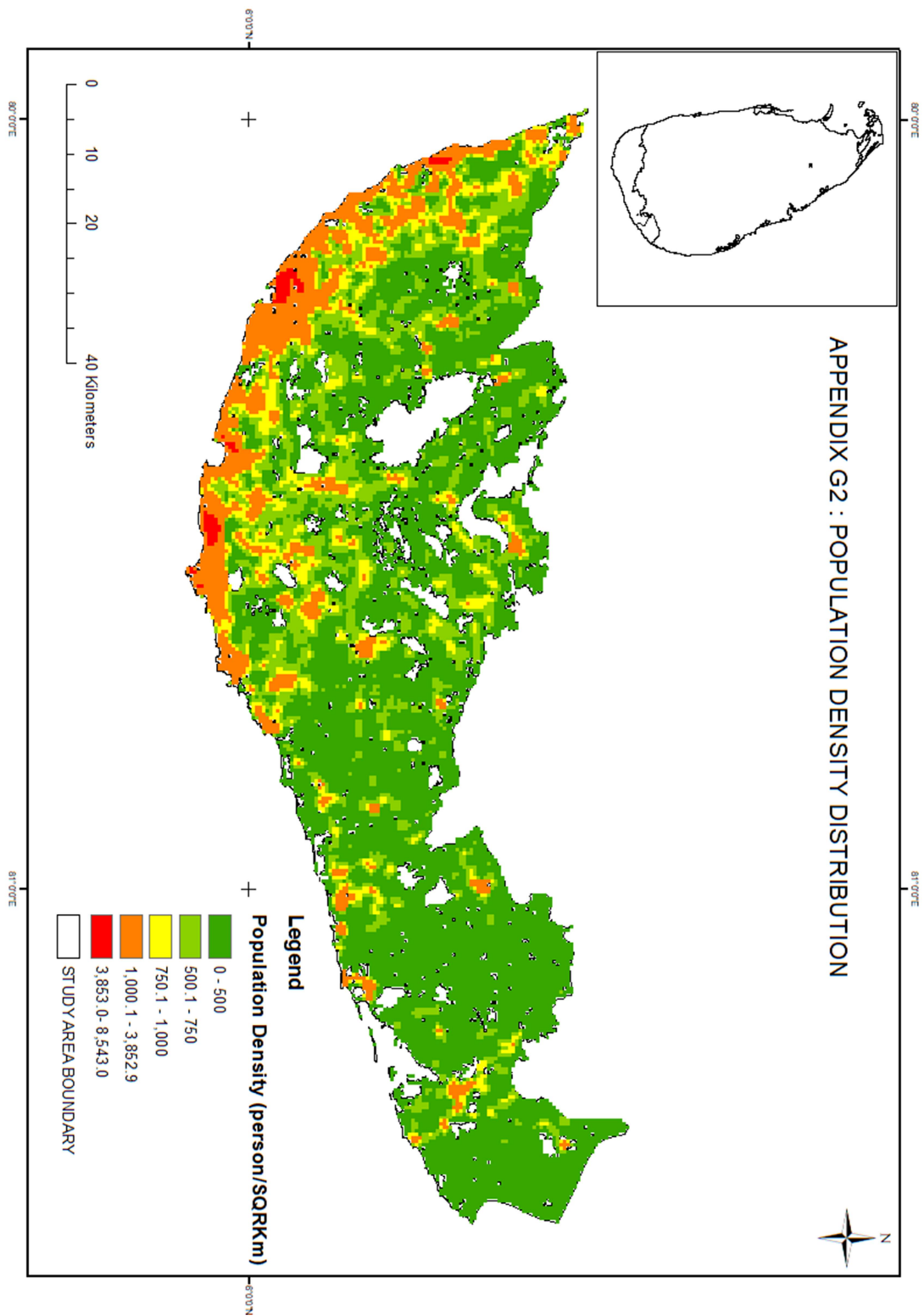
Appendix F3. – Habitable Area



Appendix G1. – Spatial Distribution of Buildings



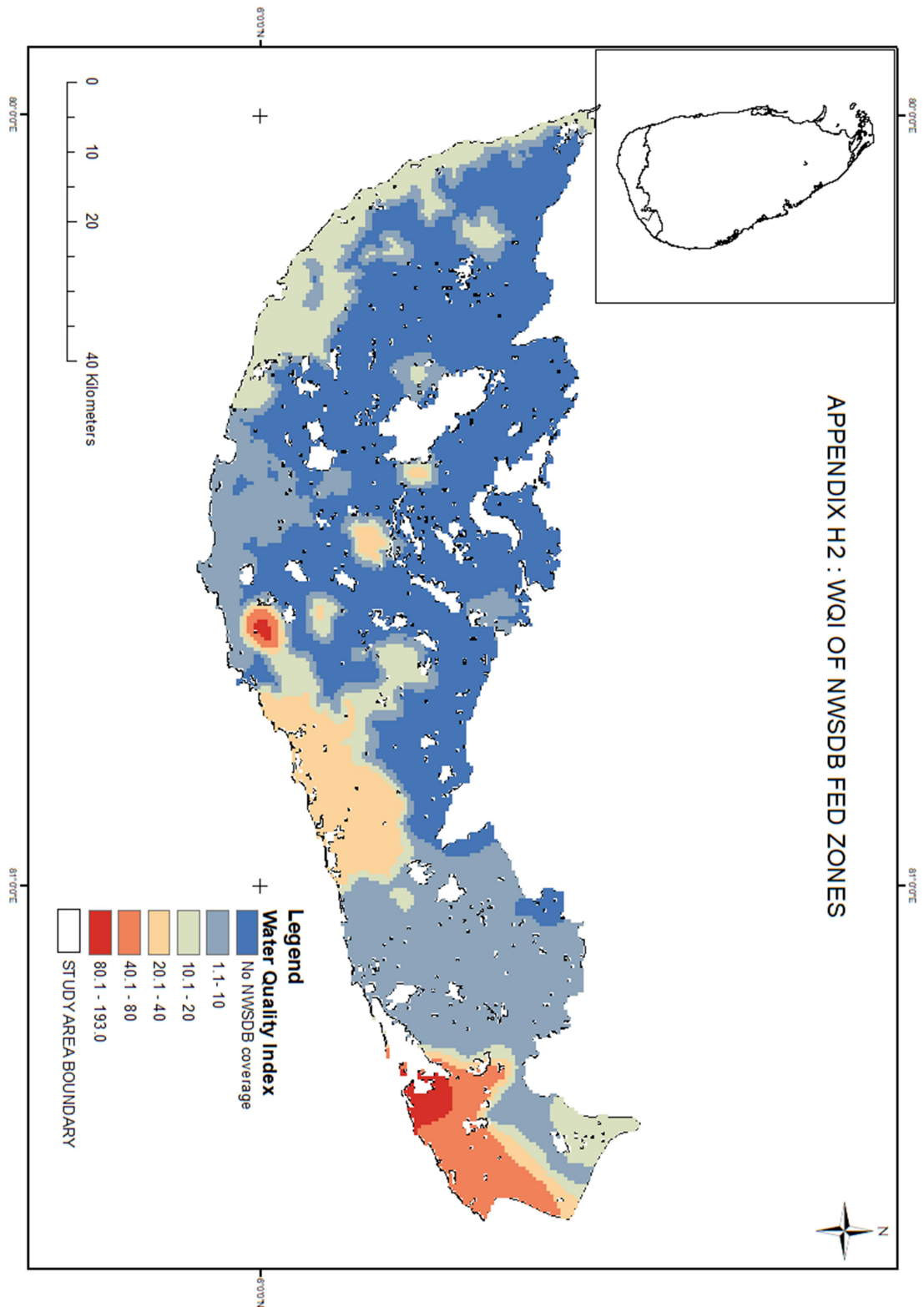
Appendix G2. – Spatial Distribution of Population Density



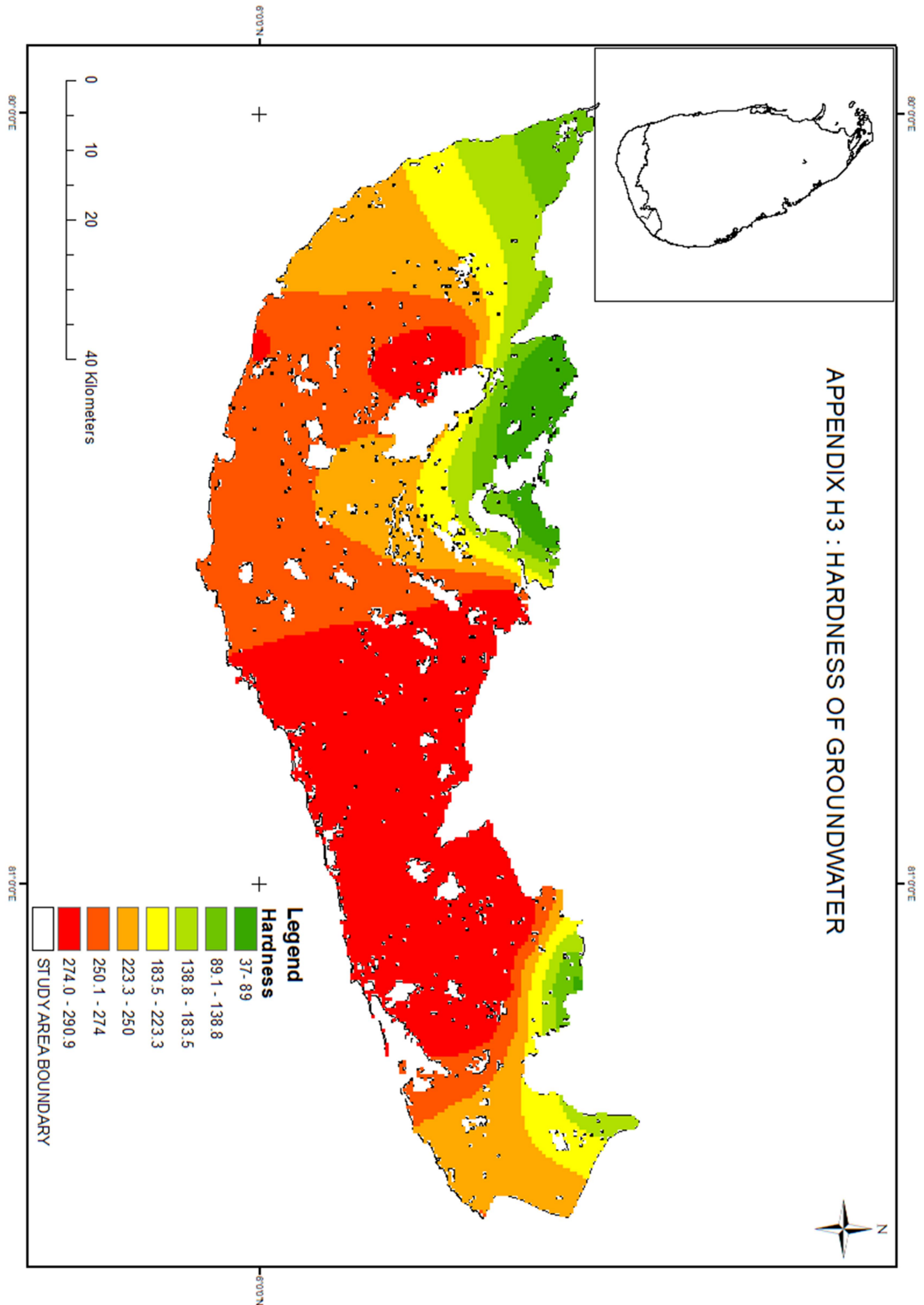
Appendix H1. – Water quality of NWSDB fed WSS

Manager Office	Name - WSS	Hardness	TDS	Nitrate	Nitrite	T.Iron	Fluoride	Chloride	Mn
		250	500	50	3.000	0.30	1.00	250	0.1
Matara	Akuressa	23.64	42.58	0.12	0.00	0.09	0.01	12.55	0.00
	Hakmana	181.33	272.62	0.03	0.00	0.22	0.20	46.67	0.00
	Makandura	167.45	235.96	0.03	0.00	0.35	0.38	14.18	0.00
	Malimbada	32.08	50.69	0.11	0.00	0.06	0.01	11.33	0.00
	Nadugala	29.09	53.76	0.13	0.00	0.07	0.01	13.64	0.00
	Pitabeddara	158.17	208.09	0.02	0.00	0.31	0.22	14.00	0.00
	Radampola	151.27	253.08	0.05	0.03	1.18	0.29	36.91	0.00
	Thihagoda	81.00	173.82	0.24	0.00	0.18	0.20	45.20	0.00
	Urubokka	12.00	27.43	0.12	0.00	0.11	0.01	7.27	0.00
	Weligama	35.86	56.09	0.13	0.00	0.08	0.02	15.14	0.00
Hambantota	Ambalantota	140.33	282.70	0.05	0.01	0.06	0.41	31.25	0.00
	Angunukolapelessa	89.78	176.16	0.03	0.01	0.15	0.25	26.11	0.02
	Beliatta	223.00	390.33	0.02	0.01	0.17	0.30	51.50	0.00
	Bundala	215.00	473.85	0.07	0.01	1.71	0.51	66.17	0.09
	Kataragama	155.00	352.49	0.07	0.01	0.13	0.42	34.17	0.00
	Lunugamwehera	118.53	219.24	0.05	0.01	0.09	0.25	16.65	0.00
	Weeraketiya	38.67	71.84	0.05	0.01	0.11	0.17	15.25	0.00
	Walasmulla	38.67	71.84	0.05	0.01	0.11	0.17	15.25	0.00
	Ranna	135.83	301.58	0.05	0.01	0.08	0.44	39.83	0.02
	Hungama	135.83	301.58	0.05	0.01	0.08	0.44	39.83	0.02
	Ruhunupura	136.17	260.60	0.05	0.01	0.05	0.29	40.67	0.00
	Hambantota	136.17	260.60	0.05	0.01	0.05	0.29	40.67	0.00
	Tangalle	101.67	220.84	0.03	0.01	0.09	0.35	42.83	0.02
	Thissamaharama	236.67	508.94	0.06	0.01	0.45	0.57	57.83	0.04
	Kirinda	236.67	508.94	0.06	0.01	0.45	0.57	57.83	0.04
Wakamulla	102.00	189.13	0.05	0.01	0.11	0.29	24.33	0.00	
Galle	Baddegama	22.09	43.24	2.34	0.01	0.1	0.05	11.35	0
	Udugama	132.5	201.08	0.97	0.01	0.07	0.14	14.75	0
	Wakwella	20	48.71	3.3	0.01	0.18	0.04	15	0

