MSc Program
Environmental Technology & International Affairs

An Index for Water Availability per capita in Asia and the Pacific with Case Studies

A Master's Thesis submitted for the degree of
"Master of Science"

supervised by
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Vienna, 6 June 2009

Affidavit

I, **Celine Helen Stocker**, hereby declare

1. that I am the sole author of the present Master's Thesis, "An Index for Water Availability per capita in Asia and the Pacific: with Case Studies", 84 pages, bound, and that I have not used any source or tool other than those referenced or any other illicit aid or tool, and
2. that I have not prior to this date submitted this Master's Thesis as an examination paper in any form in Austria or abroad.

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Abstract

The availability/consumption ratio – or AVCOR - incorporates hydrological data and socio-economic variables in order to establish a comprehensive measure of water availability per capita within a defined system borders. While the index is applicable to any area depending on the size of the system borders, the focus of this work is centred around the Asia-Pacific region, using Australia as a case study, and also applying the index to a selection of countries within Asia. The Water Poverty Index (Sullivan *et al.*, 2003) is used as a basis for this new index, and relevant criticisms and alterations of this index is made in order to formulate the AVCOR. The AVCOR itself is comprised of data portraying available water resources and the relevant consumption patterns of the population group under evaluation. Hydrological data – such as external and internal renewable water resources, and annual average precipitation values, will be integrated into this new index. Additionally, consumption patterns relating to domestic water use and water use for agricultural purposes will also be used within the formulation of this new index. The final AVCOR will then be weighted with the average GDP (in PPP, cap/year) of the evaluated population group within the system borders, in order to effectively assess the population's capacity to combat eventual water scarcity. The new index also encompasses a temporal dimension, which will assess per capita water availability at any given time of the year. The AVCOR is a useful tool on which policymakers may base their decisions pertaining to water allocation and water resource management in order to alleviate water stress and poverty to specific population groups.

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1 Introduction

Water scarcity is a many-faceted global issue, which affects millions of people worldwide, both directly and indirectly, every day. The United Nations' News Centre (2006) stated that water scarcity has far-reaching effects, and can be viewed as a contributing factor to social issues such as corruption, political participation, civil rights, and education. The problem of water scarcity is further exacerbated by influences such as climate change, population growth, and increased urbanization and urban migration. In further illustrating this point, UNESCO, in a report by the UN News Centre, (2006) stated that the global water crisis is actually a crisis of governments, which "determine who gets what water, when and how, and decides who has the right to water and related services." For many, water scarcity means suffering from disease and malnutrition caused by floods or droughts, while for others it means having to walk miles to access safe drinking water (UN News Centre, 2006). A report by Frank Rijsberman, Director General of the International Water Management Institute (IWMI), states that access to sanitary and affordable water is integral to alleviation of poverty, and warns that if exploitation of freshwater supplies continues there may be increased problems of flooding, loss of water rights and access, drought and pollution (Rijsberman, 2005). All of these issues must be adequately addressed in order to find a sound, equitable and integrated solution to water poverty, on regional, national and global scales. In view of this, the United Nations Division for Sustainable Development Agenda 21, Chapter 18 (1999) states that;

> *"The widespread scarcity, gradual destruction and aggravated pollution of freshwater resources in many world regions, along with the progressive encroachment of incompatible activities, demand integrated water resources planning and management. Such integration must cover all types of interrelated freshwater bodies, including both surface water and groundwater, and duly consider water quantity and quality aspects."*

This work aims to emphasise the imminent need for sufficient management and regulation of water resources. It is with this statement relating to management and regulation of water resources in mind that this work is written. This thesis will focus on the applicability of water-related indicators in the formation of an integrated index, so as to achieve equitable water availability within the system borders. The aim of this index, therefore, is to establish a measure of water poverty on both *regional* and *national* levels, which can be further utilized as a management tool for alleviation of water poverty. Understanding water poverty is at the heart of correct management of water resources and is required prior to an assessment of national water resources and drafting and implementation of relevant policy.

The aim of this paper is to provide an index by which water availability per capita, with relation to water consumption, can be measured. This should in turn be compared to a number of significant socio-economic and geographic indicators, which will lead to a better and more accurate understanding of water availability and allocation. The conclusion of this paper will highlight the main factors, which are most relevant for low water availability per capita. This is the first regional index for water availability, and should therefore be viewed as a starting point from which further adaptation will result in a more comprehensive localised index for water availability. Indices of this nature can be applied not only on a national or regional level, but can be utilized to assess water availability per capita on a global scale. Despite this, the focus of this paper will be on Asia and the Pacific, and therefore a number of sample countries from these regions will be taken in order to demonstrate the functioning of this index. The formulation of such an index is required due to the inherent importance of water in sustaining human life, and the considerable strain that will be placed on water resources in the future. The Water Poverty Index (2003) will be used as the basis for this work. The Water Poverty Index aims to measure water poverty in a number of countries, yet does not give an adequate breakdown of water poverty in specific regions of the country. The aim of this work, therefore, is to establish an index by which additional factors pertaining to geography, climate and demographics and so on can be introduced to give both rural and urban measures of water poverty. It will also be shown that water poverty cannot be established on a country basis, and instead should be broken down in order to demonstrate the regions in which actual water poverty is faced by population groups. This should in turn lead the way for policy makers to address water poverty on a localized scale, and serve as a useful tool with which policy makers can make informed decision with regard to revision of water legislation, allocation and policy on a regional, or even national scale. A case study will be subsequently given to support this.

The initial section of this paper will present an overview water resources and water scarcity within the Asia and Pacific regions. The follow chapter will involve methodology, and outline primary considerations for the formulation of an appropriate index to measure water availability per capita in the region. This section will also involve a quantitative comparison with important socio-economic and geographical factors. The subsequent chapter will draw together the results of this analysis, and give a detailed overview of the most important factors for diminishing water availability per capita. Each factor will firstly be described in detail, giving an explanation of what is entailed in the factor itself. A quantitative value will also be given for each factor (and for each country in the region), based on available data from international organizations such as the United Nations Economic and Social Commission for the Asia Pacific (UNESCAP), the World Bank, the World Health organization and relevant national government agencies. Data on water availability and consumption per capita in each country will then be compared with these values and a concrete index to assess water availability per capita will be established, and a value illustrating the relationship will be given. An overall figure will then be given for each country based on aggregation of these figures. The last section of this paper will be a conclusion which will draw together all of the relevant data, and provide a comprehensive overview of the index and its possibilities for further application. Australia will be used as a case study to illustrate the relationship between geography and climate on water availability. This analysis will present a clear dichotomy regarding water poverty in rural and urban population groups. While only being applied to one country, this type of analysis can be further applied to other countries, particularly where divergences in climate types and precipitation values are evident. This index will show water availability per capita as a function of water accessibility and consumption.

There are a number of other indices which have attempted to answer the same questions posed by this thesis. However, while these indices often do consider essential socio-economic issues which are affected by water scarcity, they often only analyse water poverty on a national scale, rather than on a regional scale. This regional approach would serve to pinpoint the actual water poverty of rural and urban population groups. This thesis aims to analyse the effects of relevant socio-economic (such as GDP, in PPP per capita) and geographical factors *on a localized scale* in order to distinguish a direct correlation between water availability and specific population groups, which are found to be lacking in previous models. Additionally, this model will differentiate between those populations living in rural areas, and in urban areas, and also incorporate an examination of water availability based on geography and climatic conditions. Income groupings within countries will also become a major determinant in the application of the index and its importance to management of water policies. It should also be noted that while this index will initially be formulated on a localized scale within the case study, the index itself should be viewed as applicable on a national basis, with aggregate population groups forming the foundation of this tool for policymakers. To this end, Australia will be later used as an example to which this type of analysis could be applied. The Water Poverty Index (WPI) will be used as a base index for the completion of this analysis. Naturally, geographic and hydrometerological determinants must also be considered in this analysis to ensure comprehensiveness. Criticisms of the Water Poverty Index will be discussed, as models such as these only analyse water availability on a regional or national scale, rather than adapting analytical results to a specific area within a country.

Water supply

Issues concerning water scarcity arise when the demand outweighs the supply over any significant period of time. Water shortages occur most commonly in regions with low precipitation and low water inflow, or in areas with a high population density. Scarcity of water supplies is often noted in areas with intensive agricultural or industrial activity, both of which demand a high quantity of water in order to function effectively. On top of this, overexploitation of water resources can cause natural areas to become drier, and also lead to saltwater intrusion into aquifer and other important water sources.

Each country usually operates and manages a large network of stations which systematically measure precipitation and river-flow. In order to simplify the procedure, particular attention is paid to the larger and more substantial bodies of immobile surface waters, which are generally the most secure of water resources available. However, problems still arise due to the nature of groundwater. Groundwater itself is a natural reserve of exploitable water resources, which is subject to outflows and inflows of water from other sources. Groundwater volume can be estimated and analysed in terms of exploitable potential per year, and serves to replenish rivers with a base flow in the absence of rain. The replenishment of groundwater resources by precipitation is essential in avoiding agricultural failures and droughts, but this is often impeded by removal of vegetation or soil compaction (ADB, 2001). While data outflow is relatively simple to estimate by means of extraction history and measurement of river base flows, data for inflows into groundwater is dependent on a much wider range of variables, and therefore this specific type of data is only available in a limited number of countries (ADB, 2001). The ADB (2001) states that,

> "*The agencies responsible for collecting information (for example, the department of public works or the department of irrigation) routinely analyse the raw data to derive totals, averages, measures of dependable flow, and time series indicators (including indicators of rainfall intensity). Some of the measures developed may be rather detailed. For instance, available water can be defined as the volume flowing in a river that is available at least 90 percent of the time.*"

Water Usage

The ADB (2001) uses the following categories are used to estimate water use, which can then be utilized in combination with information on water supply and utilization. Analysis of water availability indicators and data can give a clear overview of national and regional water supply issues. Anthropogenic pressures and its effects are often reflected by statistics on water usage, which can be accumulated through classification of water usage systems (ADB, 1999). As previously mentioned, water usage can be broadly defined in two primary categories – consumptive and non-consumptive usage patterns (ADB, 2001). As the type of water consumption can depict relative water scarcity, this point merits further definition and discussion

Consumptive use of water resources entails the extraction of water from its source, and involves such activities as domestic water use, irrigation and industry - particularly from groundwater resources (ADB, 1999). Data concerning consumptive use of water resources are often reported by division of sector: for example domestic water usage (household, public and commercial establishments), industrial usage (including water that is not technically consumed during heating and cooling processes), and for agricultural usage (ADB, 1999). Water for consumptive usage can also be partitioned into groundwater and surface water usage, of which groundwater is the more reliable source of freshwater as it does not possess the pathogens and other pollutants which are often found in surface water bodies, and is usually of a more acceptable colour and turbidity (ADB, 1999). The ADB's paper on *Core Environment Statistics and Methodological Issues* (1999) applies this information to specific Asian countries in stating that,

> *In India, groundwater supplies 80 percent of rural drinking water compared with 60 percent in Nepal and the Philippines (ESCAP 1995). Surface water, obtained from natural or man-made reservoirs, is a major source for industrial use. In Malaysia, surface water supplies most of the industrial demand, but in India and Nepal, groundwater provides up to 80 percent of industrial water (ESCAP 1995). Water used for agriculture is predominantly surface water, except in arid and semiarid regions where groundwater supplies a considerable volume (e.g., Pakistan).*

On the other hand, non-consumptive use involves the use of water on site, and is used for fisheries, generation of hydropower, recreation, and navigation (ADB, 1999). As opposed to consumptive usage, data for non-consumptive uses are generally not given in quality of water used, and are instead often displayed in values obtained from the use of this water (ADB, 1999). For example; values displayed for non-consumptive water used in hydropower plants for electricity generation are usually in Gigawatt hours per year (ADB, 1999). For the purposes of this new index, consumptive use of water resources is most relevant.

Two separate measures for water availability are most employed on the national level. Firstly, a measure of the renewable water supply, which is an aggregate annual quantity that is employed primarily as a foundation for further development of indicators and indices of water supply and availability. The critical level of use is attained when the rate of water extraction reaches or surpasses the average annual water availability. The second measure involves the ratio of available water resources to the total population as a whole. Countries can consequently be ranked by relative water availability per capita. An example of such a measure would be the Falkenmark Index, or the Water Poverty Index (WPI).

The pattern and degree of water use depends on a significant number of variables, but on the macroeconomic scale, the most important determinants of water consumption include; the level of development, the composition of economic activities or economic structure (which is also related to the level of development), and climatic conditions (ADB, 2001). Over the last decade or so, domestic and industrial water use has declined dramatically, which is thought to be caused by an increased sense of awareness about water scarcity issues. However, a number of other effects may have triggered this – such as an increase in water rates, restrictions on garden watering and so on. In many developed countries, groundwater accounts for around three quarters of the public water supply. It is often used as a primary source of public water supply, mainly because of its superior quality as opposed to surface waters. Groundwater often has lower pollution values, and does not need as much treatment. However, because of this fact, there is an increasing pattern of overabstraction of groundwater resources, which has caused an overall decrease in water tables in many developed countries. The consequences of this are considerable; drying up of wetlands and increased salinisation of aquifers (ADB, 2001). ADB (2001) suggests that due to a lack of credible data and information, similar conclusions cannot be drawn in developing countries. This, in turn, means that no real comparison between developing and developed countries can be made on this front.

Although possessing one of the largest economic and industrial growth rates in the world, the Asian continent continues to suffer disproportionately from large scale degradation of water resources (including surface and groundwater), which has lead to considerable depletion of freshwater resources available per capita. Inefficient irrigation techniques, water-intensive industries and a growing middle class that wants high water-consuming comforts are often quoted as exacerbating problem (Challaney, 2007). Agriculture, mainly irrigation, accounts for the major part of water withdrawals. Up to 50 per cent of withdrawals in the more industrialized countries of the region are for agricultural purposes, but this figure increases to more than 90 per cent in all South Asian countries (with Bhutan as the exception), and arrives at 99 per cent in Afghanistan (UNEP, 2000). In addition to misuse and overexploitation of water supply, most developing countries in the region have suffered from growing water scarcity, deteriorated water quality, and sectoral conflicts over water allocation (UNEP, 2000).

Scarcity of water resources, and its effects on water availability, should not be underestimated. The years between 1950 and 1995 saw a decrease of water availability of almost 70 percent in Central and South Asia, around 55 percent in Southeast Asia, and approximately 60 percent in North Asia (ADB, 2009). On top of this, Challaney (2007) states that although Asia is home to more than half of the world's population, it has less water per capita than any other continent (around 3,920 cubic meters, whereas the world average is 7,600 m^3). With increasing population growth rates in many countries in the region, problems of water availability will surely worsen. By the year 2025, an estimated 3.5 billion people (almost seven times as many as in 2000), will be living in water-stressed countries (Kataoka, 2002). It should be noted, however, that water availability differs greatly within the region. In Singapore, for example, internal renewable water resources per capita are approximately 137 to 172 m^3 per year, whereas in Malaysia this figure is several times higher than this (UNEP, 2000). India, Thailand, the Islamic Republic of Iran, the Republic of Korea and Pakistan have between 1400 and 1900m^3 water available per capita, per year, whereas UNEP (2000) states that Papua New Guinea has a huge 174,000m^3 per capita, per year.

Another significant issue with regard to water availability is the absence or insufficiency of equitable water sanitation facilities, with an estimated 600 million people worldwide living without access to potable water and without suitable sanitation in 2005 (Kataoka, 2002). Kim Hak-Su, Executive Secretary of UNESCAP, said that "… in 2005, Asia was home to 71 per cent of the total number of people in the world without access to improved sanitation; 58 per cent of those without access to safe water; 56 per cent of the world's undernourished; and 54 percent of those living in slums" (UNESCAP, 2006). Affordable, reliable and equitable water sanitation is a perpetual problem for many, despite the fact that official records in most Asian countries demonstrate an improved access to infrastructure. The Water and Sanitation Program (2006) states that "… poor quality of services could in large part be ascribed to inefficient and financially weak service providers whose performance on important parameters falls significantly short of internationally accepted best practices". A decrease in hygiene and sanitation standards has facilitated the spread of waterborne diseases in both rural and urban areas, which then prompt the urban poor to spend a significant amount of their meager disposable income on water from private vendors or to carry water from distant areas (ADB, 2009). In Nepal, for example, women and children travel up to 15 kilometers over mountainous terrain to fetch potable water, which means that female children often miss out on the opportunity to attend school (ADB, 2009). While access to proper sanitation facilities is an extremely important point, it will not be included in the formulation of the index. As previously mentioned, population groups within countries will be classified by income, and it has been shown that access to sanitation facilities can be directly related to this. Therefore, in order to ensure simplicity of the index and resist over-complication, sanitation and GDP (in PPP, per capita) will be viewed as directly proportional to each other, and therefore a measure based on sanitation coverage is not merited within this particular index.

However, water resources and sanitation are not the only problems. The region is faced with water scarcity due to industrial and agricultural practices, both being large consumers of available water supplies within Asia, which contribute heavily to water pollution. Significant sources of pollution from these practices include industrial and sewage effluent, and agricultural and urban runoff (UNEP, 2000). Freshwater resources are continuously subject to degradation by means of pollution which include (but are not limited to); eutrophication (increased input of phosphorous and nitrogenous compounds from agricultural processes), salinisation, and increased content of heavy metals such as lead and arsenic (ADB, 2009). Research conducted by the Asian Development Bank show that surface water in Asian countries contains twenty times more lead that surface water in OECD member states, which is mainly a result of industrial effluent discharge (UNEP, 2000). India and Bangladesh suffer considerably from contamination of their groundwater with arsenic, and Japan suffers from dioxin pollution (a persistent organic polluter and a known precursor of itai-itai syndrome). In Bangladesh, for example, 97 per cent of the population accesses their drinking water through around 4 million wells, of which 19 percent were found to possess unsafe levels of arsenic (UNEP, 2000).

A number of international organisations are focussed on alleviation of water scarcity, and amelioration of water management and allocation issues within the Asia-Pacific region. Kataoka (2002) gives a good overview of the institutions operating with the mandate to resolve these important issues. Two primary institutions find themselves at the forefront of water resources management within the region; UNESCAP, an international organisation operating under auspices of the United Nations, and the Asian Development Bank (Kataoka, 2002). UNESCAP (2009), details its mandate as, "working to promote regional co-operation and to strengthen regional capacity on water resources management towards inclusive and sustainable socio-economic development for all in Asia and the Pacific." In addition to this, UNESCAP (2009) outlines the following tasks to successfully attain this mandate, which includes a) research work and development, b) raising awareness of water issues, both at the policy level and within the public, and c) increasing cooperation and partnership with UN agencies and other organisations focussing on development. The Asian Development Bank operates with a similar view in mind, as it "seek[s] to promote the concept of water as a socially vital economic good that needs increasingly careful management to sustain equitable economic growth and to reduce poverty" (Kataoka, 2002). Concomitant to UNESCAP, the Asian Development bank also details a number of relevant tasks to deal with water issues, which include a mandate to;

1. Promote a national focus on water sector reform;
2. Foster the integrated management of water resources;
3. Improve and expand the delivery of water services;
4. Foster the conservation of water and increase system efficiencies
5. Promote regional cooperation and increase the mutually beneficial use of shared water resources within and between countries;
6. Facilitation the exchange of water sector information and experience and;
7. Improve governance and capacity building (ADB, 2009)

There are, in addition, a number of additional significant actors which play a vital role in rectifying water scarcity and other water-related issues within the Asia-Pacific region, which include NGOs and other specialised agencies of the United Nations (such as UNEP). Furthermore, a substantive amount of models and indices have been established – the most notable being the Water Poverty Index – which aim to clarify similar water-related issues, not only within Asia, but also on a global scale.

The Water Poverty Index (WPI) was established by Lawrence, Meigh and Sullivan for Keele University in March 2003. The index itself employs a disaggregated approach, and was formulated with the view of assessing which countries were most at risk of water scarcity, and water poverty. This is illustrated in the forward section of the paper, in which it is stated that; “The purpose of the Water Poverty Index is to express an interdisciplinary measure which links household welfare with water availability and indicates the degree to which water scarcity impacts on human populations” (Sullivan et al., 2003). The formulation of this index took into a count a number of socio-economic and geographical factors (divided up into 5 primary groups), which aimed to accurately assess water poverty. These factors will be critically discussed later. The end result of the study was to present a ranked list of the 140 assessed countries according to water poverty (Sullivan et al., 2003). The main aim of this index was to supply policy makers, through the employment of relevant indicators, with a tool by which water management and distribution policies can be effectively applied on a national scale (Sullivan et al., 2003). The results from this index, therefore, should be used as a means to ameliorate water management techniques, which are either insufficient or lacking in many countries worldwide. The Water Poverty Index (2003) also states that it; “… enables national and international organisations concerned with water provision and management to monitor both the resources available and the socio-economic factors with impact on access and use of those resources”. Despite its aim to establish a national measure of water poverty, the index does recognize the importance of geographical variations and the affect it may have on water availability and access (WPI, 2003). It also differentiates between “water poor” populations which are subject to physical water scarcity (i.e. there is no water available), and “income poor” groups, whose water supply is affected largely by economic scarcity (i.e. a lack of effective distribution or allocation, or lack of money to pay for water). It should also be noted that “access” does not only relate to drinking water or water for domestic use, but also water for irrigation of crops, pastures and other uses (WPI, 2003).The index attempts to show a link between these two elements, and uses a range of geographical and socio-economic classifications and variations in order to adequately demonstrate the strength of this link, through association to complex formulations of levels of development, such as the Human Development Index (HDI) (WPI, 2003).

2 Methodology

2.1 Summary of Approach

Water stress, which is implicitly comprised of issues concerning the pressure placed on both the quality and quantity of available water resources, has a considerable effect and influence on anthropogenic activities (ADB, 2009). Adequate management of water supplies is vital in ensuring that water resources are not only available, but also sufficiently reliable to sustain a variety of water-dependant ecosystems and economic activities (ADB, 2009). Due to increasing water stress, most countries have begun systematically collecting and analysing hydrological, hydrometerological, and hydrogeological data (ADB, 2001). This collection and analysis, however, is often marred by operational discrepancies in data collection, due to the large number of agencies that participate in this activity. This, in turn, can result in problems of data integration, which can lead to difficulties and fragmentation in drafting and implementing effective water-based management policies (ADB, 2009).

This decrease in water availability per capita can be linked to socio-economical and geographical factors such as income, population density, and annual internal renewable water resources (consumptive use, rather than non-consumptive, is most pertinent here). These are examples of factors, which may affect water availability, and it should be duly noted that the list of influencing factors suggested in this essay is neither comprehensive nor exhaustive. Income, however, is the defining factor in the formulation of this index as it is directly related to effects such as sanitation coverage and inequality or political participation. In light of this, countries in this study will be divided into income groups as stipulated by the World Bank (2009).

A comparative index of water availability per capita will be established, while using these income classifications as a basis. This eases the problem of lack of data and information, and serves to give an overview of the situation of these countries with regard to their social development. The index will ideally also utilize such data as normative or descriptive indicators in its formulation. This index will employ the “aggregate method”, and combine a number of different variables with the eventual result of illustrating the real water availability per capita in each of the sample countries analysed within this text (samples will be taken from various Asian regions, and classifications will be given). Where possible, scientifically determined weights should be used for the aggregation of variables. The end result should be the aggregation of all proposed indices to give a real reflection (and value) of water availability in Asia and the Pacific. Statistics from international development organizations such as the Asian Development Bank, the World Bank, the Food and Agriculture Organisation (FAO), and the World Health Organisation (to name a few), will be used as primary sources for data and information. UNEP and the FAO have established a database in which national estimates of these figures can be found, and from which factors such as precipitation amounts, cultivated land, and population estimates can be derived. (ADB, 1999) Unfortunately, there is no international body whose mandate allows for the collection and standardization of all environmentally related data within various countries and regions (ADB). This in itself impedes the process, and allows for possible discrepancies in results. Data sets are also often incomplete, and we must therefore this lack of data into account when examining results of the index. Statistics provided by national agencies from the countries will also be included in the study, although the problem of inconsistency and standardized measuring techniques also applies in this case, and should therefore be duly noted in analysing the index. Although most countries conduct regular and systematic collection and analysis of hydrometeorological, hydrological, and hydrogeological data, not one specific international organization has a mandate to coordinate national efforts and compile global information, particularly on freshwater resources. In addition, in most countries, the collection of water quantity and quality data is not integrated (data collection is done by separate agencies). As a result, policymaking and planning for water quantity and quality management are often fragmented. The Asian Development Bank’s paper on *Core Environment Statistics and Methodological Issues* clearly illustrates this point in saying that, “

> *These same agencies routinely analyse the primary data to derive totals, averages, dependable flows, and time series indicators (of trend and variability),*

including possibly mapping the information (as in isohyetal maps of rainfall intensities or monthly totals). Here, measures of availability are more refined. For instance, available water may be defined as the water flowing in a river that is available 90 percent of the time (also called "dependable water" in irrigation water terminology). Time series data are important for developing indices of water supply sustainability."

The factors analysed encompass a range of socio-economic and geographic issues, and should all be related (either directly or indirectly) to water availability in the region. Cumulated figures for each factor in the area will be established, and consequently compared with water availability aggregates for these system units. The relationship between the factors will be subsequently mathematically defined, and an equation will be given. These equations will be formulated with the view of future application to other regions and in other countries – be it within the Asia and Pacific regions, or elsewhere. These factors will then be weighted in order to establish their relative importance to water availability. Below is a definition of all relevant factors that will be used within this study, and information here will be taken from the large number of international organizations that collect data on demographics and social issues, as well as water resources and resource use. The index itself will be based on two different determinants of water availability: availability and consumption. A clear distinction between rural and urban populations will also be made, in order to accurately assess actual water poverty.

The application and adjustment of the Water Poverty Index will be at the centre of this paper, and will be later applied to more specific spatial areas, taking into account both rural and urban variables. Specific population groups, categorized by GDP and income-related determinants will be analysed in order to ascertain the groups within a specific country in the Asia and Pacific regions that is under actual water stress. This is the fundamental difference between the Water Poverty Index and the index that will be presented in this paper – the approach presented will depict water availability on a microeconomic level, rather than on a macroeconomic or national level.