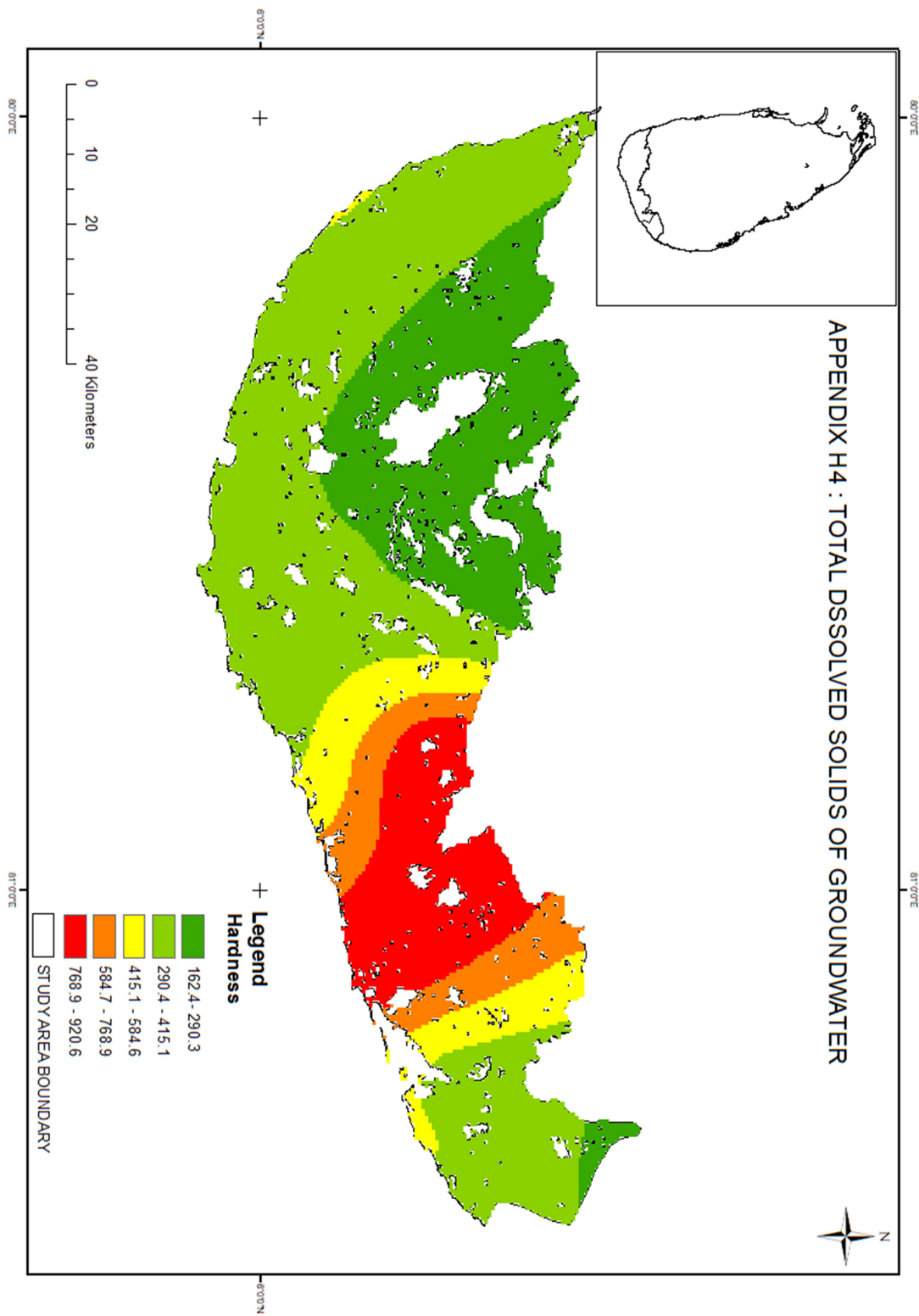
Appendix H2. – WQI of NWSDB fed Zones



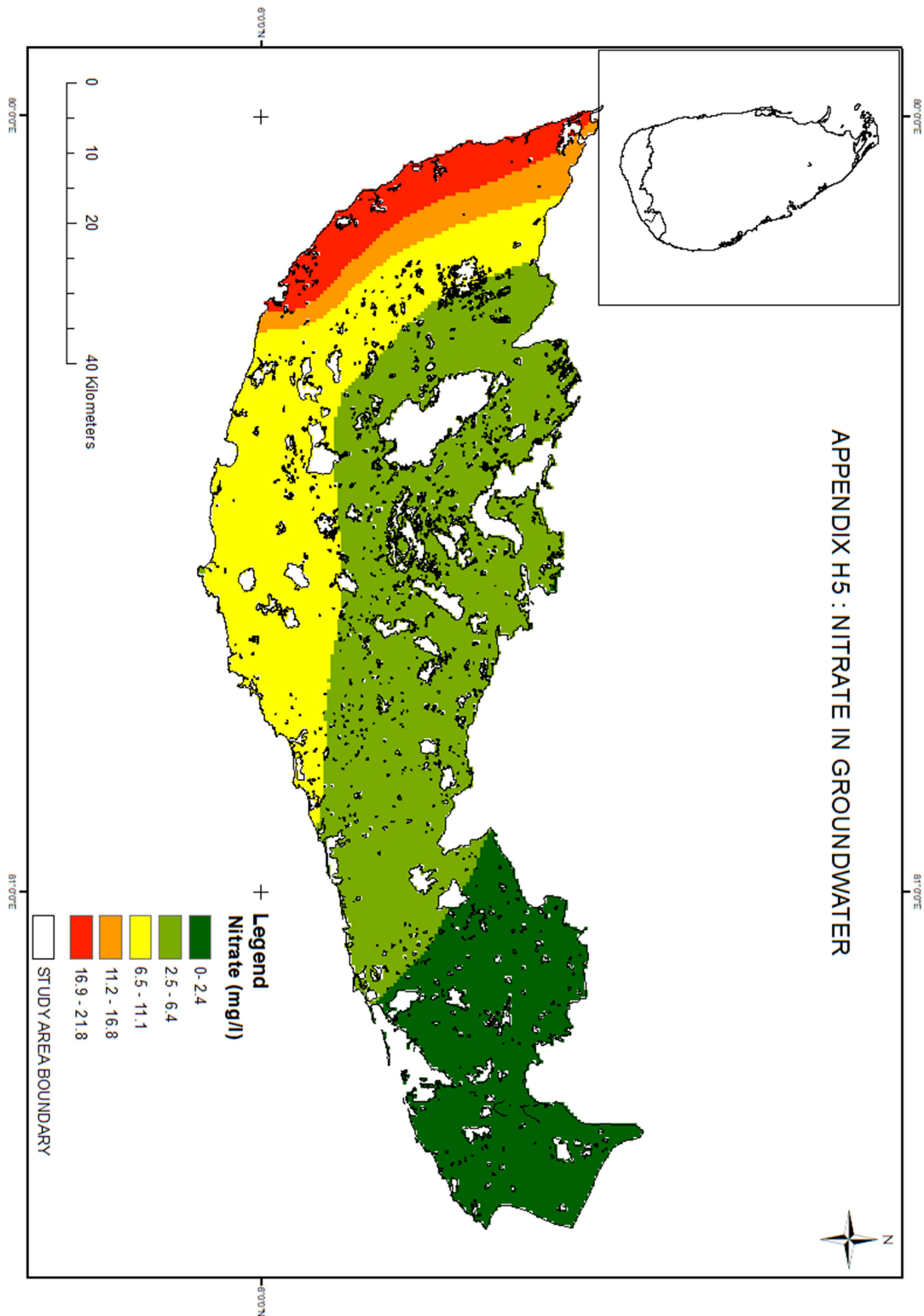
Appendix H3. – Hardness of Groundwater



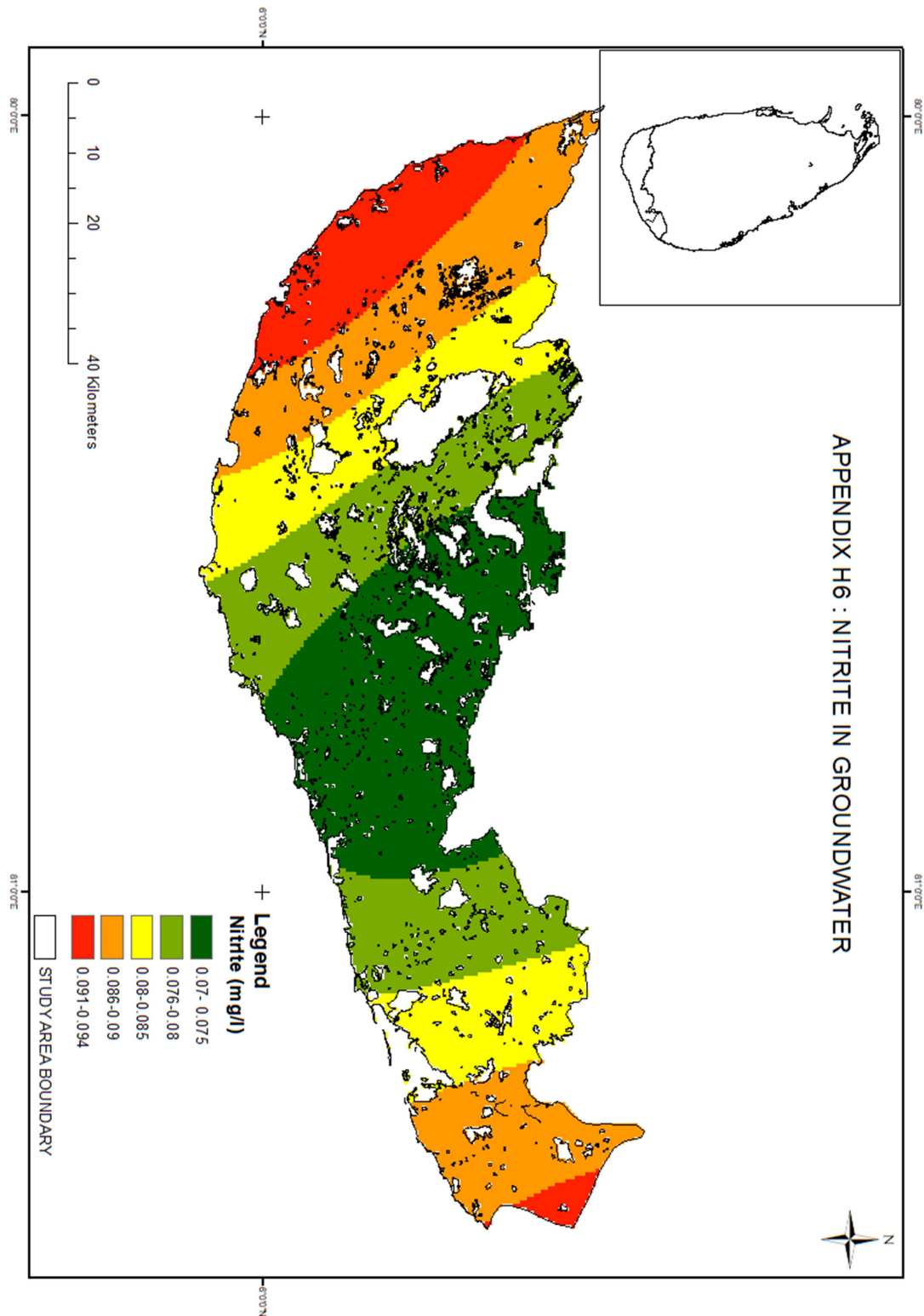
Appendix H4. – Total Dissolved Solids of Groundwater