2.2 The Water Poverty Index

The Water Poverty Index is based on five categories related to water availability, and the authors of this work have modelled these indicators in relation to each other with the view of establishing an index, which will show a comparative ranking of countries with regard to national water poverty. The aim of this section is to critically analyse and provide alterations to the Water Poverty Index (2003), based on the five main categories as outlined by the work. These five main groups are Resources, Access, Capacity, Use, and Environment. The composition of indicators used within each category is shown in the following table:

Table 1: Contents of the Water Poverty Index (2003)

Resources	• **Internal Freshwater flows** • **External inflows** • **Population**
Access	• % population with access to clean water • % population with access to sanitation • % population with access to irrigation adjusted by per capita water resources
Capacity	• PPP per capita income • Under-five mortality rates • Education enrolment rates • Gini coefficients of income distribution
Use	• Domestic water use in litres per day • Share of water use by industry and agriculture adjusted by the sector's share of GNI
Environment	• Water quality • Water stress (pollution) • Environmental regulation and management • Informational capacity • Biodiversity based on threatened species

Criticisms for the resource section

The Water Poverty Index (2003) states that, "the resources index is a basic indicator of water availability". The principle of estimating water availability is therefore essentially the same in the Water Poverty Index as it is in the new index. However, there are some fundamental differences, particularly with regard to the implementation, estimation and use of precipitation estimates as a water resource. The WPI does not account for this, but it is an important indicator, which should be considered within the formulation of the index. Precipitation is important with regard to internal freshwater supplies, and also recharge of both surface water and groundwater resources. Within the new index, precipitation will also be viewed as an important factor for contribution to drinking supplies per capita, and an estimation will be made as to how much of this precipitation will be used for drinking water within the area's borders. Additionally, a temporal aspect will be introduced into the new index, so that monthly estimates may be made of water resources, based on scientific data. This is particularly important due to the considerable seasonal variability intrinsic in water resource flows, and also precipitation. This also serves to reduce inaccuracies regarding the obligation and tendency to simply introduce averages of flows due to lack of data. A minor difference will also be made concerning internal and external water inflows – the parameters used within the new index will be total renewable water inflows, and internal renewable water inflow – although this change is not a great alteration to the current WPI. Another fundamental change will be made to the last indicator regarding population. The new index will make a distinct division between rural and urban population groups, with the view of correctly identifying which groups are under the most water stress. This will be accomplished by using system inputs that are specific to each population group, rather just by using aggregate population statistics as in the Water Poverty Index. This approach is far too general, and a more localized approach is called for in order to assess actual water poverty, within both urban and rural areas. This is the fundamental change from the Water Poverty Index, as often rural and urban groups have very different water resources available to them, and this should be duly noted. The index will allow for the input of data based on specific area limits, and population groups. For example, an analysis can be done in Australia on a state-by-state basis, as long as the scientific data concerning water inflow, population groups and precipitation values is present.

Criticisms for the access section

This section deals with issues regarding access to clean water and sanitation, and water resources for irrigation. All of these factors, however, are positively correlated with GDP, and should therefore not be considered as mutually exclusive from the GDP indicator, nor from each other. This point is illustrated by Global Health Watch, in their 2008 report on water and sanitation, “While the water and sanitation sectors remain largely sidelined by governments, it is the poor, on the rare occasions when they are asked, who repeatedly put water and sanitation as their highest priorities.” This clearly shows a positive relationship between access to clean water and access to sanitation, which further illustrates that these factors are only required in the absence of a GDP indicator. This, however, is not the case in the new formulation of the water availability index, and these factors should therefore be done away with. The last indicator, relating to irrigation, will be utilized to a certain extent. The Water Poverty Index (2003) characterizes the establishment of indicator in the following manner, stating that it is, “… an index with relates irrigated land, as a proportion of arable land, to internal water resources. This is calculated by taking the percentage of irrigated land relative to the internal water resource index and then calculating the index of the result. The idea behind this method of calculation is that countries with a high proportion of irrigated land relative to low internal available water resources are rated more highly than countries with a high proportion of irrigated land relatively to high available internal water resources”. An interpretation of this indicator will be transferred into the new index, however with a particular focus on the percentage of land used for agricultural purposes, as a percentage of total land mass of the area. This will then be related to the total amount of precipitation lost by its introduction onto agricultural land, which of course diminishes the total amount of water available to the individual.

Criticisms for the capacity section

While the Water Poverty Index does have merit, there are a considerable number of noticeable faults, which must be discussed in order to find a sufficient remedy to these problems. The first intrinsic fault, which needs to be considered, is the complexity of the index itself. The Water Poverty Index integrates a variety of additional complex indices, which are intended to act as functional components in the establishment of the index. Indeed, the formulation of the index itself is conforms largely to the methodology and structural formation of these complex indices of which it is comprised, in order to give a comprehensive outlook concerning water poverty in a number of different countries (Olcay Ünver *et al.*, 2003). There are, however, problems with this type of formulation, the most obvious being over-complication. Two such indices used in the formulation of the Water Poverty Index are the UNDP education index from the Human Development Report (2001), and the Gini Coefficient. The formulation of the Human Development Index (HDI) is dependent on three primary factors: expectancy at birth, educational attainment, and GDP per capita in PPP (WPI, 2003). These components are all featured under the heading of "capacity" within the Water Poverty Index. While GDP per capita in PPP will be incorporated in the formulation of a new index measuring water availability, the other two constituents will not. The reason for this is simple; these two remaining elements are themselves determined by GDP. Therefore, for the simple formulation of a water-related index, it is not necessary to further complicate this with abstract measures, which are already interrelated anyways. Indeed, the WPI itself provides a source to support criticisms of the index. In quoting Srivisian (1994), Sullivan *et al.* (2003), state that, "countries can be compared internationally by their real income based on values which are locally specific. This is not the case with such measures as life expectancy or educations attainment whose 'relative values may not be the same across individuals, countries and socio-economic groups'". This is precisely the rationale behind the creation of a new index, and this point gives importance to a new index based on *localized* information and data, and accounts for divergences with regard to socio-economic issues. It is for this reason, and in combination with the abstract nature of these measurements, that the HDI should be left out of an index on water availability. The authors of the WPI then go on to suggest that, "… these numbers are 'indicators' and not precise measures". While the word 'indicator' does possess a certain amount of ambiguity, it must nevertheless be a well-formed and concrete value, particularly within scientific indices. In light of this, complicated and scientifically uncertain indices such as the HDI have no place in the formulation of a scientific index. The Gini coefficient is also not needed within the formulation of the new thesis. While this measure could perhaps be useful for a national analysis of water availability, it is certainly not required on a localized basis, which is the integral point advocating the establishment of a revised index for water availability. This is because within a given area, the possibility for variances in inequality is relatively small. This difference only becomes more obvious when evaluating larger areas. Additionally, there is limited data for the calculation of the Gini coefficient on a local level, and it should therefore be omitted from the index in order to constrain uncertainties.

Criticisms for the use section

The Water Poverty Index uses two factors for this section: domestic water use in litres per day, and the share of water use by industry and agriculture adjusted by the sector's share in GDP. Inclusion of the first component is justified within a scientific index on water availability, but it still requires some additional correction. This indicator does not account for loss of water that occurs through transfer, and is therefore not statistically correct in its estimation. This figure will be adjusted in the new index to include a loss coefficient to correct the inaccuracies posed by this, and to accurately reflect the total domestic water consumption per day. This figure will also be converted into a per capita quantity. Additionally, the Water Poverty Index only uses a base figure of 50L per day for developing countries, whereas concrete country-specific data as obtained from the FAO will be used for the formulation of this new index. The second indicator – the share of water use by industry and agriculture adjusted by the sector's share of GDP – will also partially be used in the formulation of a new index. However, the assessment of industrial water use here is not particularly relevant. This is due to the fact that a large amount of water resources used within the industrial sector are used primarily for cooling and heating processes, meaning that the majority is recycled and reused. In fact, with the employment of increasingly efficient technology, the reuse of water in industry has become more economical, meaning that there is less water loss. Agriculture, on the other hand, is still the largest consumer of water in most countries, and usually accounts for around 70% of water consumption. It is for this reason that use of water for agricultural purposes will be a major indicator within the index.

Criticisms for the environment section

The index also overcomplicates itself in the employment of unnecessary and essentially redundant indicators – such as the incorporation of an index of "water stress" (designed in the context of the Water Poverty Index to mean water quality), and also an indicator dedicated to "regulation and management capacity" (WPI, 2003). Both of these factors simply lead to an over complication of the index itself and should be omitted in its formulation as they neither serve to greatly influence the ranked outcome of the index, nor adequately profess any sort of reason why they should be included. The "water stress" indicator is merely another measure of water quality, as the Sullivan et al. already state, and should therefore either be integrated into the water quality indicator, or left off altogether. For example, *fertilizer consumption per hectare of arable land* and *pesticide use per hectare of crop land* should be directly related to the *phosphorous concentration* indicator found in the initial part of this section entitled "water quality". The water stress section also only incorporates already formulated indices, which leaves this section open for further criticism and meriting further scrutiny with regard to the general lack of transparency of its constituents. For example; "pesticide use" does not adequately describe the type of pesticide to be used, and seems also to assume equitable use of pesticides over a large area. It does not, therefore, take into account that perhaps pesticides may be applied more heavily in certain areas of a country as compared to other areas. The same criticisms can in turn be applied to the index regarding "fertilizer consumption per hectare of crop land". The average values with which we are presented here is not sufficient and are filled with too many inconsistencies to warrant merit. This section also uses an indicator named "*the percentage of country's territory under severe* *water shortages*", which also applies an ambiguous and highly disputed notion of "water scarcity". The indicator of "*environmental regulation and management"* and *"informational capacity*" is irrelevant in the formulation of this index. It does not account for bureaucracy or administrative and legislative inefficiencies, which operate in many countries around the world, nor does it account for cultural divergences in policy regulation, which is also an important concept that should be considered. This means that perhaps what is considered bad regulation in one country may not be the case in another country. In many cases, this serves to hinder effective environmental policies, including those relating to water availability and allocation. The index does not allow for this, only incorporating such factors as stringency, and number of guidelines. In most cases, neither of these indicators have any relevance to actual water scarcity to the individual. These constituents rely largely on ambiguous, vague and, most importantly, subjective information – which inevitably leads to inaccuracies within the index itself. The indicator pertaining to "environmental regulation and management" incorporates components such as environmental regulatory stringency; environmental regulatory innovation; percent of land area under protected status; the number of sectoral EIA guidelines. None of these components occupy an appropriate place in the formulation of an index of water poverty based on scientific data. The place of innovation, protection of land, and quantity of EIA guidelines is irrelevant in analysing water poverty to the individual. Additionally, the subjective analysis of these components and their origin have not been properly clarified by the authors of the Water Poverty Index, and this leads to further doubt over their inaccuracy. Furthermore, these analyses cannot have been completed on a localized basis, and therefore do not account for divergences in rural and urban environmental legislative implementation. Therefore, it is impossible to evaluate which populations are more affected by this. This can also be applied to the index of "informational capacity", where only the level and quantity of accessible information is assessed, rather than the different population groups that have access to education or information about water-related issues – i.e. urban populations would definitely have more access to this information than rural population groups. Moreover, it is equally important to note that this parameter is not calculated with particular regard to water-related issues, but only environmental issues as a whole, and therefore does not employ a sectoral approach, which would be crucial to its correct formulation. The incorporation of sociological and policy related aspects such as these in the index serves to defer from the scientific information which should drive the implementation of water-related policy. This is the main downfall of the Water Poverty Index. The authors, while attempting to scrutinize the capacity of policymakers to implement water-related policy, only cause an over complication of the index, and should instead focus on an in depth analysis of the relevant and available scientific data in order to increase the viability of practically implementing the index.

2.3 The Availability/Consumption Ratio

General Parameters

The use of general parameters pertaining to population and area data is integral in the formulation of the index. This data will be used to accurately define the system area and boundaries, which are being evaluated, and provide a basis from which the index can be calculated. The majority of this data will be retrieved from the United Nation's Food and Agricultural Organisation (FAO), and is relevant for the years between 2003 and 2007, which is the most up-to-date information that can be located. The exception to this is the data pertaining to GDP per capita, which will be obtained from the World Bank. These "general parameters" falls within the category of "population and area" in the flowchart below. Specifically, this group will include the following parameters:

Total Population

For the index of national water availability, this information will be located in population within the FAO's Aquastat database, this will converted into total population within the area. This will be done for purposes of coherency and uniformity within the index. For smaller system areas, this information can certainly be found in the relevant government institutions dealing with population and statistical information. This information will be further converted in the index to give a population density estimate, which will be accomplished by dividing the total population by the system area (in km^2).

Percentage of urban and rural populations

Data retrieved from the UN Food and Agriculture Organisation (FAO). This data will be used in conjunction with population density estimates, and then cross-referenced with the World Bank's national income grouping scheme in GDP per capita.

Total area (km²)

This information will also be found in the FAO's Aquastat database, and is converted to total area in square kilometres. Once again, information about area estimates can be found within national databases when being applied to smaller area units.

Populations categorized by income

This data will be collected from various national government institutions, and also from international organizations such as the World Bank. Statistics required for the establishment of this factor are relatively difficult to find for smaller population groups, due to a lack of collected data. This point is therefore the main downfall of this study, and more research and data needs to be aggregated in order to give a clear reflection of income groups classified by GNI in rural and urban areas. However, data from the World Bank will be utilized, which gives groupings of countries based on average GNI per capita. For the purpose of this index, three primary GNI groups will be established. These include limits (in US dollars) of:

Table 2: Income groupings according to the World Bank

Low Income:	$ 935
Middle Income:	$ 3,705
High Income:	$ 11,455

This factor will then be the average national GDP (in PPP) per capita, divided by the income grouping of the country. This will be referred to as the *GDP coefficient (F).* The final point of the index will be to calculate the availability/consumption ration, multiplied by this GDP coefficient. This GDP coefficient will be defined as the average

GDP per capita within the population group, divided by 11455 (the highest income bracket). This will in turn show how GDP per capita is a factor in dictating how populations deal with depletion of water shortages.

$$Availability/Consumption \times \frac{Average\ GDP\ per\ capita}{11455}$$
$$= ability\ of\ GDP\ per\ capita\ to\ deal\ adequately\ with\ water\ shortage$$

In the event that this figure is high, then the GDP of the community is large enough to combat water scarcity. This does not, however, imply that the community itself suffers from water scarcity (i.e. that the availability/consumption ratio is less than 1).This will be further divided up into rural and urban population groups. However, for purposes of simplicity, an average output figure will be given for the GDP corrected estimate of water availability within the system boundaries. This figure will be an average between GDP corrected estimates for rural and urban population groups. It should also be noted that in the event that the GDP corrected figure is lower than the availability/consumption ratio, then the population will struggle to deal with eventual water scarcity.

The abovementioned determinants are very important in the formulation of the index, as they provide information defining the system area. The next logical step is to detail the parameters used to illustrate water availability within the system area. The formulation of this section of the index will be based around two different groups; on the one hand, categorization will be accomplished by means of availability, and on the other, consumption.

The following screenshot depict the general parameters of the index, with the pink sections illustrating data integral to the proper functioning of the index, whereas the peach fields contain optional data. This optional data does not need to be incorporated into the index, however, the more data that is available within the index, the better it functions. The white fields contain calculated figures, which are formulated by using general parameters as primary data.

	A	B	C	D	E
1	**System data**				
2	**Time scale**		number of months	12	months (t)
3				1.0	a
4	**Area**		system area	329,310	km^2
5			% agricultural area	27	%
6			agricultural area	89,243	km^2
7	**Availability**		total renewable	10,338	$m^3/p/a$
8			internal renewable	4,251	$m^3/p/a$
9			system input	6,087	$m^3/p/a$
10			total withdrawal	1,240	$m^3/p/a$
11			withdrawal for agriculture	1,000	$m^3/p/a$
12	**GDP**			2,900	$/p/a
13	**Population**		total population	86206000	p
14			% urban	33	%
15			% rural	67	%
16			Population urban	28,097,984	p
17			Population rural	58,108,016	p
18			Population density	262	p/km^2
19					

Figure 1: Screenshot of general parameters within the index

The following flow chart (Figure 2) depicts the processes involved in the formulation of the new index, and the relation of all factors.

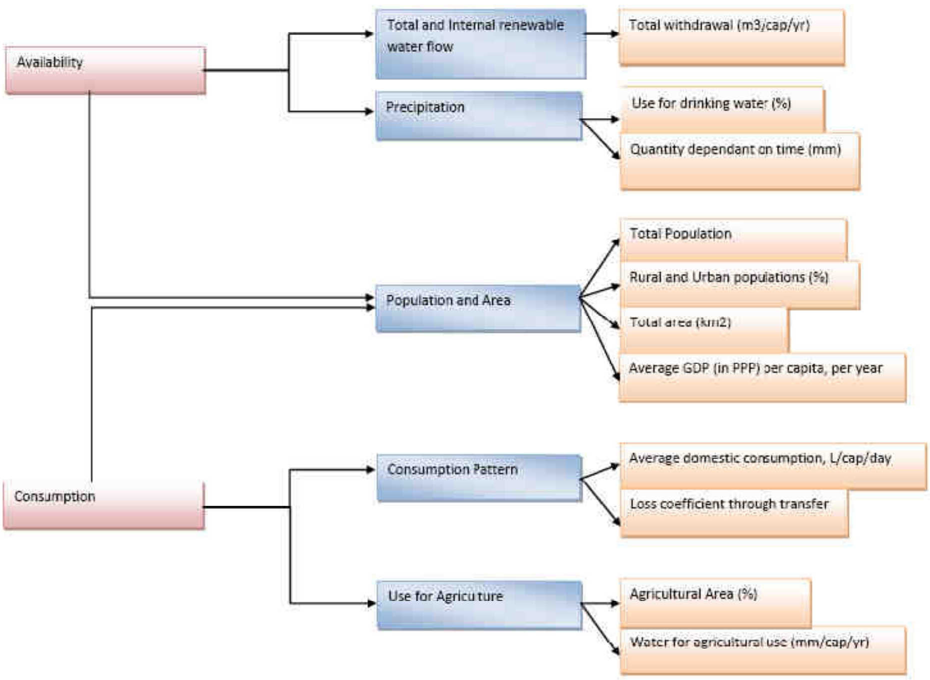

Figure 2: Flow chart of parameters in the new index

Availability

Availability of water resources within a predefined area can be attributed to two main sources as outlined by the Asia Development Bank: internal renewable water resources, and total renewable water resources (ADB, 1999). Indicators such as precipitation and use for drinking water will also fall under this heading. The calculation of the index, however, can be done by using only one of these determinants, or even a combination of these factors can be utilized when possible. It is important, however, to describe the possible methods of calculation used within what is referred to as "system input", which aims to show the amount of water entering the system area boundaries.

Concept of system input

Within the framework of the index, the system input data can be viewed as a conversion from data detailing the availability of freshwater resources, to actual available water resources entering the confined area, which is being evaluated, and also within a given monthly timeframe. Following on from this, this conversion should also be considered as a measure for actual availability of freshwater resources for the purposes of potential exploitation by the community. Although it is obviously true that the more scientific information known the better, the system input of freshwater resources can be calculated by using either

a) information pertaining to internal and external water flows,
b) precipitation values given for the specific timeframe, or
c) calculating the total discharge from a river or other body of water within the system boundaries.

The application of this data, therefore, depends on the reliability of the data given, the scientific basis of measurement criterion employed to quantify water resources, and the characteristics of the area being analysed (i.e. the hydrogeological properties of the system). These three factors are important in the formation of the index, because the use of each method depends on the system area; i.e. For areas with no external water input, the precipitation option is best employed; for larger areas relying on system input, then a calculation based on external water flow is needed; and for small areas situated on a river, water availability can be measured by calculated discharge of the water body, and thus the third option should be used. This indicator is integral when performing evaluations on a more localized scale, where the water flows and precipitation amounts have already been scientifically investigated. The advantage of this conversion mechanisms is that it is able to calculate within, in the first instance, a given timeframe, and secondly within specific system borders. One large assumption that the index makes is the use of system input water for drinking purposes. An assumption, between 0 and 20, will be made to illustrate the percentage of water from external sources used within the area for drinking water. This estimate will be based on the relative quantity of external and internal renewable water resources.

Total internal renewable water resources (m^3/cap/year)

The ADB defined total renewable water resources as, "…the sum of the annual average freshwater flow of rivers and the groundwater produced from rainfall within the country's borders" (ADB, 2009). Around two-thirds of this figure is from flood runoff, while the rest can be classified as regular groundwater and surface water supply. It should also be noted that the distribution of water resources is largely uneven, and is dependent on both spatial and temporal criterion (i.e. water resources vary depending on the region, and also on seasons and meteorological phenomena). Both of these criteria directly affect internal renewable water resources. This value will also be dependant on precipitation;

$$x.y = z$$

Where x is precipitation, y is a coefficient variable, and z is total internal renewable water resources. This figure will ultimately give a solid analysis of water availability in rural and urban population groups. It should also be noted that approximately one third of this number can be counted as usable surface and groundwater, as around two-thirds of this water source is deemed to be attributed to flood run-off, which quickly flows into the ocean (ADB, 1999). The source of all internal water is ultimately rainfall, which is integral to recharging groundwater resources that supply a type of "base flow" in months with little or no precipitation (ADB, 1999). The incapability to adequately recharge groundwater resources (due to removal of vegetation and soil compaction) is an essential element which contributes significantly to instances of crop/agricultural failure and drought, and should therefore be closely observed and monitored (ADB, 1999).

Total renewable water resources per capita (m^3/cap/year)

Total renewable water resources per capita, however, show water resources, which enter the country from outside its borders, and also need to be considered when evaluating water availability. According to the ADB's Handbook on Environmental Statistics, renewable water supply is obtained from two sources: precipitation that falls directly on its land area, and water from rivers originating from outside the country (external water sources). Although the majority of countries in this study depend largely on internal water resources, others such as India, Bangladesh and Thailand depend on external water supplies such as river flows from neighbouring countries. Thailand is a perfect example of this. Almost 70 m^3 of water flows into Thailand each year from neighbouring countries, a figure which corresponds to more than half of Thailand's internal water resources (ADB, 1999)

The ADB further illustrates the importance of renewable water resources by stating that;

> *"The renewable water resources statistic is an aggregate annual average figure that is useful mainly as basis for developing indicators of water supply availability. A critical level of utilization is considered reached when the water withdrawal rate reaches or exceeds the average annual available water supply. Another useful indicator is the ratio of available water supply to the total population. The resulting indicator is "per capita available water supply." Based on this indicator, countries may be ranked according to relative per capita water availability or scarcity."*

Average precipitation in depth (mm)

In each case, average precipitation will be given as an average over a specific period of time, and will be given in millimetres. Average precipitation values should be allocated not for the country as a whole, but for different areas within the country (which is, of course, dependant on climatic conditions). Therefore, the value taken to represent this indicator should accurately reflect the rainfall within the region being analysed, rather than the national average rainfall. This is an integral component of the index, and requires scientific investigation into the rainfall patterns of the specific region, which can then be used as a useful and applicable policy mechanism by both local and national policymakers. This indicator will also be correlated with population estimates within the index itself. In practice, each country should define itself an appropriate population estimates that clearly illustrates the dichotomy between rural and urban areas. An assumption will be made to estimate the amount of precipitation for drinking water used within the system boundaries. This data will be obtained from Food and Agriculture Organisation; however, in the event that this data is not available, it will be located from other sources. Data for China, for example, will be obtained from Ramphal & Sinding's book on *Population Growth and Environmental Issues,* in which a national precipitation estimate is given.

Calculations for Availability

The following methodology will be implemented to calculate water availability within the system units, by incorporating the above parameters. For purposes of clarity and coherency, these calculation methods will be presented in the following order; by calculation on precipitation input, calculation on system input, and calculation on runoff.

System Input

Calculation on precipitation

This will be accomplished by utilising data on precipitation within the system borders. Consequently, the total amount of precipitation within the system borders (referred to in the index as *total flow to area)* will be calculated by incorporating both the quantity of average annual precipitation (in mm), and also the area of the system (in km^2). Furthermore, this figure will be converted from L/m^2/time, to m^3/s. This will be done with the following calculation:

$$Total\ Flow\ to\ Area\ (m^3/s) = \frac{Precipitation(mm)}{1000} \times\ (1000.1000) \times \frac{Area(km^2)}{365 \times 24 \times 60 \times 60}$$

The estimated percentage used for drinking water will then be integrated into the index, from which the amount for drinking water will be calculated, using the following calculation:

$$Amount\ used\ for\ drinking\ water\ (m^3/s) = Total\ flow\ to\ area\ \times \frac{\%\ drinking\ water}{100}$$

The availability from system input will then be calculated by utilising the following calculation, which will also convert the value to m^3/capita/year:

$$Availability\ from\ system\ input\ (m^3/cap\ /\ year) = (Used\ for\ drinking\ water\ (m^3/s) \times \frac{60 \times 60 \times 24 \times 365}{time})/population$$

Calculation on system input

This section will calculate the amount of water availability from system input sources (i.e. External sources). It should be noted that this mode of calculation is only relevant for areas in which there is an exogenous water inflow through the system borders. Without this, there would be no system input. The method of calculation is the following:

System input as mm precipitation requires the conversion of precipitation to total values for the entire area being evaluated.

$$\text{System input as mm Precipitation} = \frac{\text{quantity as total flow to area} \times 1000}{1000 \times 1000} / \text{system area} \times (365 \times 24 \times 60 \times 60)$$

The total flow to area, which is needed to calculate this equation, is defined as:

$$\text{Total flow to area } (m^3 \ / \ s) = \text{used for drinking water } (m^3 \ / \ s) \times \frac{100}{\% \text{ used for drinking water}}$$

The next step is to calculate the amount of this system input that is used for drinking water by the entire population, per unit of time. It is also important to note that the availability from system input is equal to the difference between external and internal renewable water resources. In view of this, the following equation will be used:

$$\text{Used for drinking water } (m^3 \ / \ s) = \frac{\text{availability from system input } (m^3 \ / \ s) \times \text{population}}{60 \times 60 \times 24 \times 365} \times \text{time}$$

Calculation on system runoff

This calculation should only be employed in small system units, in which surface water is flowing through or into the system. From this surface water, a total amount of runoff can be calculated, which is valuable information when assessing water availability. The first step in this series of calculations is to convert the total flow from mm/unit of time, into L/m^2/time, which ensures compatibility with future units of measurements. For this section, the total amount of runoff, and the percentage of runoff water used for drinking water, should be known. The total amount of water used for drinking water will then be evaluated using the following equation:

$$Used\ for\ drinking\ water\ (\ m^3\ /\ s) = \ total\ runoff(m^3/s) \times \frac{\%\ runoff\ for\ drinking\ water}{100}$$

The availability from runoff, calculated based on the system input (i.e. Surface water), can be calculated in the following manner, while keeping in mind that the use of runoff for drinking water is a factor of the percentage used for drinking water, and also the quantity of runoff:

$$Availability\ from\ system\ input = (use\ of\ runoff\ for\ drinking\ water(m^3\ /\ s) \times \frac{60 \times 60 \times 24 \times 365}{time})/population$$