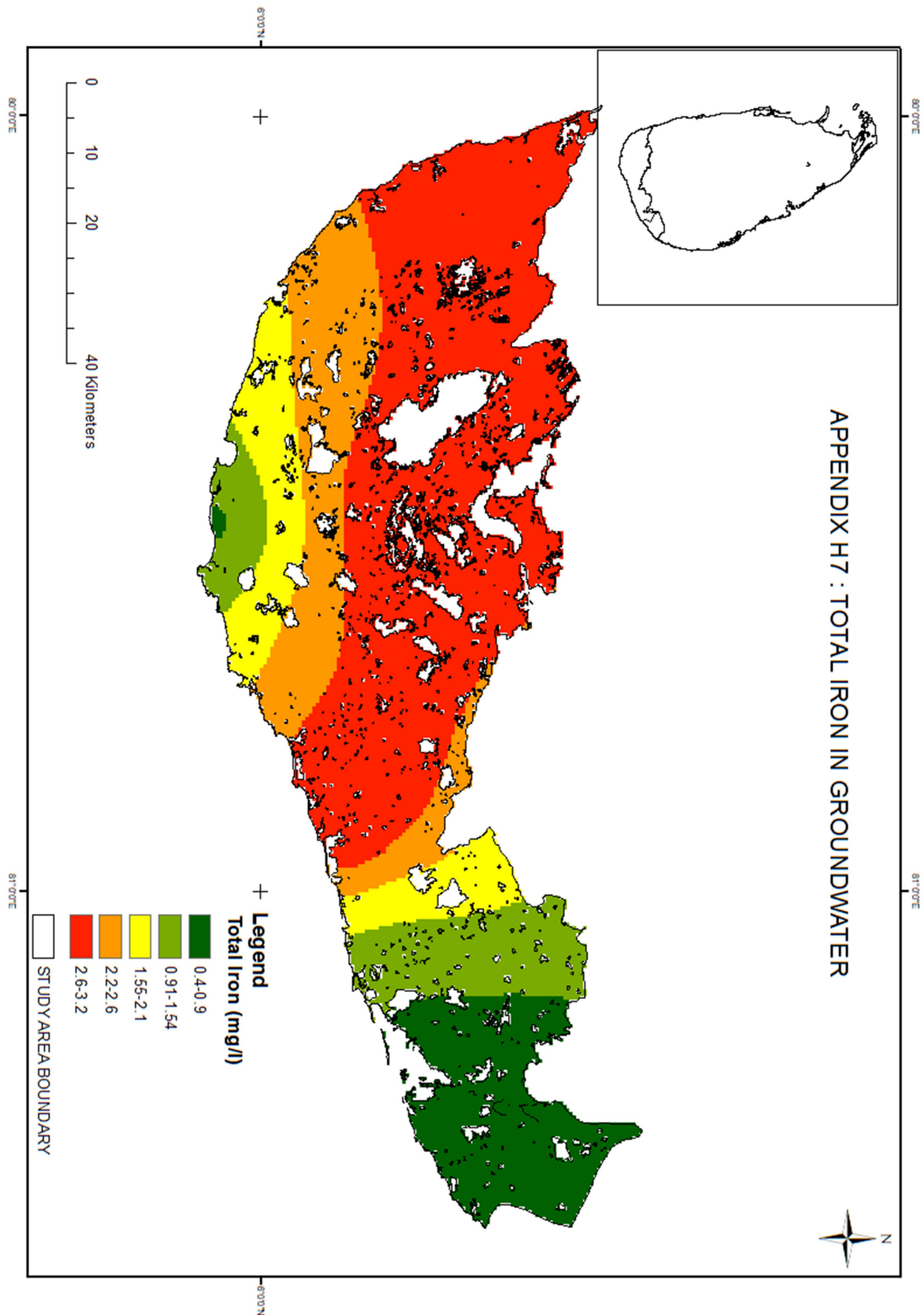
Appendix H5. – Nitrate in Groundwater



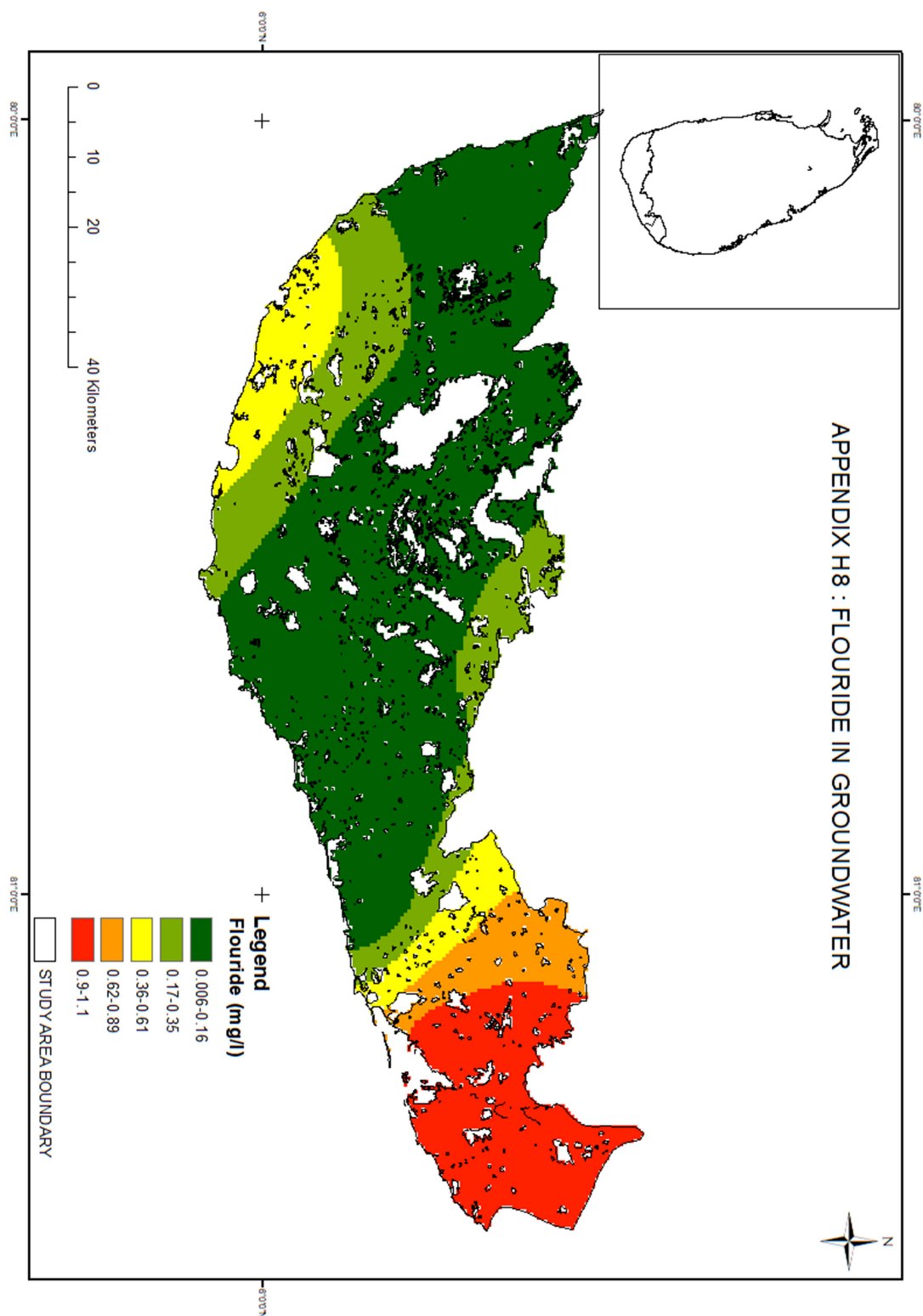
Appendix H6. – Nitrite in Groundwater



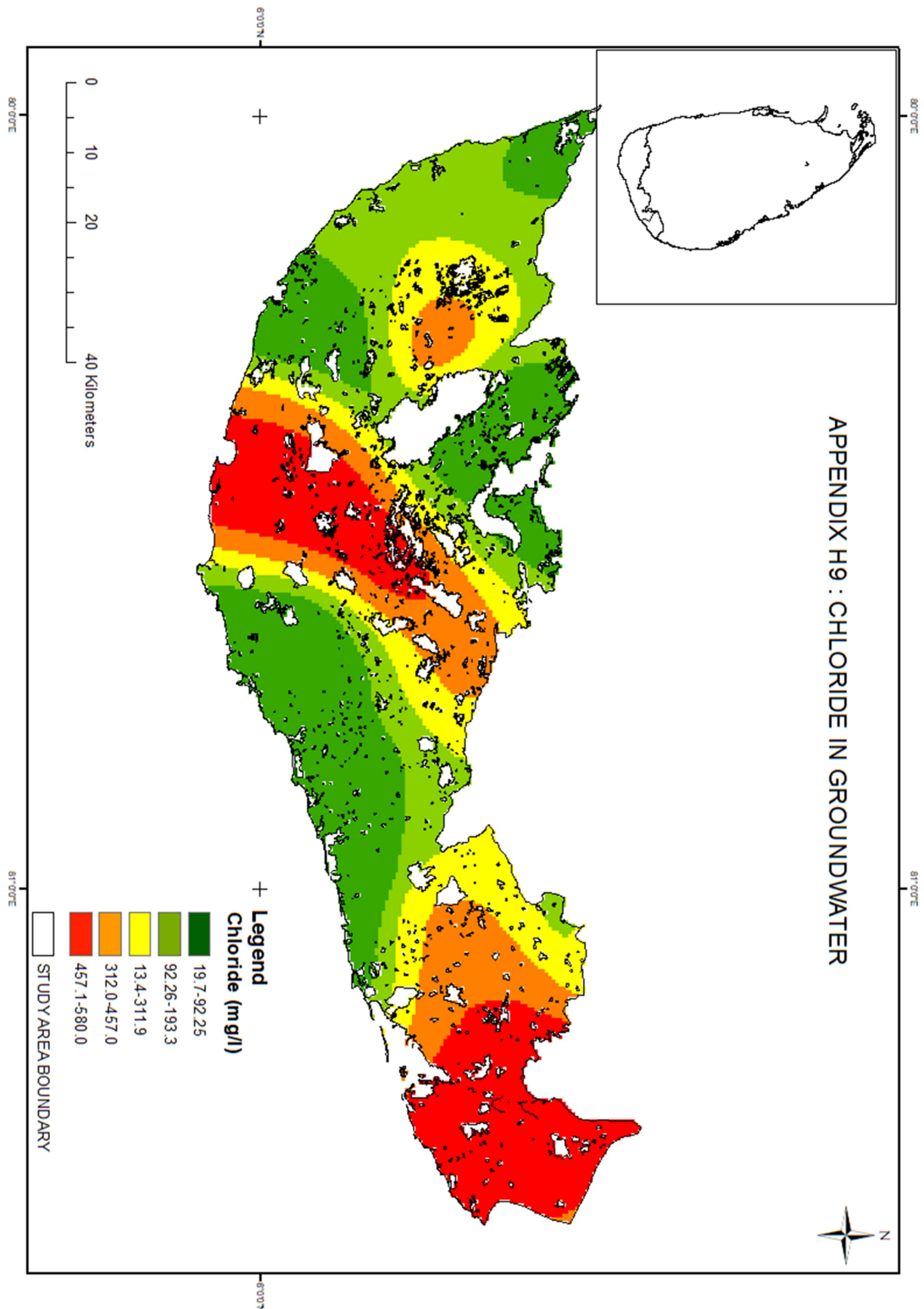
Appendix H7. – Total Iron in Groundwater



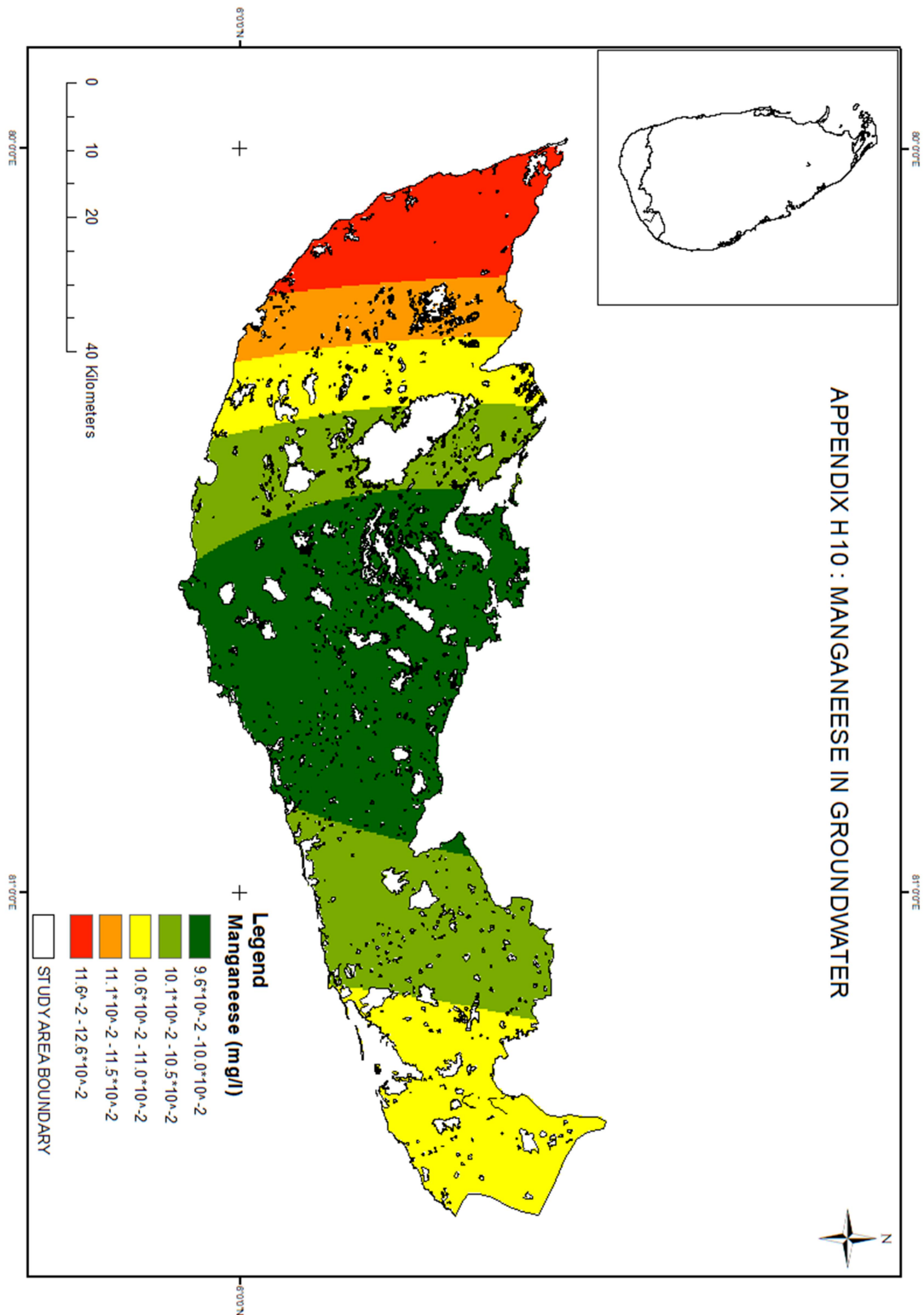
Appendix H8. – Flouride in Groundwater



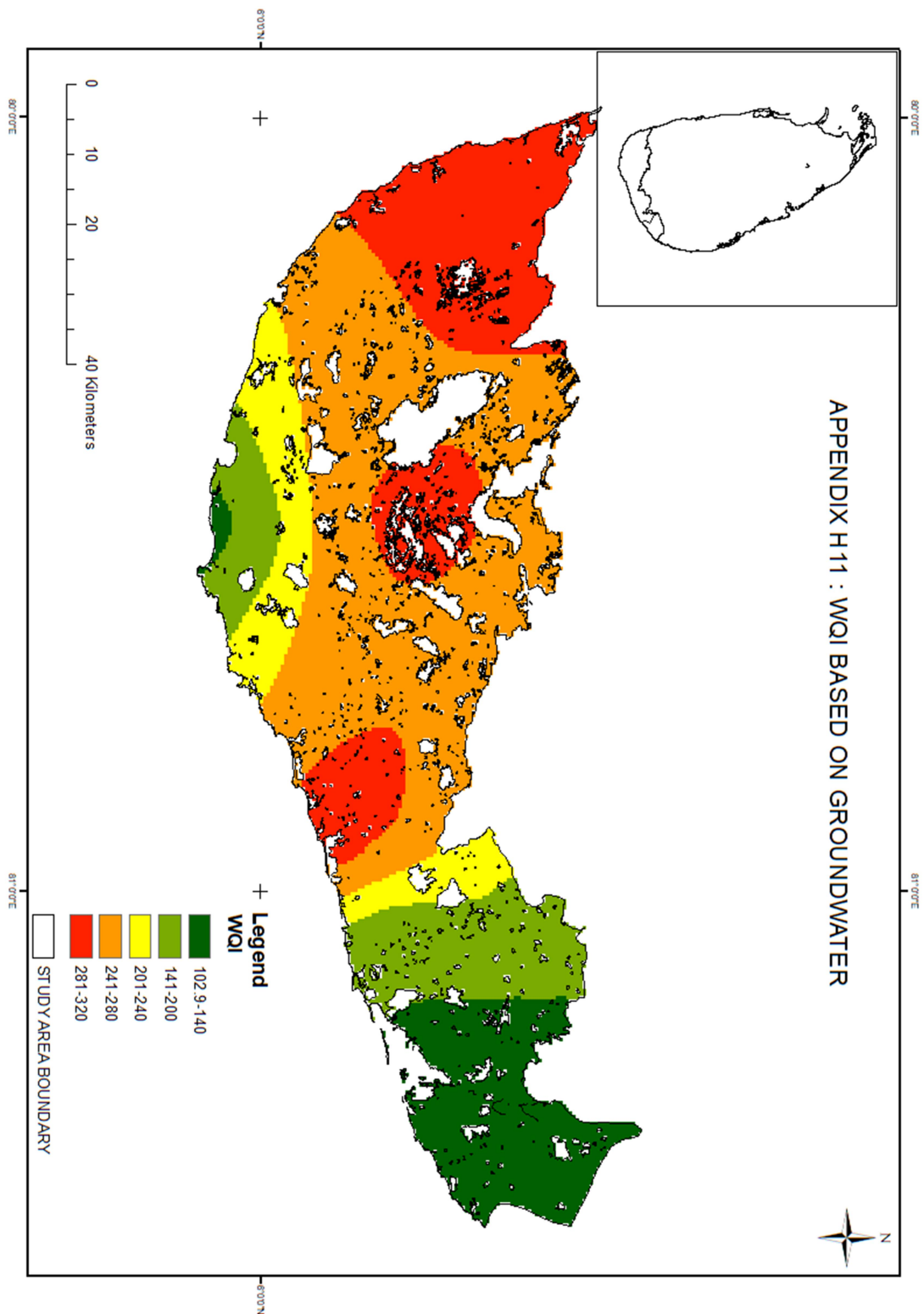
Appendix H9. – Chloride in Groundwater



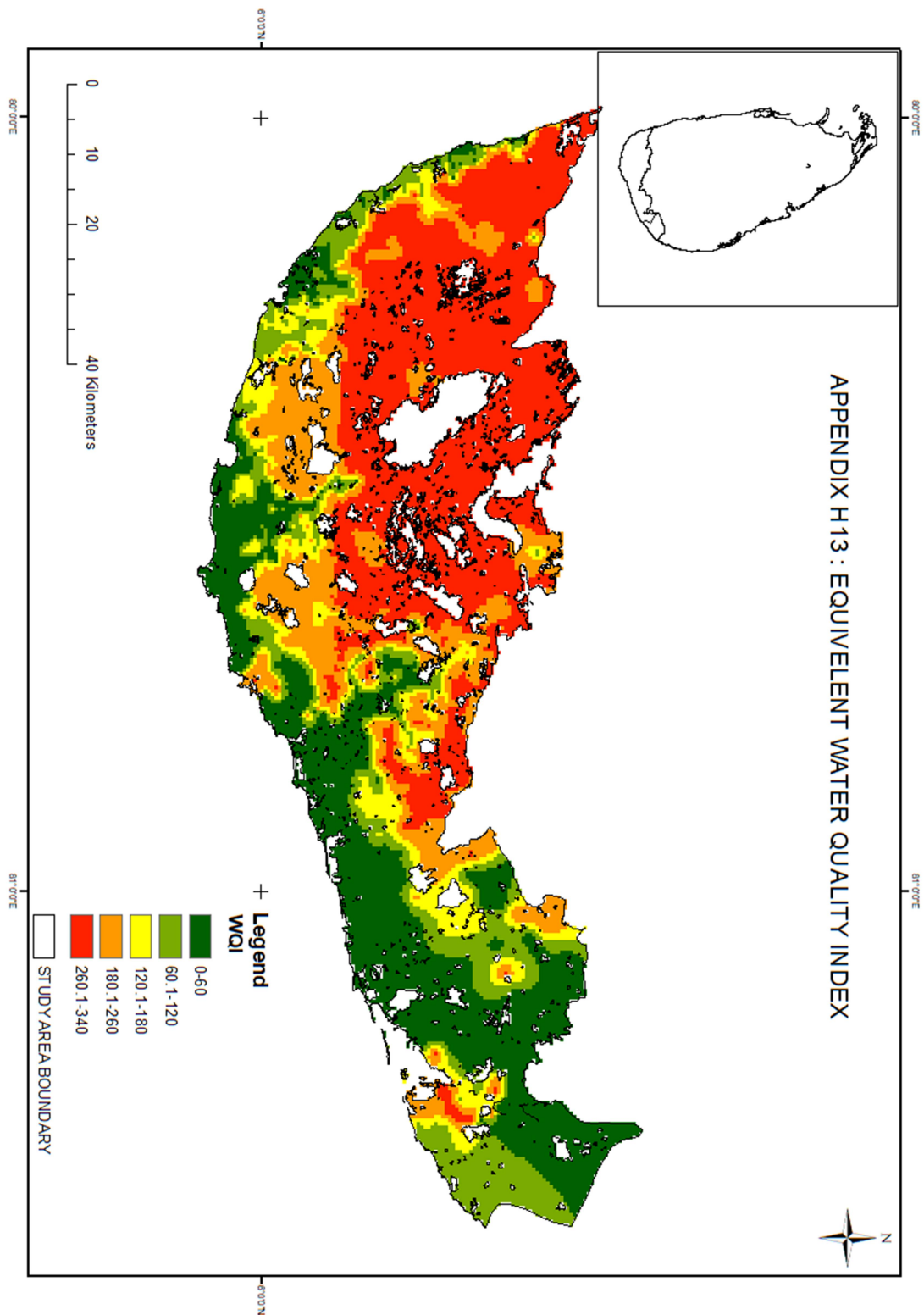
Appendix H10. – Manganese in Groundwater



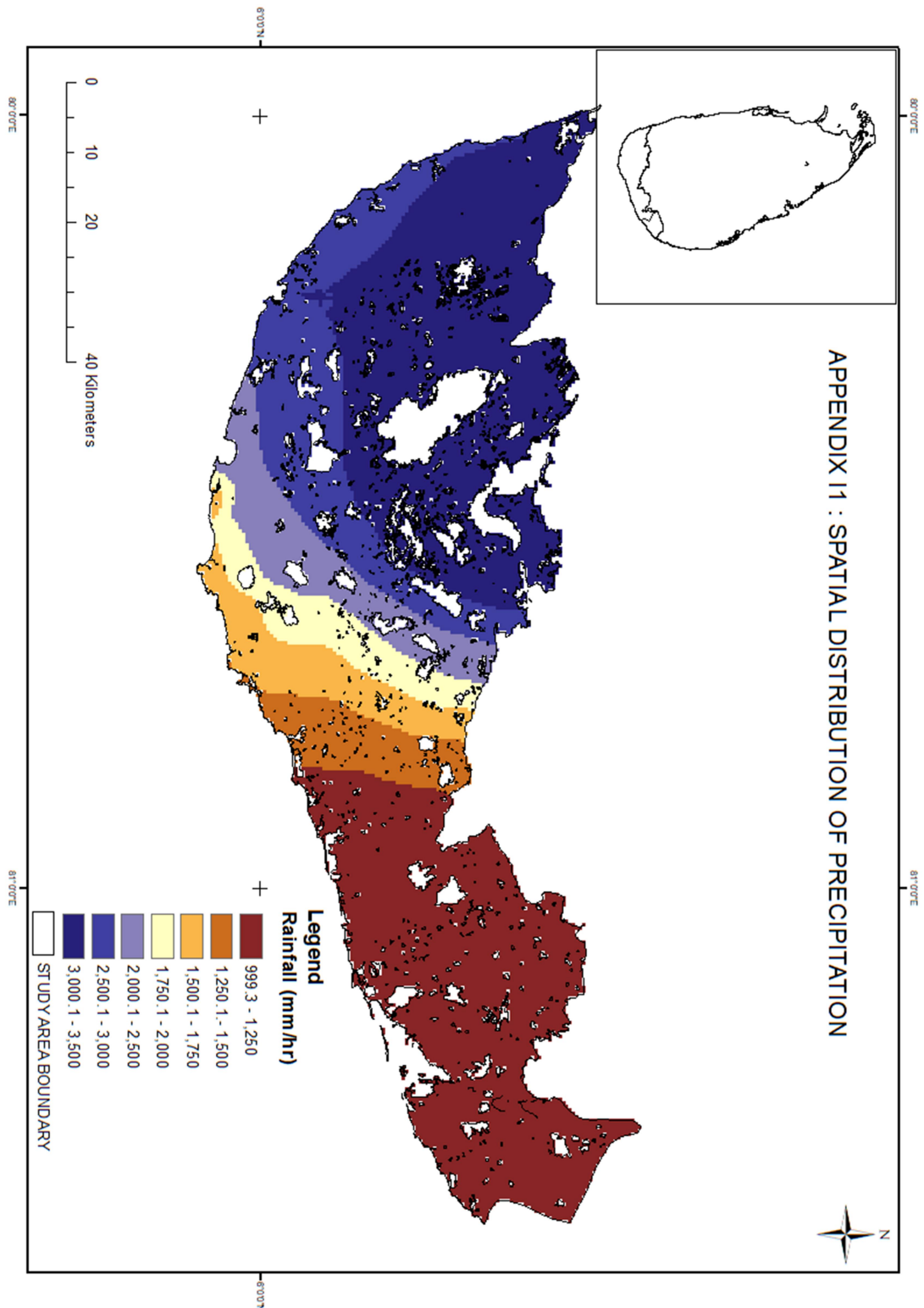
Appendix H11. – WQI based on Groundwater quality



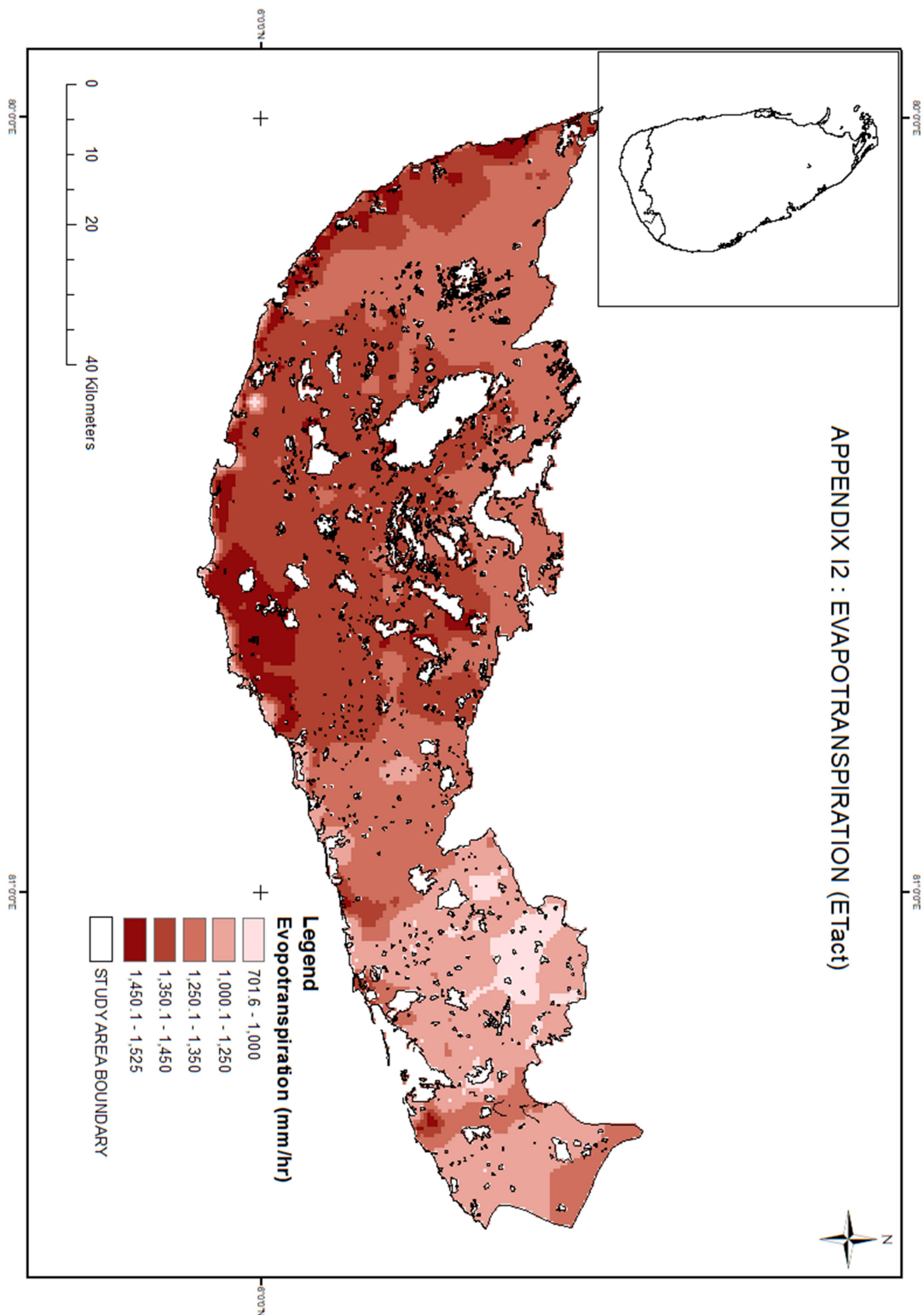
Appendix H13. – WQI based on Groundwater quality