Internal from precipitation

Calculation on precipitation

After the input of an average annual precipitation value (in mm), this figure will then be converted to m^3/km^2/time, which will be accomplished using the following equation:

$$Total\ precipitation\ (m^3\ per\ km^2\ per\ time) = \frac{Precipitation(mm)}{1000} \times (1000 \times 1000)$$

The second step involves calculating the water availability from precipitation within the system borders, by means of employment of the following calculation:

$$Availability\ from\ Precipitation\ (m^3\ /\ cap\ /\ year) = \frac{\frac{precipitation(mm)}{time}}{population\ density}/time$$

Consequently, the amount of precipitation used for agricultural purposes will then be calculated, using the total amount of agricultural area and the total population. This calculation also involves the assumption that one person requires 1000m^3/year of agricultural land for food production. Therefore, the equation that analyses the quantity of water used for agricultural purposes can be calculated into the following manner:

$$Minus\ for\ agriculture = \frac{agricultural\ area(km^2) \times 100 \times 1000 \times 4}{total\ population} / time$$

Following on from this, an equation to quantify the amount of water available for drinking water will then be implemented into the index:

$$Available\ for\ drinking\ water\ (m^3\ /\ cap\ /\ year) = \frac{Available\ from\ precipitation}{minus\ for\ agriculture}$$

The quantity used for drinking water will then be calculated:

$$Used\ for\ drinking\ water\ (m^3\ /\ cap\ /\ year) = \ Available\ for\ drinking\ water \times \frac{\%\ used\ for\ drinking\ water}{100}$$

In light of these above calculations, therefore, the total water availability using precipitation values can be calculated in the following manner:

$$Total\ water\ availility\ from\ precipitation\ (m^3\ /\ cap\ /\ year) = \frac{\%\ used\ for\ drinking\ water}{availability\ from\ system\ input}$$

Calculation on system input

With regard to the internal precipitation values, the system input quantity should be equal to (or at least roughly equal to) the amount of average annual precipitation for the system area (in mm/year). This value will then be converted into cubic meters per square kilometre, per unit of time. This will be done for the purposes of subsequent calculations within the index, in which the unit measurements must be comparable. Due to the fact that later calculations will be done in cubic meters, this value also needs to be converted – hence the need for a calculation.

The amount available from precipitation based on system input is as follows:

$$\begin{aligned} &Available\ from\ precipitation \\ &\qquad = Available\ from\ drinking\ water\ (m^3\ /\ cap\ /\ year) \\ &\qquad + \ use\ for\ agriculture\ (m^3\ /\ cap\ /\ year) \end{aligned}$$

The amount of water used for agriculture based on system input is calculated in the same way as when using precipitation values (see above). The amount of water used for drinking water can then be calculated, with the following equation:

$$\begin{aligned} &Used\ for\ drinking\ water\ (m^3\ /\ cap\ /\ year) \\ &\qquad = total\ availability\ through\ precipitation \\ &\qquad - availability\ from\ system\ input \end{aligned}$$

Lastly, the total water availability of the area (in m^3/cap/year) using system input is calculated by:

$$\begin{aligned} &Total\ water\ availability \\ &\qquad = total\ water\ withdrawal\ (m^3\ /\ cap\ /\ year) \\ &\qquad - \ withdrawal\ for\ agriculture\ (m^3\ /\ cap\ /\ year) \\ &\qquad + \ available\ from\ system\ input\ (m^3\ /\ cap\ /\ year) \end{aligned}$$

The screenshot below shows the formulation of the water availability section within the index itself. Once again, pink fields illustrate data essential to the calculation of the index; peach fields are optional data, and white fields contain calculations based on these previous data input figures. Figures in the far right-hand column are calculations based on total (rather than per unit) figures.

	A	B	C	D	E	F	G	H	I
22	**Availability**			calc on mm	calc on syst input	calc on runoff			
23	**system input**		as mm Precipitation	1,821	13,278	176	mm/t = l/m² /t		
24			as total Flow to area	19,016	138,654	1,842	m³/s	599,673,510,000	m³/a
25			used for drinking water	12	12	0	%		
26			used for drinking water	2,282	16,638	-	m³/s	71,960,821,200	m³/a
27			availability from system input	835	6,087	-	m³/p/a		
28									
29	**internal from Precipitation**			calc on mm	calc on syst input				
30			in mm	1,821	1,806	mm/t = l/m² /t			
31				1,821,000	1,806,417	m³ / km² / t		599,673,510,000	m³/a
32			availability from precipitation	6,956	6,901	m³/p/a			
33			minus for agriculture	414	414	m³/p/a		35,697,204,000	m³/a
34			available for drinking water	6,542	6,486	m³/p/a			
35			used for drinking water	3.7	3.7	%			
36			used for drinking water	242	240	m³/p/a		20,867,123,322	m³/a
37									
38	***total Water Availability***		***Input & Precipitation***	***1,077***	***1,075***	***m³/p/a***		*92,827,944,522*	*m³/a*

Figure 3**:** Screenshot of Availability section within the index

Consumption

Secondly, this analysis will be done on both a rural and an urban level, so as to pinpoint the exact population groups that are most effected by water scarcity. Although the definition of what constitutes rural and urban population groups is largely left at the discretion of the country completing the analysis, it is still important here to formally define the border between urban and rural population groups. The United Nations Statistics Division’s definition of urban and rural populations is as follows:

> “*Because of national differences in the characteristics that distinguish urban from rural areas, the distinction between the urban and the rural population is not yet amenable to a single definition that would be applicable to all countries or, for the most part, even to the countries within a region. Where there are no regional recommendations on the matter, countries much establish their own definitions in accordance with their own needs*” (United Nations Statistics Division, 2008).

This is the method that will be applied in this study with regard to urban and rural population groups, and all data collected that differentials between the two groups will be utilized in accordance with the above-mentioned principle. The factors listed below are relevant for the formulation of this index. A flow chart of the formulation process will also be given below.

Average domestic water consumption (L/cap/day)

This factor will be measured in conjunction with a *loss coefficient,* which will be estimated at about 25 %. This coefficient aims to indicate actual domestic water consumption per capita, by allowing for losses. Therefore, the end result for this factor will be the average consumption of water of the total population, multiplied by a factor of 1.25. Ideally, a clear distinction and two separate calculations should be done here – a calculation for the water usage per capita, per day in rural areas, and also in urban areas. This data will be drawn from the 2007 *Statistical Yearbook for Asia and the Pacific* (published by UNESCAP). It should be noted, however, that domestic consumption patterns have changed slightly since this period, but the data is still largely applicable to many Asian countries. Therefore, it is still considered suitable to apply this data in the formulation of the index. In the event that this data is not available (in the case of Singapore for example), standard data will be applied in line with the consumption estimates from national government institutions.

$$
\begin{aligned}
&\mathit{Final\ value\ for\ water\ consumption\ per\ capita}\ (L/day) \\
&\qquad = \mathit{Average\ water\ consumption}\ (L/cap/day) \times 1.25
\end{aligned}
$$

Agricultural Area (km^2)

This parameter will be extracted from the FAO’s Aquastat database, under which it is defined as “cultivated land”. The FAO (2009) takes “cultivated land” to mean, “The sum of the arable land area and the area under permanent crops.” This figure was originally given in (1000 hectares), but will be converted into square kilometres for the purpose of the index. Figures regarding agricultural land use within a specific area within a nation's borders can be obtained from national government institutions.

Total water withdrawal (m^3/cap/year)

This figure will be based on the total water footprint per capita within the various countries being analysed, and will be obtained from Hoekstra and Chapagain's 2006 article on the Water Footprint. This figure contains all relevant information on per capita water footprint for national water intensive sectors – such as industrial, agricultural and household water usage. In the event that this figure is not available, the global average of 1240 m^3/cap/year will be applied.

Quantity of water used for agricultural purposes (m^3/cap/year)

The concept of a national water footprint is not unlike the concept of virtual water, and was largely developed and extrapolated by Hoekstra and Chapagain (2006). This agricultural-based indicator will be measured using the Water Footprint model, particularly the section pertaining to the water footprint caused per capita for direct and indirect agricultural purposes. Hoekstra and Chapagain (2006) effectively divided water consumption based on categories. The most pertinent categories used for the development of this index will be: water used for internal consumption of agricultural products, and water used for external consumption of agricultural products. These factors require clear definition in order to avoid confusion about what is included in these indicators, and what is not. Hoekstra and Chapagain (2006) state that; "… agricultural water use includes both effective rainfall (the portion of the total precipitation which is retained by the soil and used for crop production) and the part of irrigation water used effectively for crop production. Here we do not include irrigation losses in the term of agricultural water use assuming that they largely return to the resource base and thus can be reused." Therefore, it is important to note that this indictor is comprised only of water, which is used for agricultural purposes, and does not include rainfall or runoff water, which would serve to further complicate the index. These indicators will instead be included in other sections of the index. Additionally, this indicator includes not only *internal* water footprint for production of agricultural goods, but also the *external* water footprint for production of agricultural goods. It is important to illustrate the distinct difference in definition and formulation of these indicators. Hoekstra and Chapagain (2006) effectively detail the difference between these two factors in stating that, "The internal water footprint is the volume of water used from domestic water resources; the external water footprint is the volume of water used in other countries to produce goods and services imported and consumed by the inhabitants of the country". This definition will be applied specifically to agricultural products. This indicator will be further divided up into rural and urban categories, in order to ascertain a ratio of water consumption for agricultural usage. The index will calculate this ratio based on the average national water footprint given, but when there is no water footprint value given, a standard figure of 1000 m^3/cap/yr will be applied. This average will be calculated by using the following formula:

$$\begin{aligned} &Average\ water\ footprint \\ &\qquad = (rural\ water\ footprint \times \%\ rural\ population) \\ &\qquad + (urban\ water\ footprint \times \%\ urban\ population) \end{aligned}$$

Calculations on Consumption

The calculations referring to the consumption patterns of the area's inhabitants is dependent on a number of integral determinants, including: the use of water for domestic use (in L) per capita, and per day, and also the loss coefficient involved in the transfer of water. This loss coefficient will be fixed at 25%, in order to ensure simplicity. In practical situations, however, this loss coefficient should be accurately measured to ensure there are no inaccuracies in the calculation of this index. With this in mind, the following calculations will be used in the index:

Consumption per time

$$Consumption\ per\ time\ (L\ /\ cap\ /\ time) = daily\ domestic\ consumption\ \times \frac{100+25}{100} \times 365 \times time$$

In much the same manner, the consumption per year will then be calculated. This figure will then be converted into m^3/cap/year by dividing the output figure by 1000.

$$Consumption\ per\ year\ \ (L\ /\ cap/year) =\ daily\ domestic\ consumption \times \frac{100+25}{100} \times 365$$

This converted figure can then be utilised in the total per capita water demand, which can be calculated by using the following equation:

$$Total\ domestic\ water\ demand = total\ domestic\ consumption\ (m^3\ /\ cap\ /\ year) +\ withdrawal\ for\ agriculture\ (m^3\ /\ cap\ /\ year)$$

Urban/Rural Calculations

These calculations follow roughly the same pattern as the other calculations pertaining to domestic consumption. To avoid confusion, the calculation of urban domestic consumption per time and per year will be included. However, seeing as this calculation is the same as the calculation for rural population groups (except the consumption of rural populations is used), the calculations will not be presented within the body of this paper. Calculation of domestic urban consumption is as follows:

$$Domestic\ urban\ consumption\ per\ time = urban\ domestic\ consumption\ (L\ /\ cap\ /\ day) \times \frac{100+25}{100} \times 365 \times time$$

$$Domestic\ urban\ consumption\ per\ year\ \left({}^{L}/_{cap}/year\right) =$$

$$daily\ domestic\ consumption \times \frac{100 + 25}{100} \times 365$$

This figure must then be converted into m^3/cap/year, which will be accomplished by dividing this figure by 1000. This final output figure will then be added to the agricultural per capita water withdrawal in m^3/cap/year. The total water demand for urban population groups therefore is:

$$Total\ water\ demand\ (m^3\ /\ cap/year) = \frac{urban\ domestic\ consumption\ per\ year}{1000} + withdrawal\ for\ agriculture\ (m^3/cap/year)$$

The same calculation can be used for the calculation of total water demand for rural groups, except of course by incorporating the quantity of rural domestic consumption per year, rather than the consumption value for urban groups. The withdrawal for agriculture, once again, is defined by the national water footprint caused by the production of agricultural goods. Further development is needed in order to effectively distinguish between agricultural water footprints for rural and urban population groups. This figure is also fixed at 1000m^3/cap/year in system boundaries where no data is available.

The screenshot below shows the formulation of the water consumption section in the index.