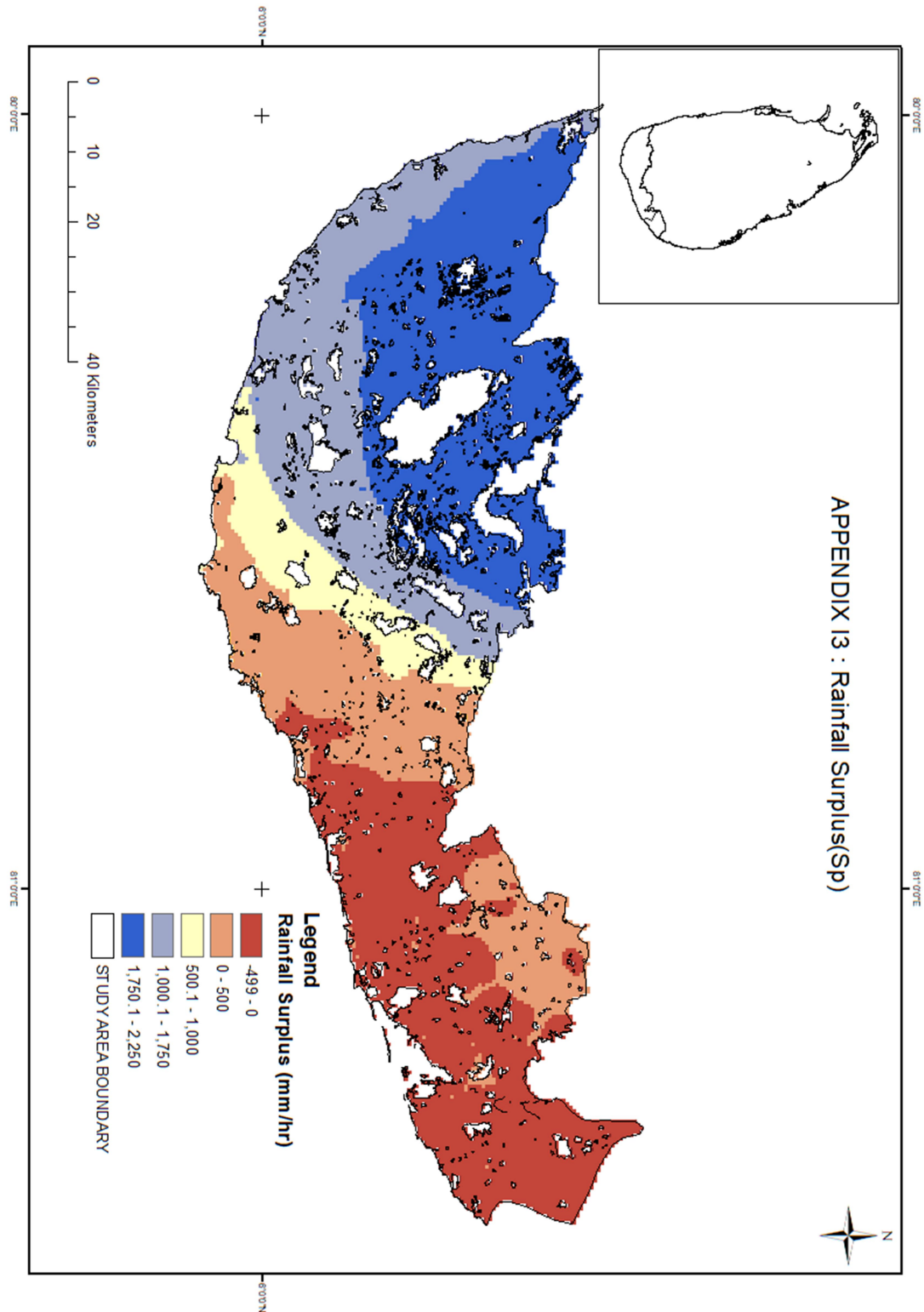
Appendix I1. – Spatial Distribution of Precipitation



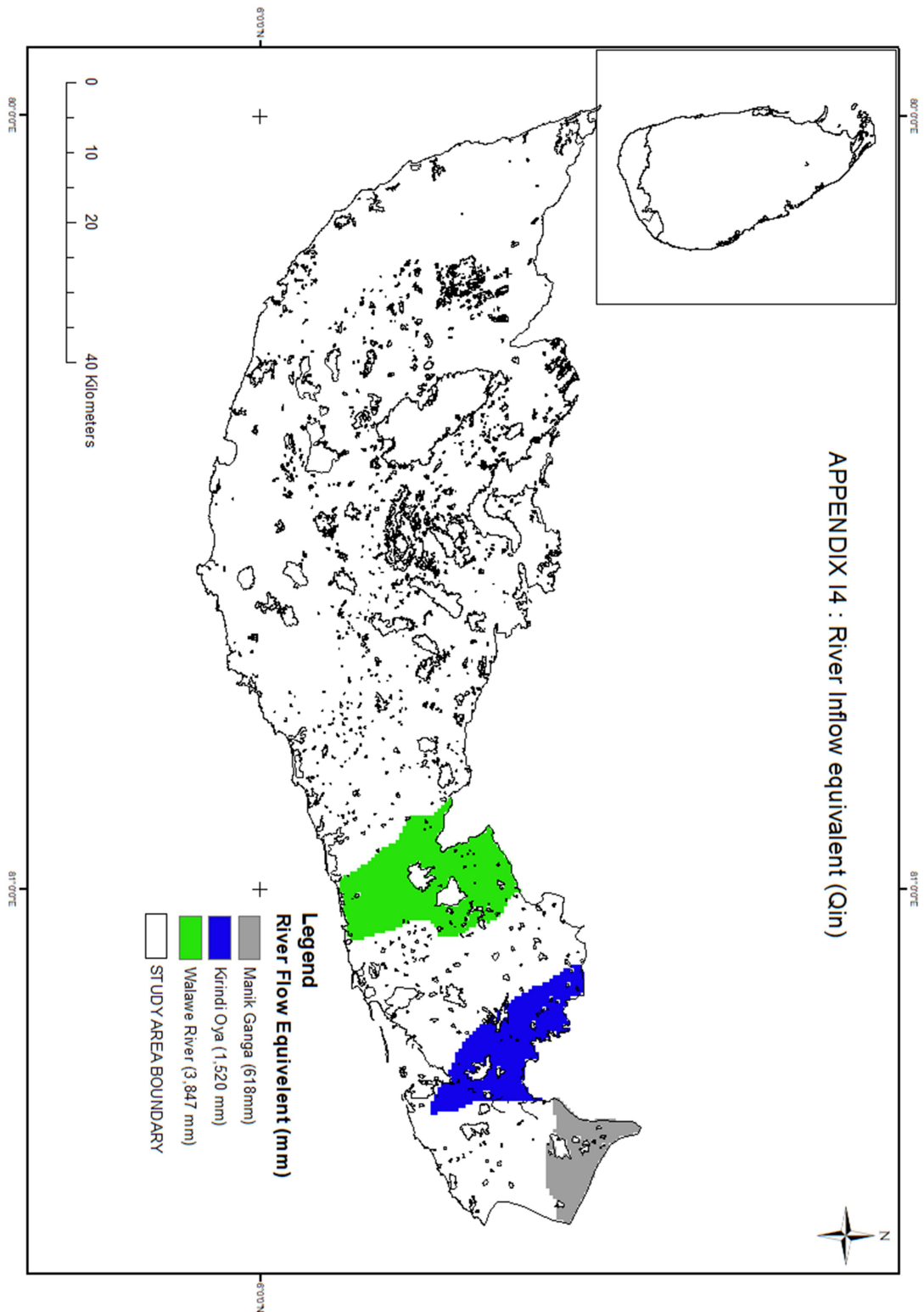
Appendix I2. – Spatial Distribution of Evapotranspiration



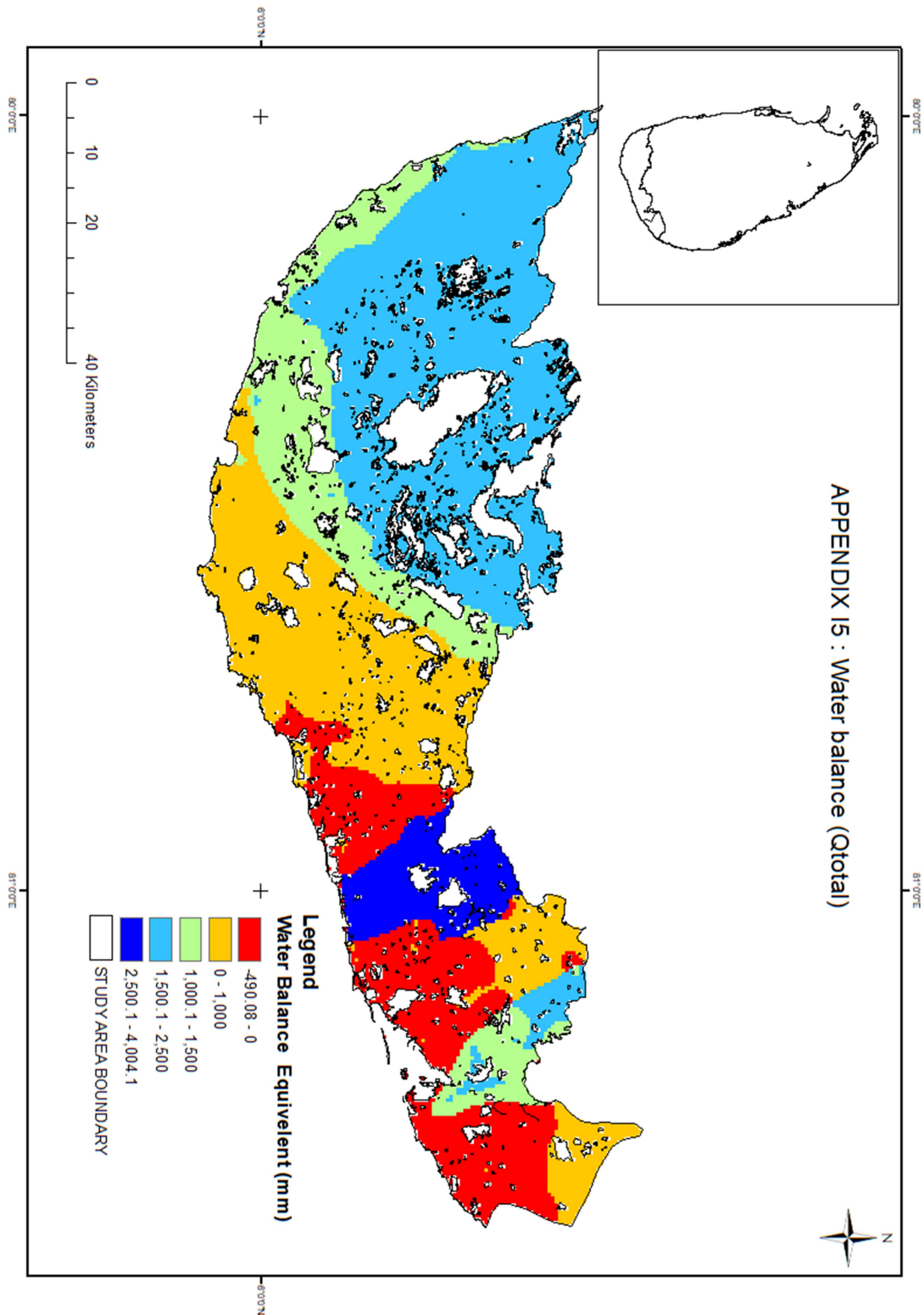
Appendix I3. – Spatial Distribution of Rainfall Surplus



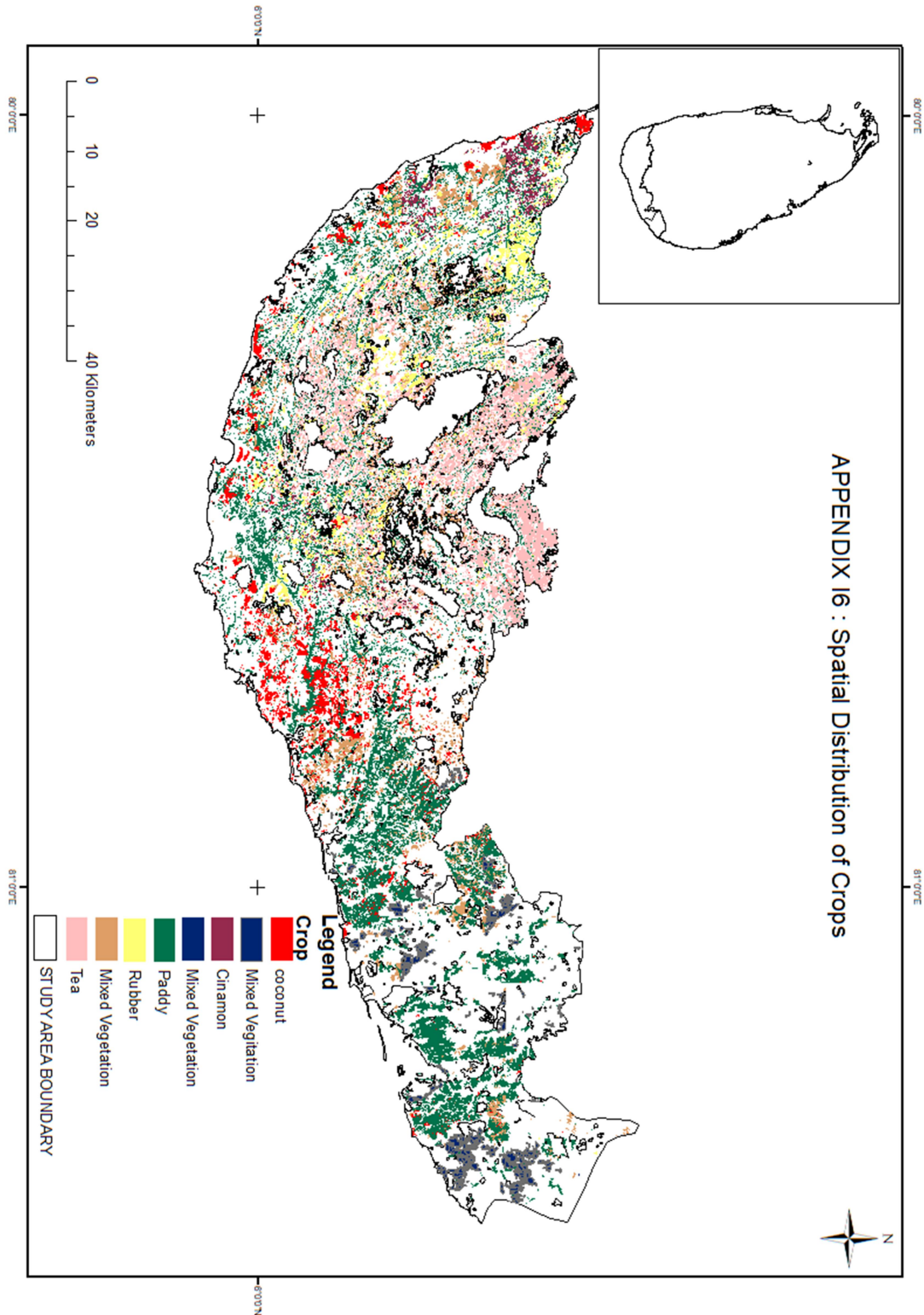
Appendix I4. – Equivelant River inflow



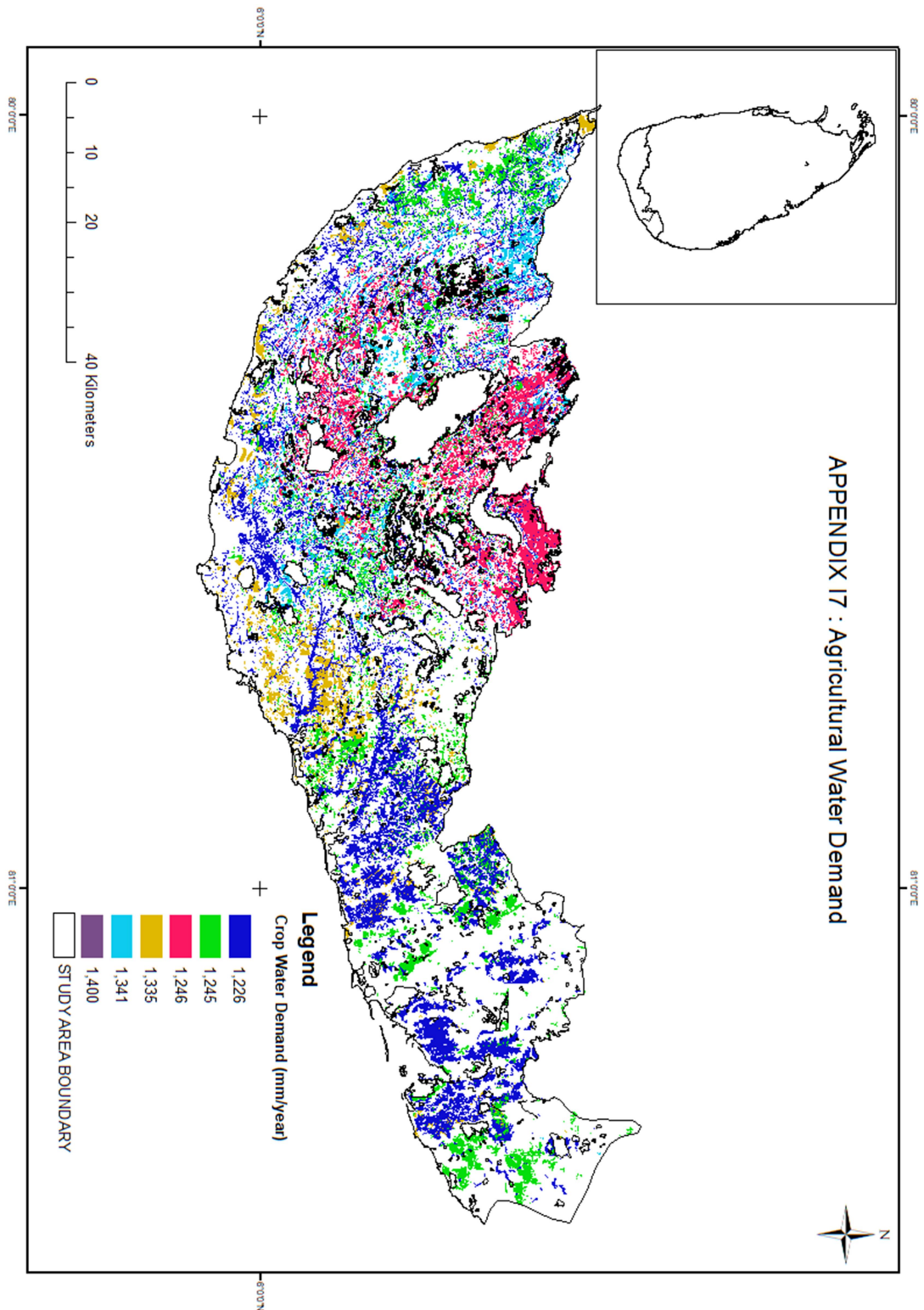
Appendix I5. – Water Balance



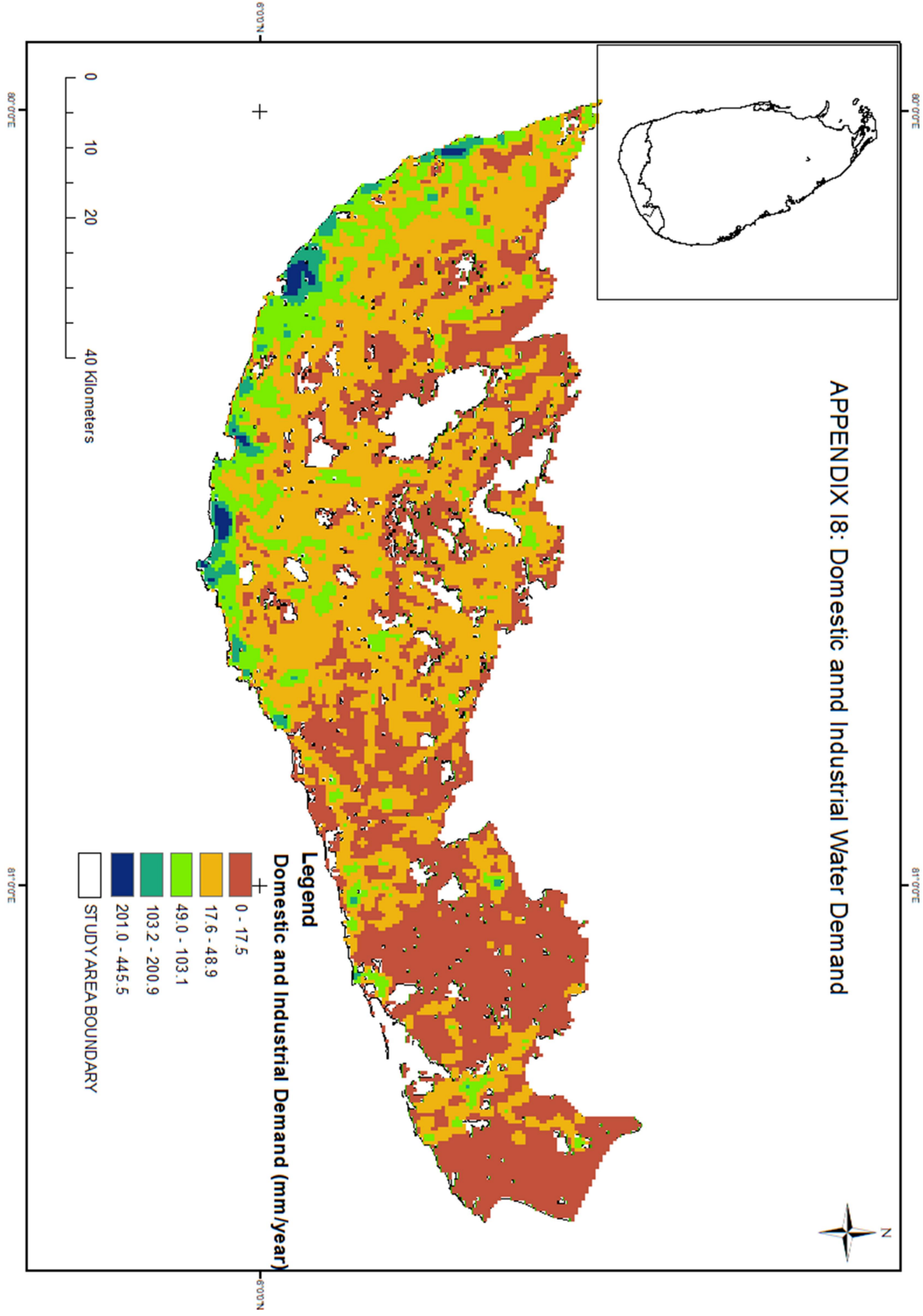
Appendix I6. – Spatial Distribution of Crops



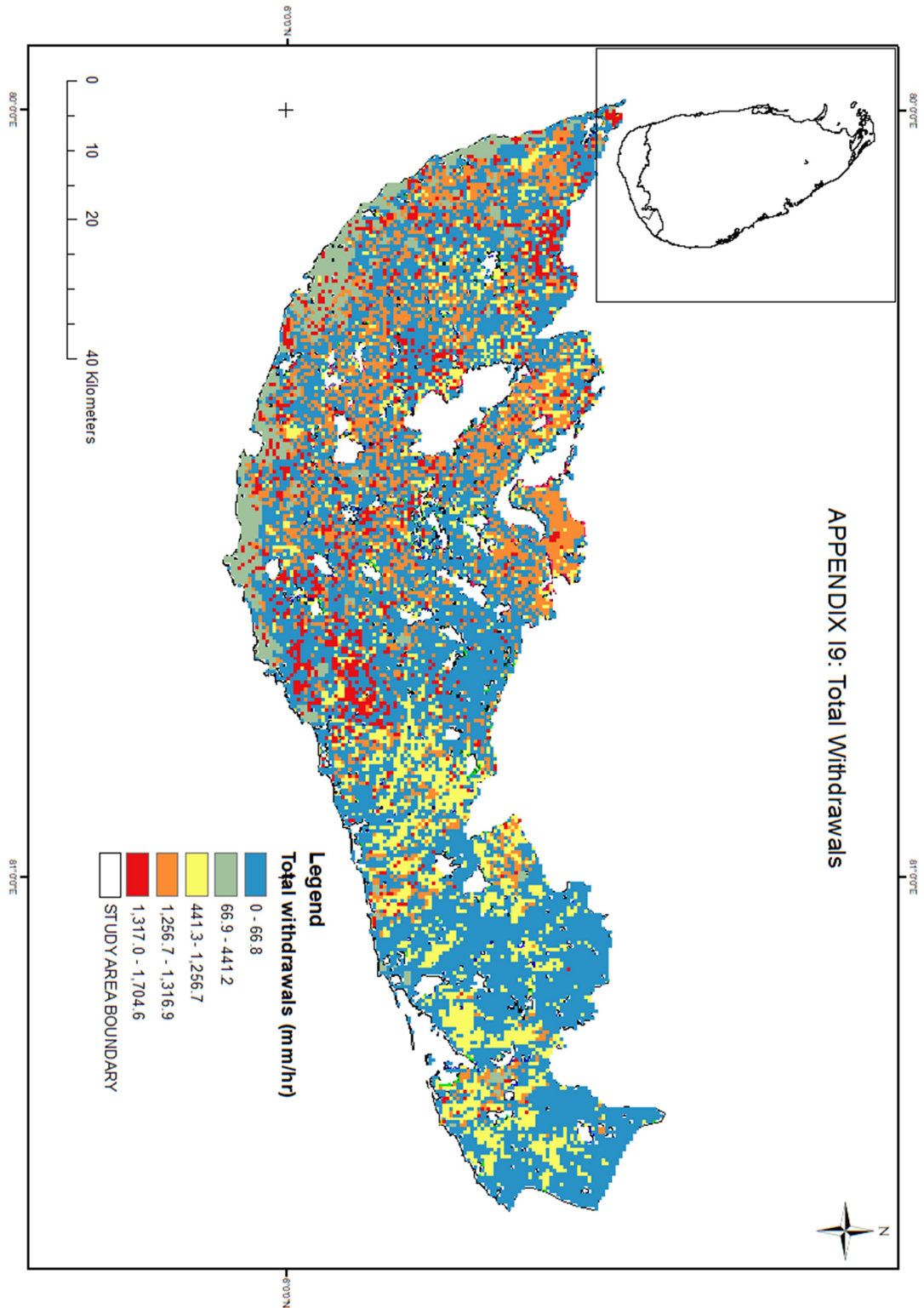
Appendix I7. – Agricultural Water Demand



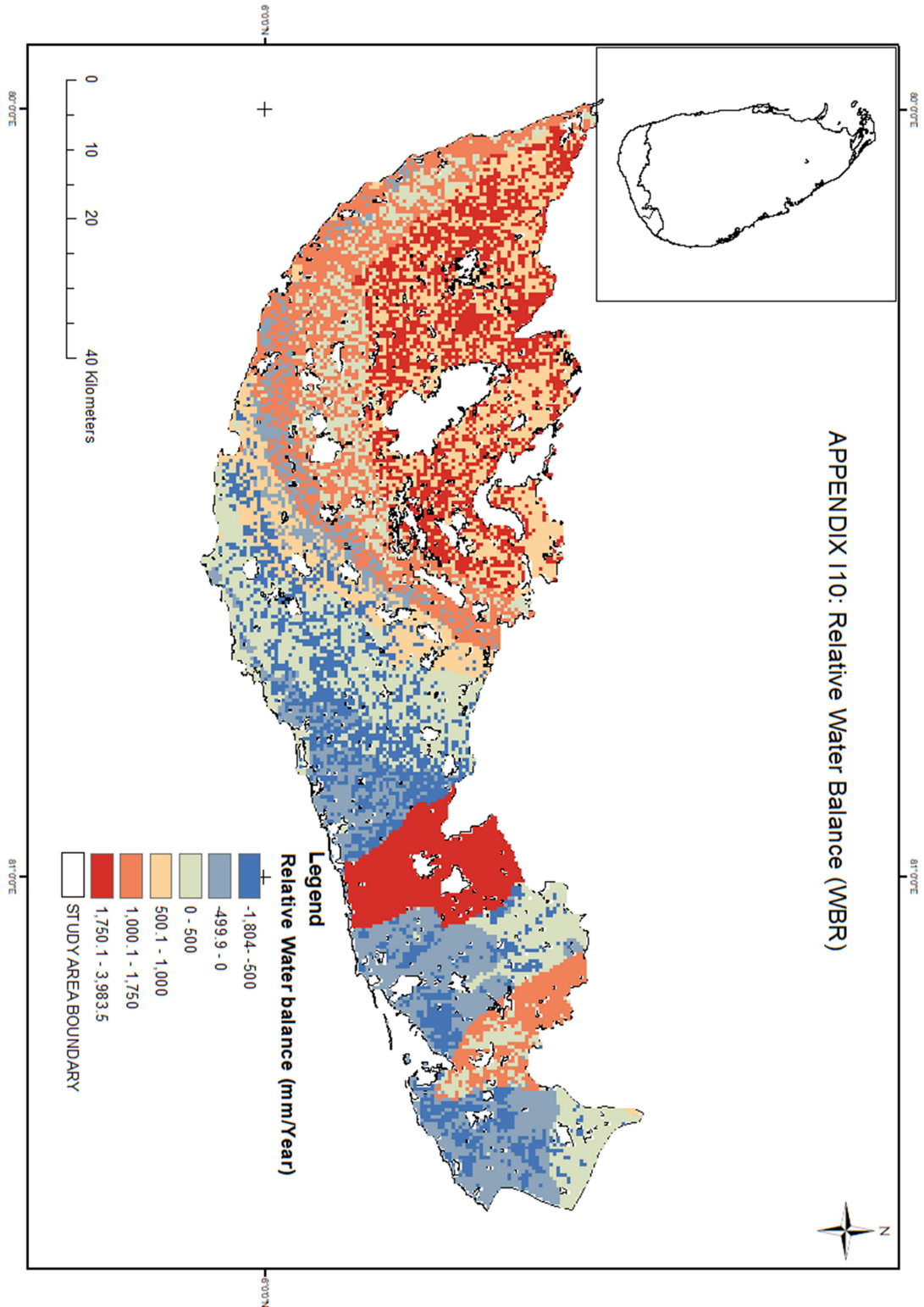
Appendix 18. – Domestic and Industrial Water Demand