	A	B	C	D	E	F	G	H	I
42	**Consumption**								
43	**Consumption 1**		daily domestic consumption	192	l/p/d				
44			distribution loss	25	%				
45			domestic consumption per time	87,500	l/p/t				
46			domestic consumption per year	87,500	l/p/a				
47				87	m^3/p/a				
48			agriculture	1,000	m^3/p/a				
49									
50	***total Water demand***		***domestic***	***1,087***	***m^3/p/a***			93,748,392,673	*m^3/a*
51									
52				urban	rural				
53	**Consumption 2**		daily domestic consumption	200	150	l/p/d			
54			distribution loss	25	25	%			
55			domestic consumption per time	91,250	68,438	l/p/t			
56			domestic consumption per year	91,250	68,438	l/p/a			
57				91	68	m^3/p/a			
58			agriculture	1,000	1,000	m^3/p/a			
59				1,091	1,068	m^3/p/a			
60									
61	***total Water demand***		***domestic rural & urban***	***1,076***	***m^3/p/a***			93,431,312,248	*m^3/a*

Figure 4: Screenshot of Consumption section within the index

Calculation of Availability/Consumption Ratio

The availability/consumption ratio can be calculated in the following manner:

$$Availability\ consumption\ ratio = \frac{Total\ water\ availability\ based\ on\ precipitation}{Total\ average\ water\ demand}$$

In addition to this, two calculations will be used in order to effectively distinguish between urban and rural population groups. The first calculation will give an average output value for both of these groups combined. The second calculation will be specific to urban or rural population groups. The calculation for the availability/consumption ratio will be shown for urban populations, however the methodology is also the same for rural populations, and the only change is replacing the total urban water demand with total rural urban demand.

$$Total\ overall\ water\ availability/consumption\ \ ratio = \frac{total\ water\ availability\ based\ on\ precipitation}{total\ water\ demand\ based\ on\ rural\ \&\ urban\ consumption}$$

$$\text{Total urban water availability/consumption ratio} = \frac{\text{total water availability based on precipitation}}{\text{total water demand based on urban consumption}}$$

This availability/consumption ratio will henceforth be referred to by the acronym AVCOR. The following screenshot shows how this information will be displayed in the index:

64	**Availability / Consumption**							
65	**Consumption 1**			*1.0*				*1.0*
66	**Consumption 2**		domestic rural & urban	*1.0*				*1.0*
67			urban	*1.0*	*1.00*			
68			rural	*1.0*				
69								
70	**GDP corrected Availability / Consumption**							
71	**Consumption 1**			*0.3*				*0.3*
72	**Consumption 2**		domestic rural & urban	*0.3*				*0.3*
73			urban	*0.2*	*0.25*			
74			rural	*0.3*				

Figure 5: Screenshot of the final calculations of the AVCOR, and the GDP corrected data within the index.

2.4 Data

Accurate data is imperative to the correct formulation, and thus application, of this index. A selection of relevant data sets for specific country groupings has been compiled, based on GDP per capita, which is one of the primary indicators for this study. The World Bank gives an accurate breakdown of countries based on their GNI per capita. In order to ensure complete transparency in the formulation of this index, it is integral to clearly define all the relevant indicators – while addressing what is incorporated into the indicator, and what is not. This is particularly true for GNI, as it is essentially the cornerstone and one of the main building blocks for the establishment of this index. The World Bank (2009) defines GNI as,

> *"GNI per capita (formerly GNP per capita) is the gross national income, converted to U.S. dollars using the World Bank Atlas method, divided by the midyear population. GNI is the sum of value added by all resident producers plus any product*

taxes (less subsidies) not included in the valuation of output plus net receipts of primary income (compensation of employees and property income) from abroad. GNI, calculated in national currency, is usually converted to U.S. dollars at official exchange rates for comparisons across economies, although an alternative rate is used when the official exchange rate is judged to diverge by an exceptionally large margin from the rate actually applied in international transactions."

The World Bank stipulates that the established income categories were founded on the Bank's operational lending categories (for example, civil works preferences). These guidelines were first established themselves in order to assess real need from developing countries, and were founded with the view that these poorer nations deserve better conditions from the Bank, and that an accurate method of economy capacity assessment was required so that this could be accomplished (World Bank, 2009). The GNI was used as the best possible gauge for economic capacity and progress in this regard, while also taking into account that this measure does not integrate a view of success or welfare in development (World Bank, 2009). It is for this reason that the World Bank chose this measure to classify countries, and why it will be justifiably incorporated into this index on water availability. It should be noted, however, that within the index itself, data for the GDP indicator will be obtained from the CIA Factbook. Classifications of countries by GNI as accomplished by the World Bank should be viewed as a guide of the country's social and economic situation. However, the classification is also of concrete importance within the formulation of the index itself, as the higher income bracket ($11455) will be used in the relevant calculations (see above). This will display an evaluation of the country's ability to deal with water scarcity – if the GDP corrected figure is less than the AVCOR, then the country will struggle to implement effective water policies to combat water stress. Indeed, it is expected that most countries falling within the lower groups will encounter this problem – if indeed water stress is a problem within the particular country. With this in mind, the countries analysed in this paper will be found in one of these categories outlined by the World Bank. These can be found in the table below:

Table 2: Countries classified by GNI groupings

Low Income $935 or less	Low-Middle Income $936 - $3,705	Upper-Middle Income $3,706 - $11,455	High Income $11,456 or more
Bangladesh (BD)	India (IN)	Malaysia (MY)	Australia (AU)
Cambodia (KH)	Indonesia (ID)		Japan (JP)
Myanmar (MM)	Iran (IR)		Republic of Korea (KR)
Nepal (NP)	Mongolia (MN)		New Zealand (NZ)
Pakistan (PK)	Philippines (PH)		Singapore (SG)
Papua New Guinea (PG)	Thailand (TH)		
Vietnam (VN)	China (CN)		

3 Australian Case Study

Australia is the driest inhabited continent on the planet. Unstable water resources are continuously placed under mounting pressure from natural and anthropogenic activities (the latter of which include industry and agriculture, often requiring large amounts of water). The following section aims to give an overview of Australia's water resources, and provide sufficient information by which an index comprising all relevant geographical factors may be established. The reasons for choosing Australia as a case study are the following: firstly, there is a large amount of information to be utilized and can be subsequently folded into the index, and secondly, it is a country of diverse climatic conditions and therefore is perfect for an analysis of regional water poverty. This case study will first give an overview of water availability in Australia, and secondly present information regarding the use and application of water resources. The third part of this case study will show the development of trends pertaining to water usage over the last decade or so. The forth section will be comprised of datasets by which the calculation of the index on a state-by-state basis will be made, followed by an analysis and discussion of the results. Most of the statistical data information provided in this section will be obtained from Australian federal government institutions, or from international organizations dealing with water supply issues, such as the United Nations Development Programme, and the Food and Agriculture Organisation.

3.1 Water availability in Australia

According to the Australian Water Resources branch of the National Water Commission, sources of water availability in Australia can be broadly divided into 4 groups; rainfall, runoff, stored water and groundwater (2005). The specifics of these categories with - particular emphasis on Australia - will be further discussed below.

Rainfall in Australia is largely dependent on seasonal and climatic conditions, which means that rainfall is highly variable in most parts (Australian Water Resources, 2005). The degree of variability is considerable: measurements of more than 2000mm of precipitation have been noted in the northern most parts of the country, which are classified mainly as tropic (see Figure 7). On the other end of the scale, less than 200mm per year have been noted in the central (and mostly desert) parts of Australia (Australian Water Resources, 2005). When comparing rainfall over a period of time, inconsistency in rainfall patterns can be seen. For example, the Australian Bureau of Statistics counted a total rainfall amount of 2,789,400 gigalitres in 2004-2005. This gives an Australia average figure of 364mm, which is well below the long-term rainfall average of 457mm per year (Australian Water Resources, 2005). This figure can only be seen as close to average in parts of northern New South Wales, and parts of south-western Australia (Australian Water Resources, 2005). The years leading up to 2004-2005 also demonstrated below average rainfall, whereas 2006-2007 saw a rainfall average slightly higher than the national average (Australian Water Resources, 2005). Most climatic models indicate a decline in rainfall within the continent over a number of years, which will greatly affect water availability, and this will serve to further illustrate the importance of effective management and policy making tools, which will lead to efficient allocation of water resources. This is imperative not only on an individual level, but also because water shortages and increased demand will influence all sectors of the Australian economy, with agricultural activity suffering the most (Connected water, 2006).

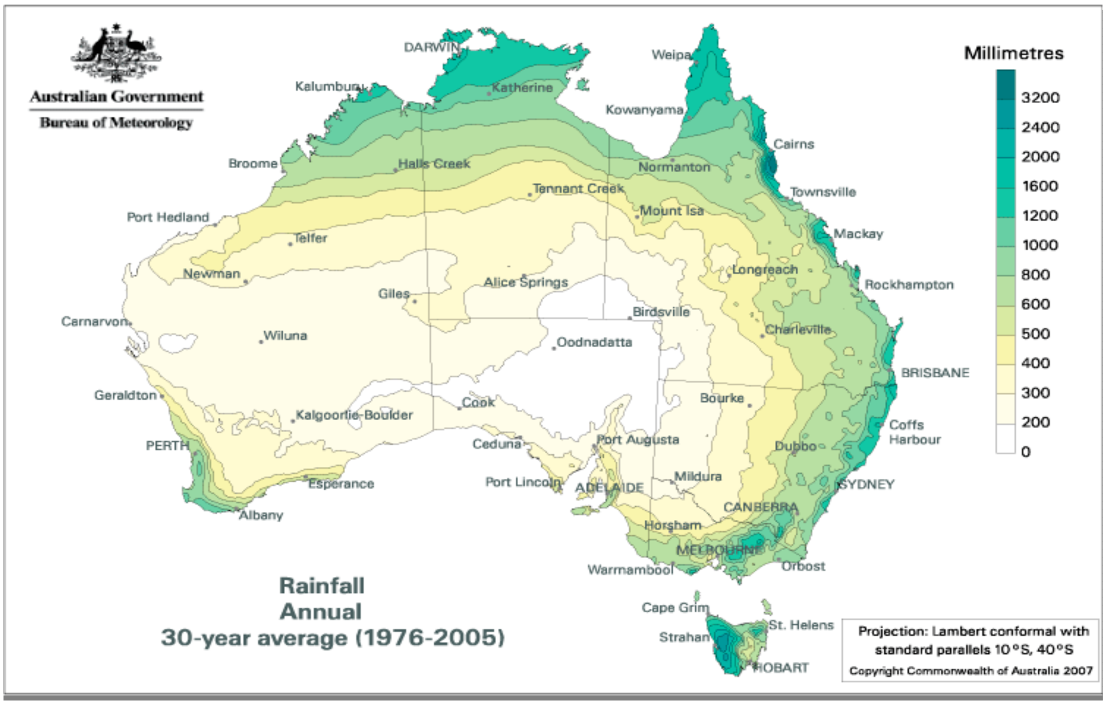

Figure 6: Map of Australia showing large disparities in rainfall quantities throughout the continent.

Only 10% of rainfall becomes runoff into rivers or serves as a source for groundwater recharge, whereas the remaining 90% is subsequently evaporated (Australian Water Resources, 2005). However, the amount of runoff and recharge water varies considerably across Australia, which also in turn leads to disparities in water availability for a number of population groups within the country (Australian Water Resources, 2005). 2004-2005 estimates for total water runoff was put at around 242800 gigalitres, and 49,200 gigalitres for groundwater recharge. An analysis of this figure shows a total input quantity of 292,000 gigalitres into ground and surface waters (which accounts for approximately 10% of the annual rainfall estimate) (Australian Water Resources, 2005). Therefore the following conclusion may be drawn: surface runoff to rivers can therefore be attributed to around 83% of all inflows, and recharge to groundwater reserves accounts for around 17% (Australian Water Resources, 2005).

It should also be noted, as previously mentioned, that surface runoff is a highly variable phenomena, which is dependent on a large number of geographical and meteorological factors. This in itself is the primary reason for the high level of variability in surface runoff throughout Australia. The Australian Water Resources (2005) states that approximately 60% of the country's total runoff was from three main drainage divisions, all of which are located in the countries north. These are (in order of highest to lowest); the Gulf of Carpentaria drainage division, the Timor Sea drainage division, and the North Cost drainage division. This is demonstrated in Figure 8.

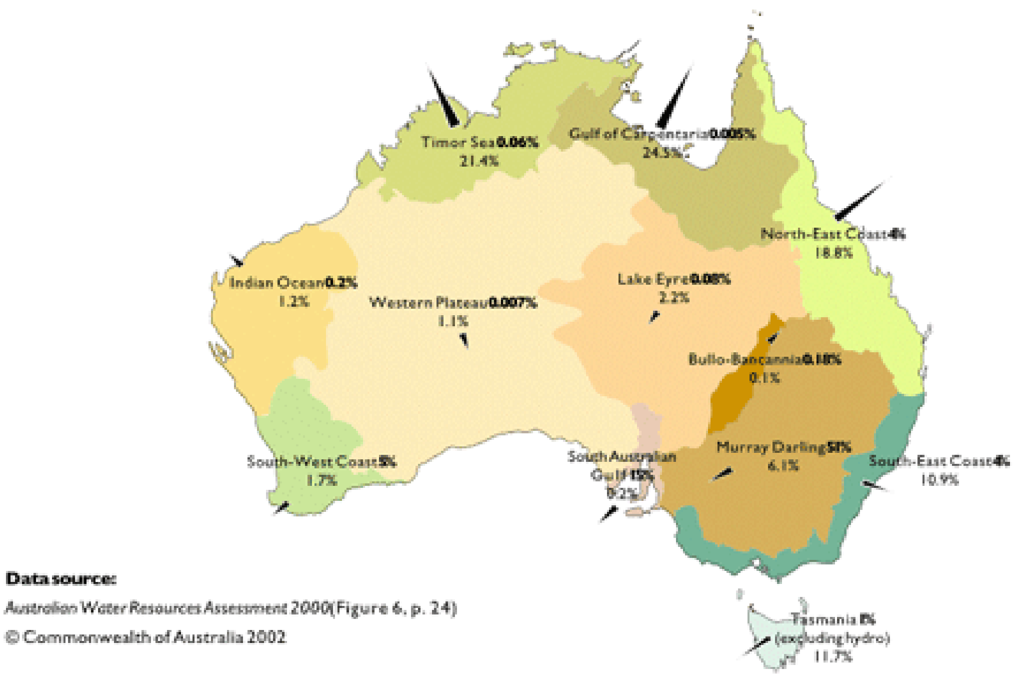

Figure 7: Map of Australia showing drainage divisions showing the percent of total Australian run-off. The figures in bold represent the percentage of water diverted for use from the drainage division. From Australian Water Resources Assessment, 2000.