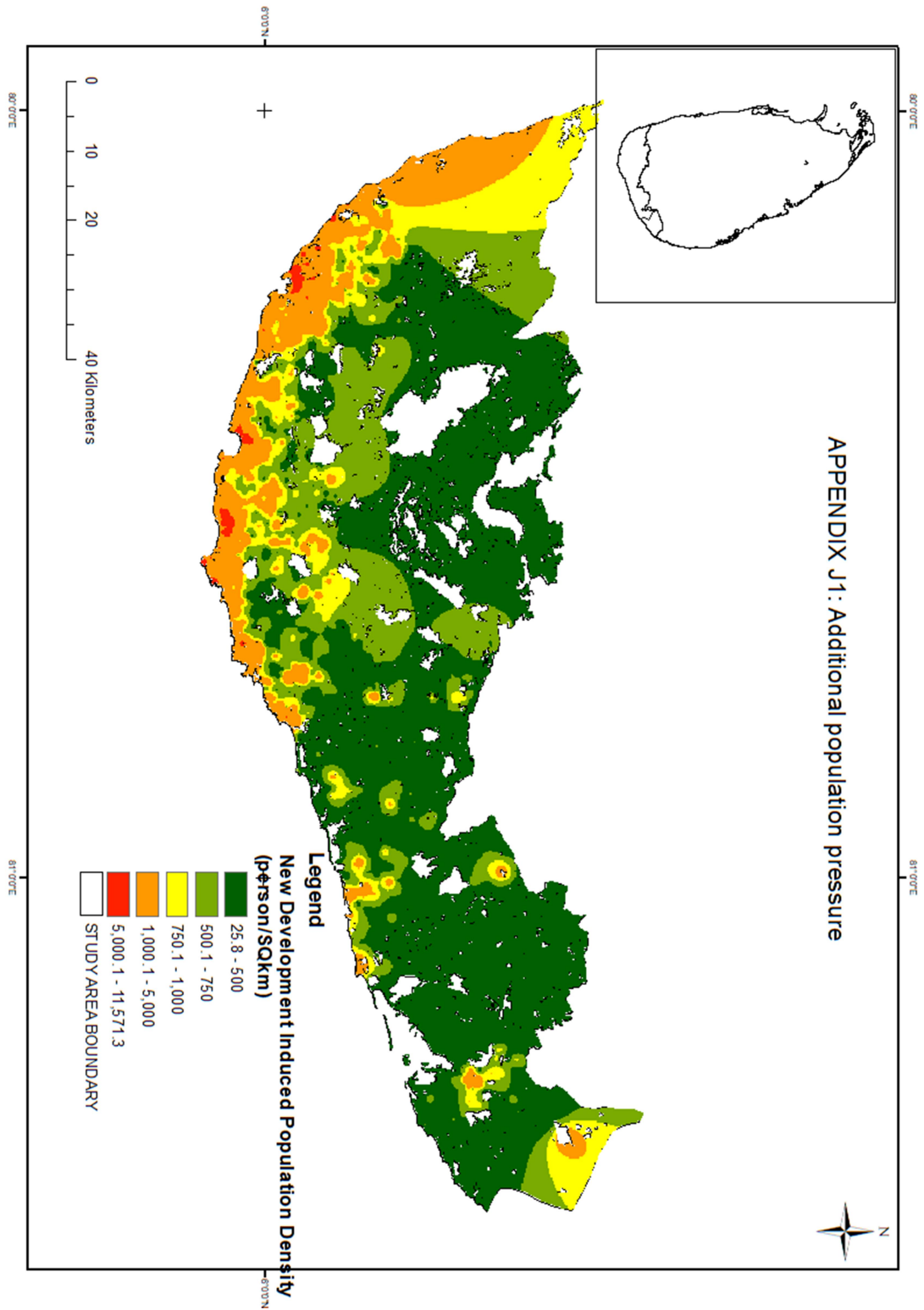
Appendix I9. – Total Water Withdrawal



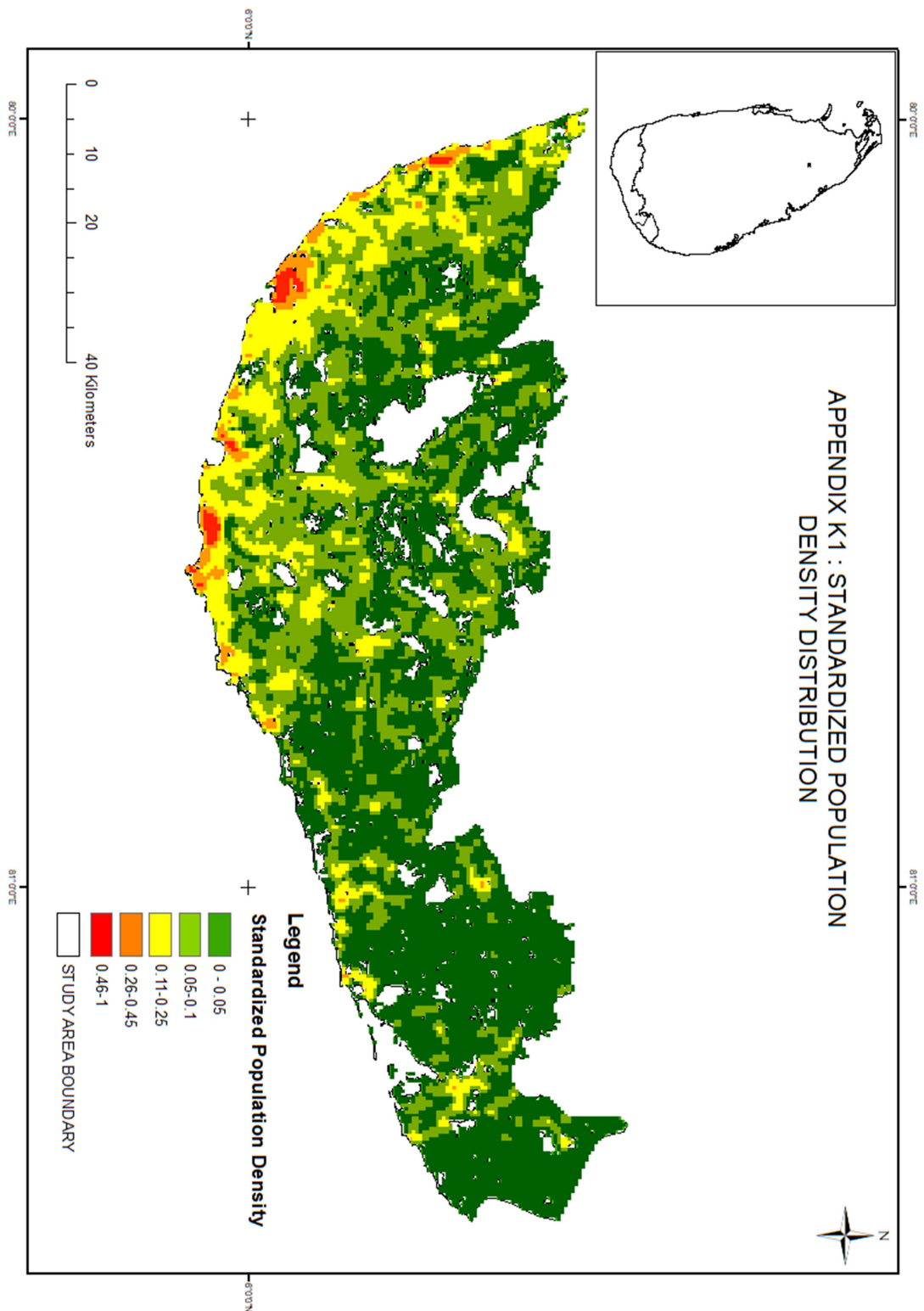
Appendix I10. – Relative Water Balance



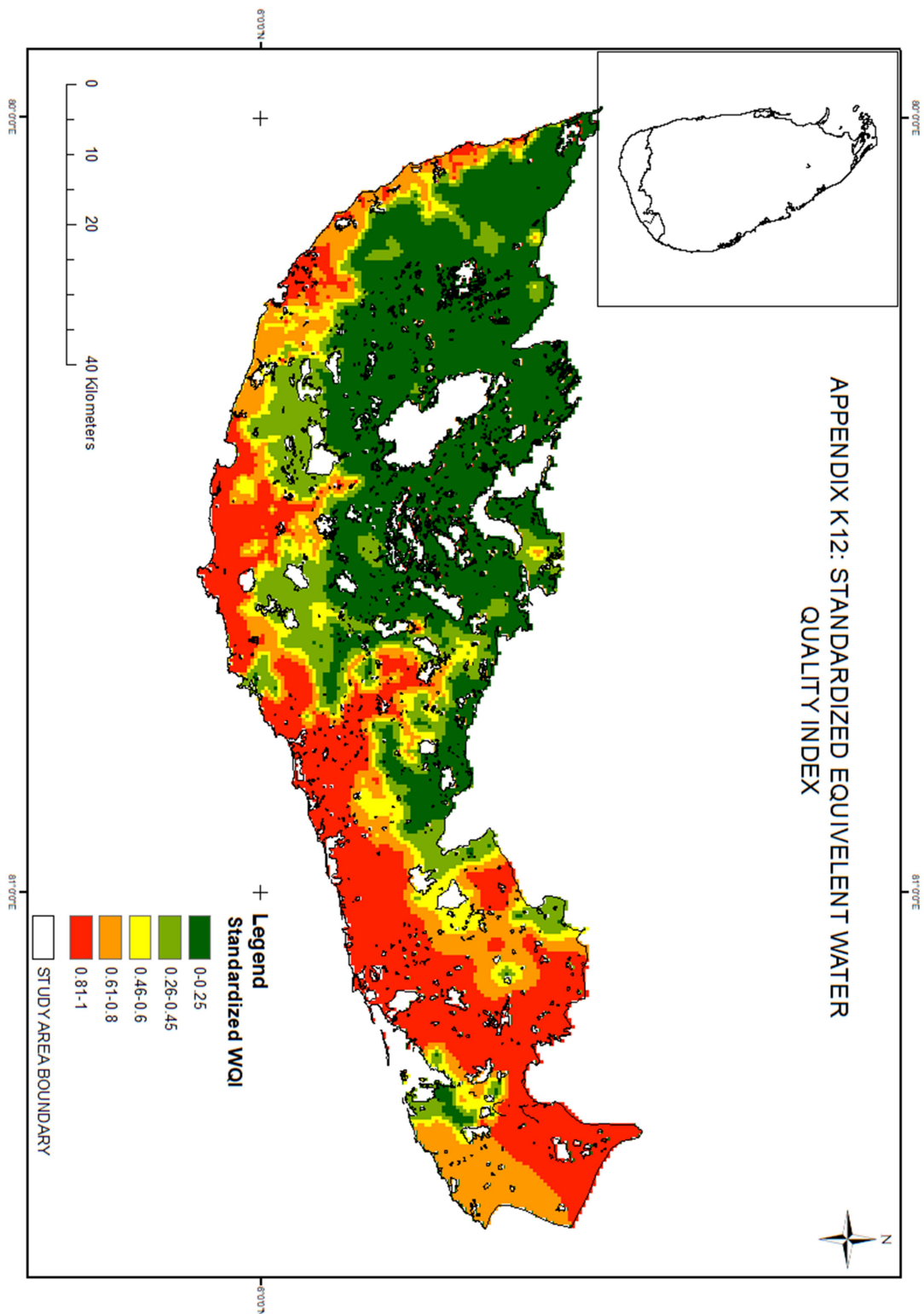
Appendix J1. – Population Pressure due to New Development



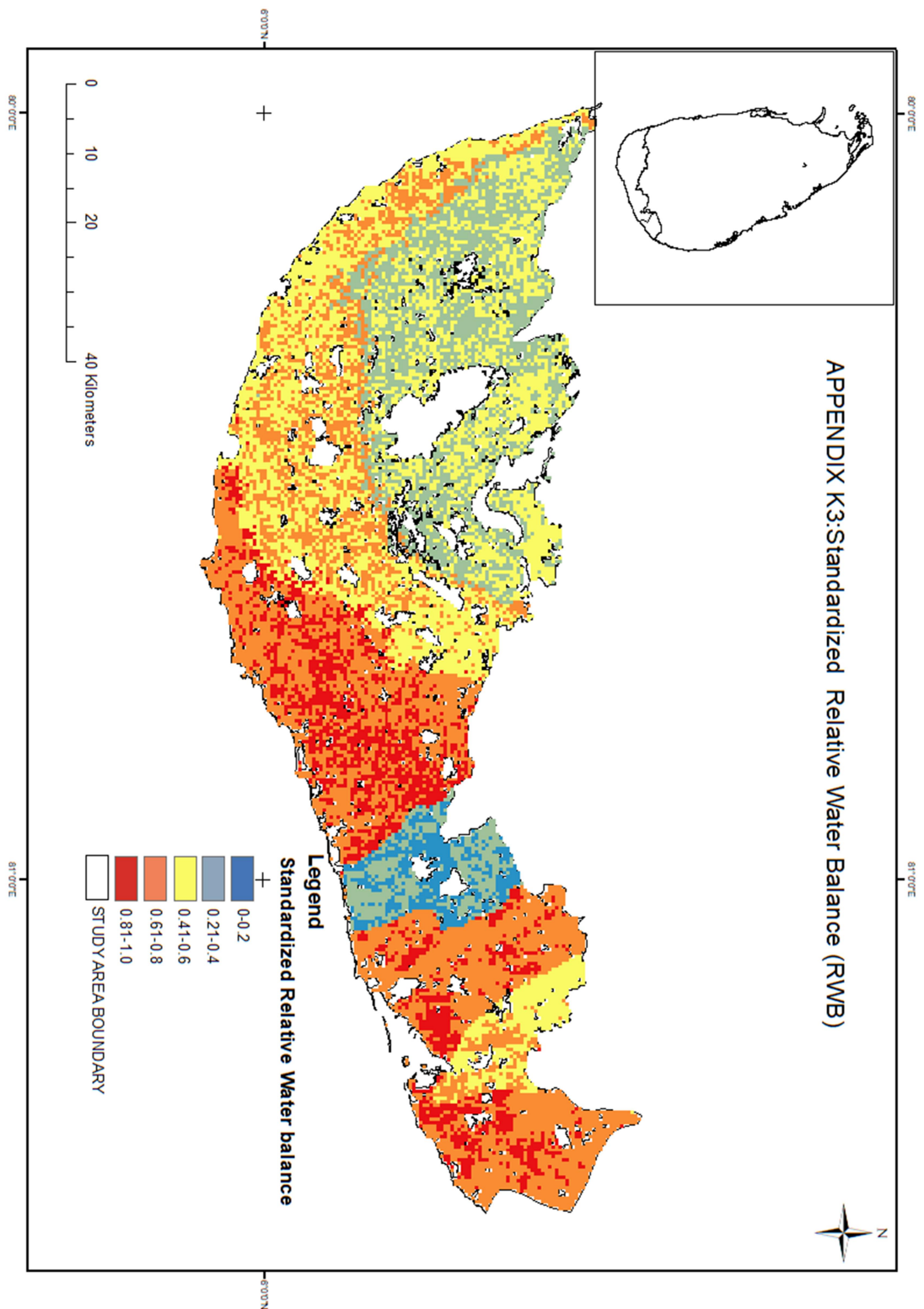
Appendix K1. – Standardized Score for Population Density