The total combined capacity of all of Australia's 501 dams was found to be 83 853 gigalitres in 2004-2005. In Addition to this, there are also around 2 million farm dams in Australia, which are estimated to possess a total storage capacity of 8000 gigalitres (Australian Water Resources, 2005). Australia stores around 4 million litres per person – more than any other country – which aims at sustaining the population's water demand in dry periods (OzH20, 2001). This information indicates that a larger proportion of water in contained in flows than in any other country (i.e. in dams) (OzH20, 2001). Groundwater accounts for around 17% of Australia's rechargeable or renewable water resources, and most of this is drawn from the Great Artesian Basin in the north of Australia, which covers approximately 22% of Australia's land surface, and may contain water which is up to two million years old (Australian Water Resources, 2005). However, unlike surface waters, it is exceedingly difficult to accurately assess the actual quantity and quality of groundwater (Australian Water Resources, 2005). It should also be noted that surface and ground waters are physically connected, and can therefore should not be considered as mutually exclusive bodies, for example rainwater falling into a surface water body may in turn recharge the groundwater (Australian Water Resources, 2005). It is for this reason that groundwater does not individually represented in the index itself, but should be intrinsically considered in the indicators pertaining to surface waters and precipitation.

3.2 Water Use

Issues concerning the use of Australia's water supply have in recent years become more public due to an escalating demand for water, and a decrease in water availability. The problems concerning water availability stem largely from factors which exacerbate water scarcity in many other parts of the world, and to which Australia is of course not immune despite its expansive landmass. These factors include an increase in population growth, development of the agricultural sector, industrial growth, and increased urbanization (Connected Water, 2006). It is therefore necessary to understand the abilities of Australia as a nation to address this augmenting demand trend and to assess specific population groups and areas that are most affected by lower water availability. The Australian Water Resources (2008) suggests a number of effective ways in which to deal with increasing water demand. These include implementing water restrictions on usage, pricing water in an economically efficient way (while also considering sustainability), and development of more efficient technology to stop water wastage.

3.3 Water scarcity and demand: Trends since 2000

The Australian Bureau of Statistics states that in the year 2000-2001, Australian households and businesses combined consumed a total of 25,909 gigalitres, and that water use between the years of 1983 and 1997 increased as much as 65% (or 9,400 GL) (Connected Water, 2006). This increase in water consumption can be largely attributed to increases in agricultural activity, whereas urbanised areas showed a relatively small change in consumption over this period. The Commonwealth of Australia's account on water availability, which was published by Connected Water (2006) in conjunction with the Australian Bureau of Statistics, states that;

> *"The agriculture industry had the highest water consumption in 2000-01, accounting for 16,660 GL (or 67%). Households were the next highest water consumer, using 2,181 GL (or 9%). The water supply, sewerage and drainage services industry was also a significant consumer of water, with 1,794 GL (or 7.2%), followed by the electricity and gas supply industry with 1,688 GL (or 6.8%). According to the ABS, most water is consumed in NSW/ACT (39%) and Victoria (30%), followed by Queensland (17%), Western Australia (6.4%), South Australia (5.7%), Tasmania (1.4%) and Northern Territory (0.5%)"*

In some cases, this water consumption pattern not only exhausted water reserves, but in some parts of Australia also surpassed what was known to be the sustainable limit of extraction of water resources (Connected Water, 2006). This information was incorporated into the National Land and Water Resources Audit of 2001, which was concerned primarily with inherent inefficiencies of water management techniques, and future concerns in the event that this consumption pattern were to continue (Connected Water, 2006). Despite this, trends in recent years have shown an improvement of water use among the various sectors. The use of water as a critical resource knows no bounds, as it is used in practically every area of life: from domestic use, to industrial use for commercial and public works, and agricultural use for irrigation of crops and eventual food supply. The Australian Water Resources report (2005) states that roughly three-quarters of all water used within the Australian economy (which amounts to around 80,000 gigalitres) in 2004-2005 was returned into the environment. Concerning water consumption, an estimated 18 767 gigalitres of water were used in the year 2004-2005 (Australian Water Resources, 2005). The water left over from this was used in a number of different sectors, and of which (unsurprisingly) agriculture was the main consumer, where most of the water is used for irrigating crops and pastures (Australian Water Resources, 2005). Agricultural practices were followed by other areas such as industry and domestic usage. It should also be noted, however, that although agriculture still uses the majority of water, the quantity of water used particularly for agricultural practices has declined sharply in recent years (see Figure 9) (ABS, 2006). The Australian Water Resources report (2005) states that this may be due to dry conditions and limited water availability, which caused a decrease in water consumption of approximately 3000 gigalitres (14%) between the periods of 2000-2001 and 2004-2005. The specific reductions in consumption by sector (and over the same time period) are as follows:

- Agriculture: decreased by 23%,
  primarily due to a decrease in cotton and rice crops
- Household consumption: down by 8%,
  from 115 to 104 kilolitres per capita, per year.
- Household use of recycled or reused water increased from 11% to 16%
- Consumption of water by the mining industry increased by 29% as a result of increased levels of mining activity, especially in Western Australia.
  (From Australian Water Resources, 2005).

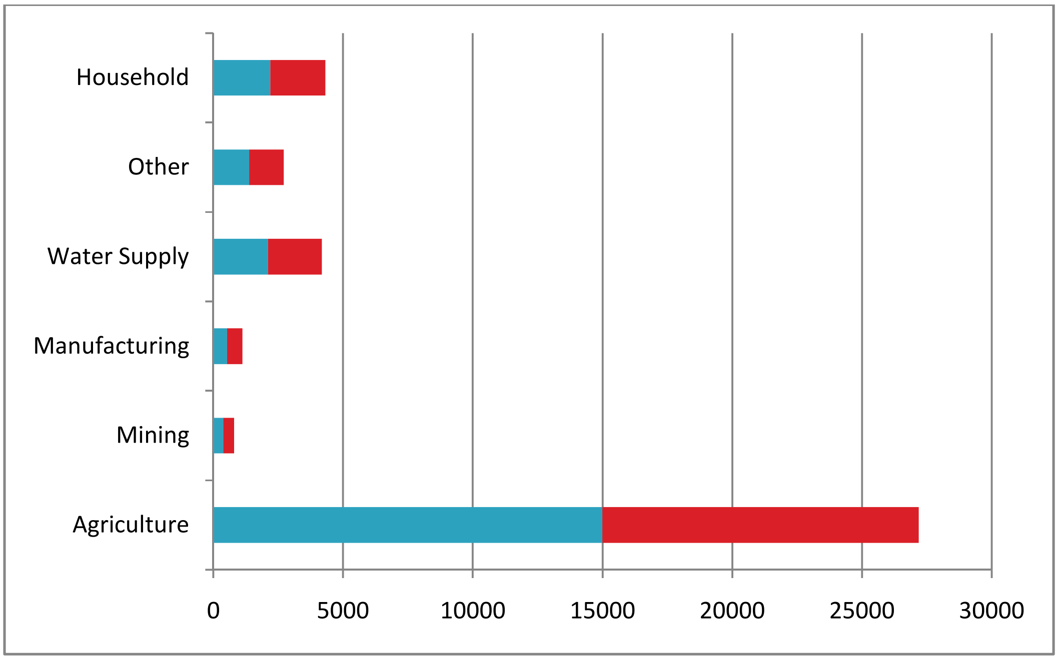

Figure 8: shows differences in water consumption by sector in the years 2000-2001 (red) and 2004-2005 (blue). Quantities are given in gigalitres per year. Source: Australian Bureau of Statistics, 2006.

According to the Australian Water Resources publication of 2005, water consumption in 2004-05 was 18 767 gigalitres. The specific sectors using this water were:

Agriculture	65 %	12 191 gigalitres
Household	11 %	2108 gigalitres
Water supply industry	11 %	2083 gigalitres
Other industries including electricity and gas	7.4 %	1330 gigalitres
Manufacturing	3 %	589 gigalitres
Mining	2 %	413 gigalitres

Although the largest figure here is the water used for agricultural purposes, of which a large proportion goes to food production, it is also important to note domestic water usage of individuals. The importance of household usage should be highlighted, in that it is this quantity of water that the individual is consciously aware they are using in everyday household chores and activities. It should also be noted that there is a considerable difference between the amount of water consumed in rural areas, and the amount of water consumed in urban areas, even for residential purposes. Estimates regarding water use per capita can be henceforth correlated with data pertaining to population density in order to get a clearer picture about water actual water usage according to population density (Figure 10). This is particularly important for a country such as Australia which has a large land mass, but whose population is primarily situated in coastal areas. An analysis such as this should provide information relevant to policy making in that it shows actual water shortages. Not surprisingly, however, the analysis does portray that areas of particularly large usage per capita are concentrated around areas in which a higher population density as been recorded (i.e. in, or in close proximity to, major cities).

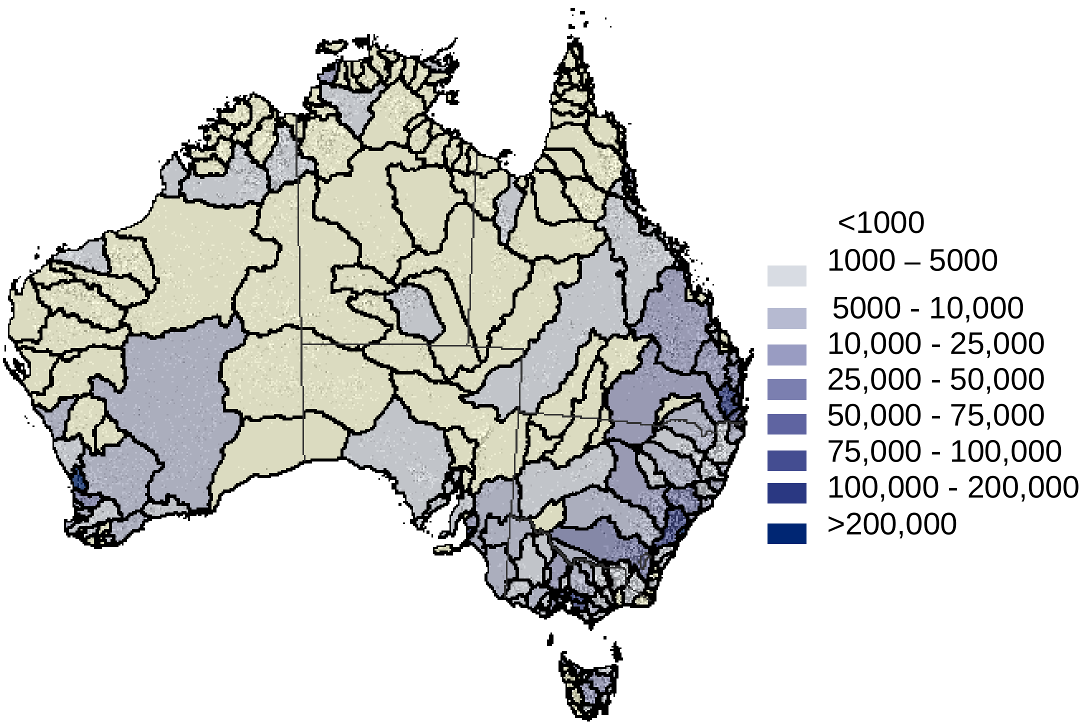

Figure 9. Map showing water use per capita (2004/2005 data) correlated with state population density estimates from 2006 surveys. Source: Rural Water, 2006. Data is from the 2006 Census of Population and Housing, and the 2004/2005 Water Account by the Australian Bureau of Statistics. All measurements are in ML (= m^3) per year.

Nevertheless, Australia does face future water supply risk. There are a number of threats to Australia's national water supply, and these range from climate change factors to changes in land use and agricultural practices (Australian Water Resources, 2005). The aim of water policy, not only in Australia but also on a global scale, is to minimize these risks and establish a clear framework by which water supply can be ensured (Australian Water Resources, 2005). An additional aim of this reviewed index is to allow a measure by which water poverty in Australia can be estimated on a regional level, rather than a national level. This requires taking into account the various problems, which may exacerbate water supply issues, and cause further strain – such as an increase in population and therefore water demand, ongoing severe drought problems, which are predominant particularly in rural parts of the country, an increase in economic activity, and limited surface waters, which are often exploited as a valuable water source. It is imperative that Australian water policy takes these effects into account, and accurately assesses the risk that they pose to Australia's water supply, particularly with regard to water availability for future generations. Even without droughts, high water consumption patterns suggests that these resources could very well be considerably depleted in further years without the appropriate political and technological infrastructure in place. Many Australian towns are now facing problems of water shortages and are presented with the challenge to meet not only current, but also future water demands (Australian Water Resources, 2005). With this in mind, it is important to assess which areas in particular are most affected by water shortages, and modify water policy accordingly, so as to ensure that water resources are not unfairly distributed within the country. This requires the installation of mechanisms such as demand management, in which better pricing of water should be implemented, as well as further restrictions on water usage (Australian Water Resources, 2005). This would lead to an increase in efficiency of allocation of water resources within the country as a whole. Improvement of technology (including irrigation technology for crops and pastures) would also be necessary in order to improve this (Australian Water Resources, 2005). Other measures, such as recycling of water, rainwater tanks, use of stormwater and desalination techniques should also be encouraged in order to reduce the strain on current water supplies (Australian Water Resources, 2005).