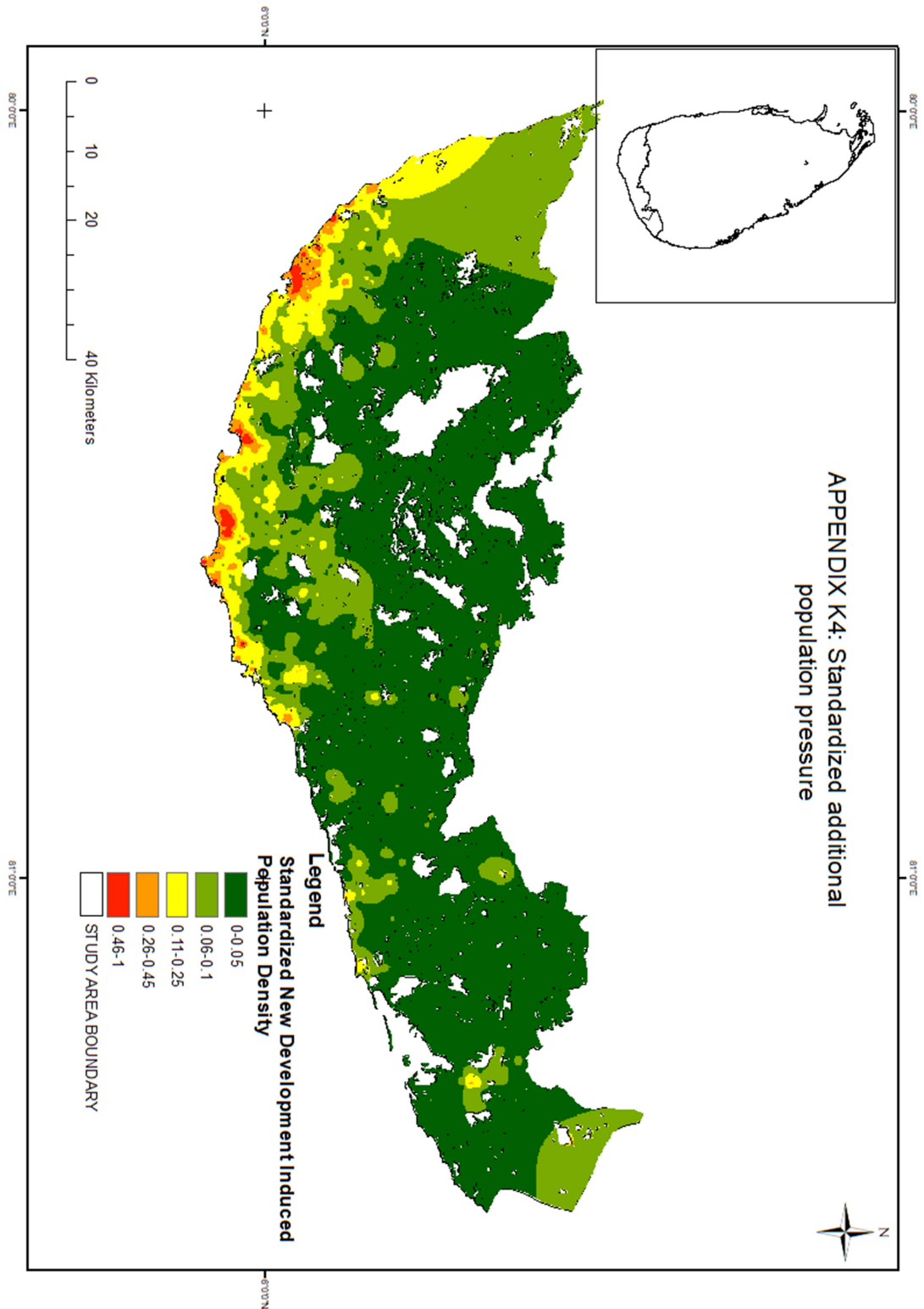
Appendix K2. – Standardized Equivelent Water Quality Index



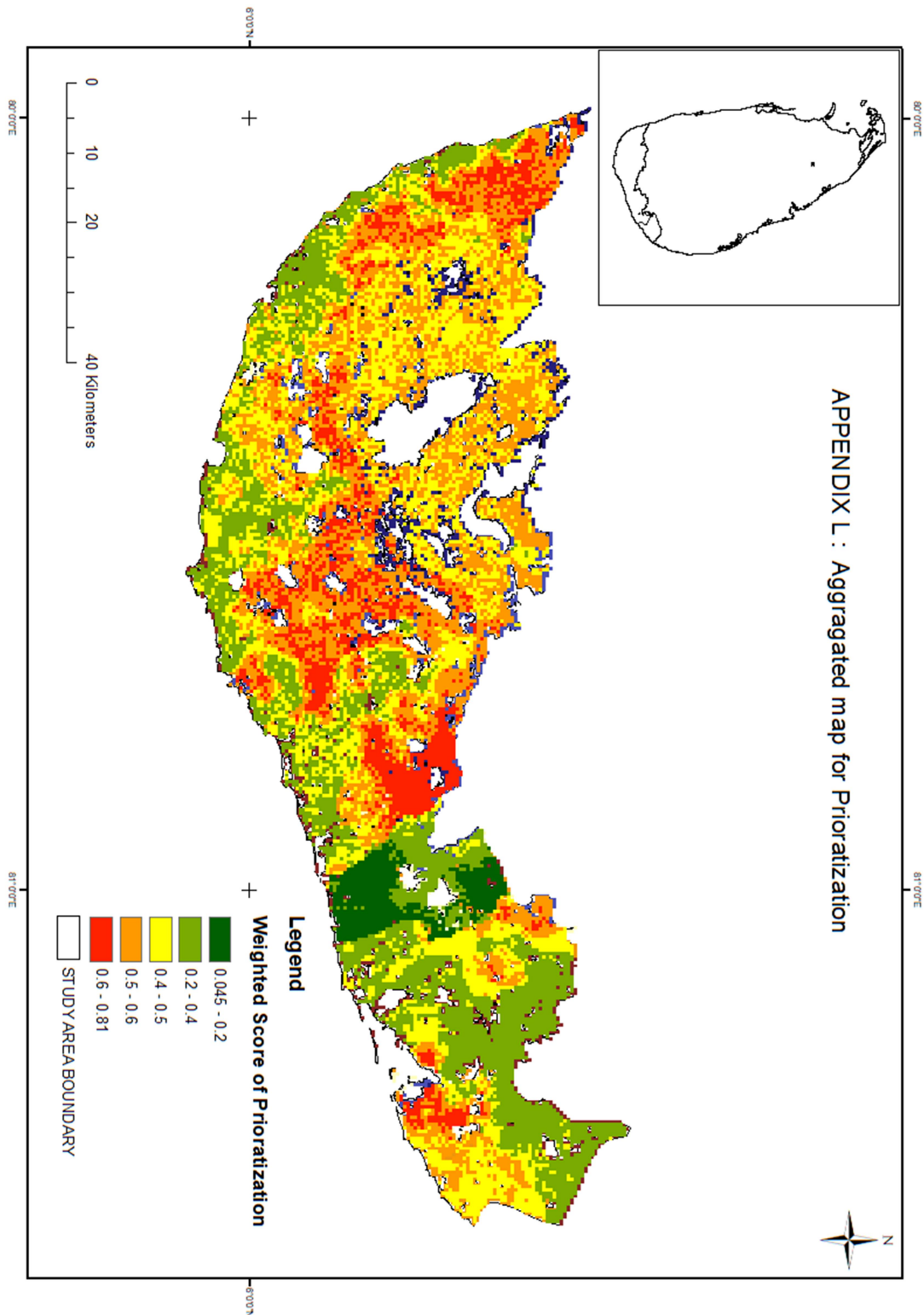
Appendix K3. – Standardized Relative Water Balance



Appendix K4. – Standardized New Development Induced Population Pressure



Appendix L. – Aggregated Map for Prioratization



Appendix M. – Questionnaire on weighting the criteria

Master Degree Research 2016/2017 - University of Moratuwa Sri Lanka

*A.S.Hewapathirana, Senior Engineer, Sector Planning Division,
RSC(S), NWSDB, Pamburana, Matara, Sri Lanka*

Dear Sir/Madam,

I am currently engaging on a research work of on GIS-MCDA Based Approach in Prioritization of Drinking Water Supply Need pertaining to the master's degree of Environmental Engineering and Management. GIS-MCDA Based Approach in Prioritization of Drinking Water Supply Need. In This Questionnaire I am willing to recognize the main parameters to plot the prioritization of neediness for drinking water supply

.....
A.S.Hewapathirana

Identification of Main parameters

It was understood that the main parameters to rank the drinking water need as follows. Please state any parameter or sub parameter required additionally.

	Main Parameter		Sub Parameter
1	Water resource availability	1	Relative water Balance
		2	Other (Please Specify)
2	Drinking Water Quality	1.	Equivalent Water Quality Index
		2.	Other (Please Specify)
3	Magnitude of Water Demand	1.	Population Density
		2.	Other (Please Specify)
4	Possible Developments	1.	Population thrust due to new development
		2.	Other (Please Specify)

Stage 2. Prioritization of sub parameters

It is vital to weight the sub parameters to build the final prioritized zones for drinking water need. Please provide a score for each sub parameter compared to each other.

Please tick a score for the sub parameter based on following 0-9 scale compared to each.

Compared parameter :Population Density										
Sub parameter	Score (0-9)									
	0	1	2	3	4	5	6	7	8	9
Relative water Balance										
Equivalent Water Quality Index										
Population thrust due to new Development										

Compared parameter : Relative water Balance										
Sub parameter	Score (0-9)									
	0	1	2	3	4	5	6	7	8	9
Population Density	Already filled									
Equivalent Water Quality Index										
Population thrust due to new Development										

Compared parameter : Equivalent Water Quality Index										
Sub parameter	Score (0-9)									
	0	1	2	3	4	5	6	7	8	9
Population Density	Already filled									
Relative Water Balance	Already filled									
Population thrust due to new Development										

Comment (If any)

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.....

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Name Of respondent:

Designation :

Division:.....

Date:.....

Appendix N. – NWSDB prioritization guideline for implementation of Water Supply Projects

Government of the Democratic Socialist Republic of Sri Lanka

Ministry of Water Supply & Drainage

National Water Supply & Drainage Board

Draft 1

The Criteria for Deciding the Priority of Water Supply Projects

January 2012

Policy & Planning Division

When the consumers have a high affordable and willingness to pay the scheme shall assign a high priority.

18. Annual Rainfall

Need for piped water scheme is largely govern by the rainfall received in the area. When there is a regular high rain fall the water resources constraints will be minimum and the demand for piped water schemes becomes less. Accordingly when there is a high rainfall the priority assigned to the project shall be less.

3.0 ASSESSMENT OF THE PRIORITY

The Model to develop the priority as elaborated below could be useful as a decision making tool.

	Criteria	Weightage	Range/Rank	Factor
1.	Population Density (Person/Km ²)	10%	High (>3000)	1
			Medium (3000 - 1500)	0.5
			Low (<1500)	0.25
2.	Demand	5%	High	1
			Medium	0.5
			Low	0
3.	New Development	8%	High	1
			Medium	0.5
			Low	0
4.	Age of the Scheme (Years)	5%	Old(>20)	1
			Middle (<20)	0.5
5.	Level of Service (hrs.)	3%	Low (0-6)	1
			Medium (6-12)	0.5
			High(>12)	0.25
6.	Quality of Water (major indicators)	5%	Lying inside	1
			Lying outside	0
7.	Possibility for Integration	2%	Possible	1
			Not Possible	0
8.	Water Resource (yield)	4%	High	1
			Medium	0.5
			Low	0.2
9.	Service Coverage (Population served/ design population)	5%	Low (<0.5)	1
			Medium (<0.85)	0.5
			High (>0.85)	0.2
10.	Potential increase of coverage	5%	High	1
			Low	0.5

11.	No. of Breakdowns		5%	High (>20)	0	
				Medium (<20)	0.5	
12.	Social & Environmental Impacts		3%	Low	1	
				Medium	0.5	
				High	0.2	
13.	Financial Viability	Unit Cost of water (Rs.m ³)	10%	Low(<50)	1	
				Medium (50-100)	0.5	
				High (>100)	0	
		EIRR %		5%	Low (<12)	1
					Medium (5-12)	0.5
					High (<5)	0
		Capital Investment (Rs.1000/Person)		10%	Low(<10)	1
					Medium (10-15)	0.5
					High (>15)	0
14.	Alternative Water Resources		5%	Dry	1	
				Partially reliable	0.5	
				Alternative source reliable	0.2	
15.	Financial Affordability (%) (population %)		5%	High (>20%)	1	
				Low (<20%)	0.5	
16.	Average Annual Rainfall (mm)		5%	Low(<1500)	1	
				Medium	0.5	
				High (>2500)	0	
TOTAL			100%			

4.0 CONCLUSION/ RECOMMENDATION

The weightage given to each parameter is a subjective judgment. The appropriate weightage and range/ranks shall be determined after a detailed consultation.

For each individual identified Parameter the weightage and range/ranks shall be cross checked through a consultative process. This exercise could be carried out through a trial and error process to validate the Model.