3.4 Results

Upon following the previously outlined methodology, the results of an AVCOR for each Australian state have been formulated. It should be noted, however, that due to a lack of quantitative data concerning external and internal water flows to each state's boundaries and also unspecific agricultural water footprints, the first method of analysis – that which analyses precipitation intake as the primary element constituting water availability per capita – may be used. The results on a state-by-state basis are as follows:

Table 3: Table showing ranked AVCOR and GDP corrected ratio for every Australian state

State	AVCOR (Average)	Corrected by GDP (Average)
Tasmania	**0.66**	**2.00**
South Australia	**0.69**	**1.81**
Western Australia	**0.62**	**2.16**
Northern Territory	**0.64**	**1.97**
Queensland	**3.47**	**10.93**
New South Wales	**0.74**	**2.27**
Victoria	**2.36**	**6.75**
Australian Capital Territory	**1.17**	**3.56**

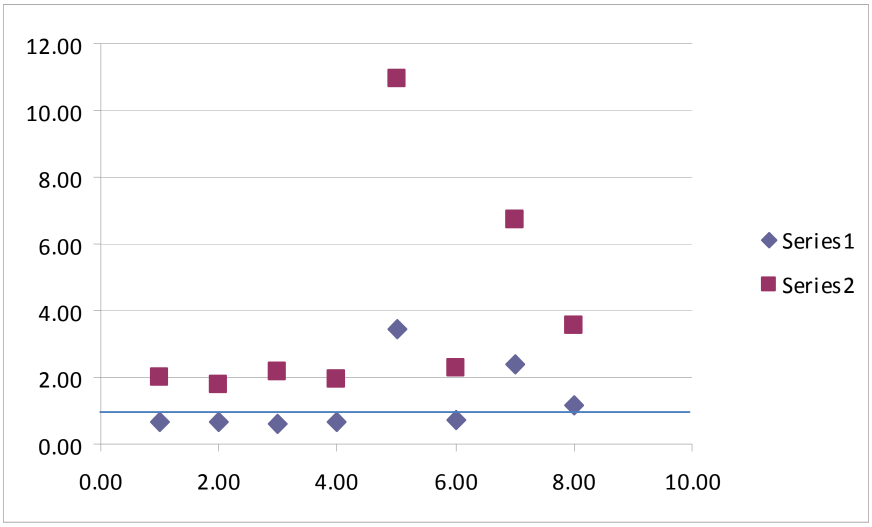

Figure 10: Graphical representation of the above table. Series 1 represents the AVCOR. Series 2 represents the AVCOR as adjusted by GDP in PPP per capita within the different states

3.5 Analysis

The above table and graph give an overview of overall water availability to the individual, and their individual capacity to rectify the water scarcity, within every Australian state. AVCOR figures that are less than 1 suggest that there is water scarcity to the individual, whereas those values greater than 1 suggest that there is no water scarcity to the individual. An AVCOR figure of 1 means that availability is equal to consumption. Additionally, the higher the GDP corrected figure, the more able the state is to deal with water unavailability. In light of this background, an analysis of the Australian case study may commence.

Western Australia

Western Australia comes across as (unsurprisingly) being the driest state, with an AVCOR of 0.62, which presents a case of considerable water scarcity to the individual. This is due to low annual average amount of precipitation (approximately equal to 352mm per year), combined with a lack of water inflow from external sources i.e. A lack of surface water which can be exploited for domestic water consumption. This scarcity is further exacerbated by a high amount of per capita domestic water consumption (493 L/cap/day), and the large percentage of water (44%) used for agriculture (Australian National Water Account, 2001). This ranking of Western Australia can also be seen to correlate with the quantity of water in drainage division (see Figure 8), which is of course exceptionally low compared to other Australian States. The only drainage division of note in Western Australia is the Timor Sea Drainage Division, in which half is also in the Northern Territory. Despite this, Western Australia's high GDP (in PPP) per capita compensates for this, and the figure of 2.16 suggests that the individual level of income within the states means that there are enough finances to implement an effective water distribution scheme in order to rectify this problem. Options for this will be discussed later.

Northern Territory

Following on from Western Australia, the next state with a low amount of water availability per capita is the Northern Territory. Despite the fact that the northern (and also tropical) part of the state, in which the Timor Sea and Gulf of Carpentaria Drainage Divisions are found, comprises approximately one quarter of the state, there is still a lack of water availability to the individual. This is also not surprising, as the majority of the state, whose climate is not categorized as tropical, is classified as grassland or desert, which no doubt causes a large amount of evaporation and therefore water loss to the individual. The concentration of drainage divisions in the northern part of the state also means that the rest of the state is still lacking in water. It would be necessary to know the exact amount of water flowing into the Northern Territory to give a more exact estimate of water poverty in the state. However, being partly tropical, the state does have (at least by Australian standards) a reasonably high average amount of annual rainfall (548mm), but a higher domestic per capita usage than Western Australia and most other states (548 L/cap/day). The GDP adjusted data (1.97) suggests that the Northern Territory can still combat this problem of water scarcity due to the high level of average income in the state, although it cannot be done as well as in , for example, Western Australia.

Tasmania

It is surprising to see Tasmania with such as low water AVCOR (0.66); however, this can also be explained in a certain way. Firstly, 53% of water in Tasmania is used for agriculture (Australian National Water Account, 2001), which essentially negates the effect of the high average annual amount of precipitation (1168mm). Additionally, there are a very high percentage of rural population groups (58%), particularly with reference to other Australia states, which most likely have less water availability than those living in the capital city. Additionally, there is a relatively high amount of per capita domestic water consumption in the state (392 L/cap/day), which lowers the AVCOR. The AVCOR in Tasmania would no doubt be considerably higher when evaluating availability for urban population groups.

South Australia

South Australia is regarded as one of the driest states in Australia, and this viewpoint is consistent with the data returned by the AVCOR. There is a minimum amount of rainfall within the state, approximately 236mm per year. This, combined with the large amount of agricultural area (40%) and the large amount of water used for agricultural production (79%), accounts for the water-stressed state of this area (Australian National Water Account, 2001). The South Australian Gulf is also relatively small, and diversion from the Murray Darling Drainage Division is integral – although this seems to also be minimal. Perhaps the only reason that this AVCOR is as high as it is, is because there is a large urban population (of which the majority live in Adelaide), and who are relatively close to Murray Darling Basin and the Lake Eyre Drainage Division, and therefore have more access to the water contained within these bodies.

New South Wales

New South Wales, within this index, is presented as also being under water stress, with an AVCOR figure of approximately 0.7. The rationale behind this is simple; New South Wales needs to share the Murray Darling Basin, in equal amounts, with Victoria and South Australia. In addition to this, the state of New South Wales has by far the largest population and population density (2,937 people per square kilometre), and the sharing of water resources among the population has led to further strain. However, in view of this, the inhabitants of New South Wales have made a concerted effort to reduce their domestic water consumption, which has alleviated the problem to a large degree. Additionally, water for agriculture is approximately 78% of total consumed water in New South Wales (Australian National Water Account, 2001).

Australian Capital Territory

The Australian Capital Territory (ACT) has no water scarcity to the individual, with an availability/consumption ratio of 1.17. This conclusion is justified considering that a large part of this state is occupied by the Murray Darling Basin, which means there is a seemingly small amount of external input into the state itself. The Southeast Coast Drainage Division, which presents around 4% of water diverted for use, also adds to this water-rich status. Additionally, inhabitants of the ACT use a comparatively small amount of domestic water - only 260 L per capita, per day. The ACT also boast a relatively large amount of annual average rainfall (approximately 566mm), compared to the majority of Australian States. On top of this, the high income of ACT inhabitants means the state is well equipped to deal with reallocation of water resources in the future if need be (GDP correction of 3.52 and 3.56 respectively). The temperate climate of both of these regions means that evaporation of water resources is not a particularly important issue.

Victoria

The state of Victoria also does not possess any water unavailability. This is, once again, due to the fact that a large part of the Murray Darling Basin is situated well within the borders of Victoria, and this, coupled with a high amount of precipitation (654mm per year) and a low amount of domestic usage per capita (222 L/cap/day) confirms this deduction. Additionally, there is a small amount of water inflow coming from Victoria and Queensland, which further contributes to this. These factors balance the large amount of water used for agricultural within the state (52%) (Australian National Water Account, 2001). The GDP corrected factor of 6.75 means that, once again, the state is able to deal with any eventual water shortages within its boundaries.

Queensland

Queensland also has a high annual average precipitation of approximately 630mm overall. Furthermore, inhabitants of this state also have access to water from the Great Cartesian Basin (the largest Basin in Australia, despite the high amount of runoff), and also partly from the Murray Darling Basin, and the North East Coast and Lake Eyre Drainage Divisions. The agricultural sector in Queensland, however, utilizes approximate 73% of the state's water consumption, but this is still relatively low given the population of the state and the populations of other states such as New South Wales, which also uses a very high amount of water for agricultural production. Again, the state average GDP would be available for implementation of water saving measures in the unlikely event of water shortage within Queensland, as the GDP corrected ratio for this state is 10.93.

Overall, the availability/consumption index has served its purpose, which was to give a scientific evaluation of water availability per capita, within defined system limits, which, in this case, are the state borders of all Australian states. While some results were surprising (for example, Tasmanian inhabitants being water poor), these conclusions become understandable upon further reflection and consideration of state water resources, precipitation, use of water for agriculture, and even population and population densities. The results are therefore coherent indications of water poverty within these system borders. Additionally, the incorporation of a GDP adjustment factor allows for the integration of income groupings – in this case on a state-by-state basis. However, it should also be noted that this index could be further applied to small units, particularly based on surface runoff in areas where surface water is present. One problem with this index is the lack of data for actual system input (i.e. the amount of water flowing into an area from an external source). This value, of course, presents a high degree of variability, due mostly to seasonal variations more than anything else. More information in this regard would serve to eradicate any possible uncertainties.

4 Results for the Asia-Pacific Region

The formulated index will be applied to a selection of Asian countries on a national level, in order to accurately assess the water AVCOR figure in both urban and rural population groups. Additionally, as with the Australian case study, an analysis of the country's capacity to deal with potential water shortages will be assessed by incorporating an income aspect to give a GDP (in PPP) adjusted figure. The following countries will be analysed: Bangladesh, Cambodia, Myanmar, Nepal, Pakistan, Papua New Guinea, Vietnam, India, Indonesia, Iran, Mongolia, Philippines, Thailand, China, Malaysia, Australia, Japan, Republic of Korea, New Zealand and Singapore. The results of this analysis, in comparison to the Water Poverty Index, can be found in Annex 2. A graphical overview, showing the correlation between the AVCOR and the Water Poverty Index can be seen below, along with graphs comparing the AVCOR and the GDP corrected figures, and also the Water Poverty Index and the GDP corrected figures.

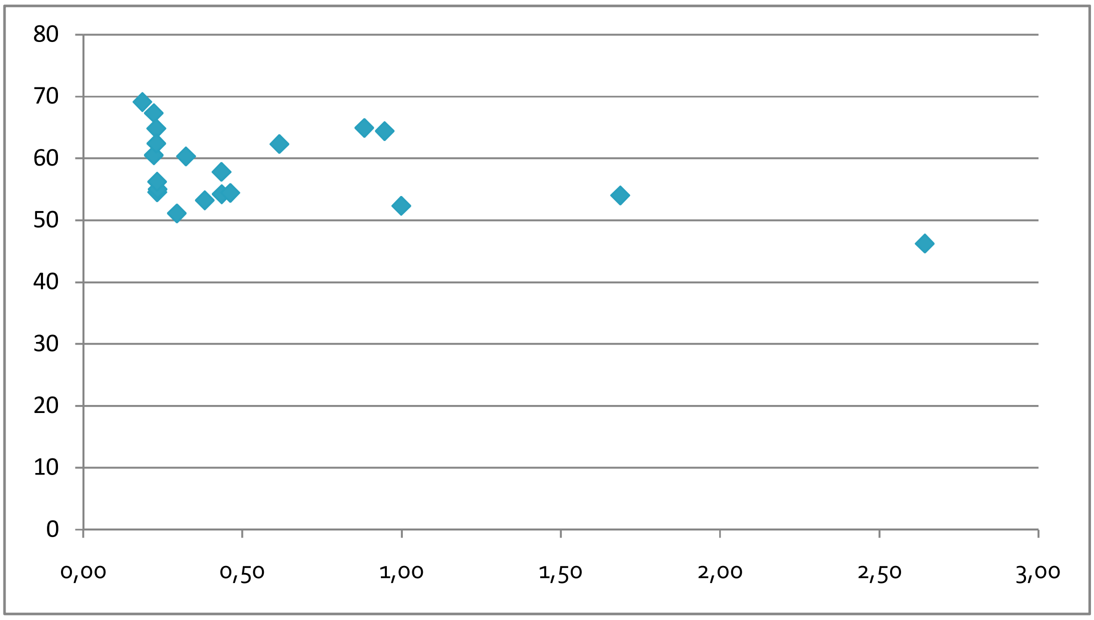

Figure 11: Graph showing correlation between the AVCOR figure (x axis), and the Water Poverty Index (y axis). Correlation coefficient is equal to -0.46.

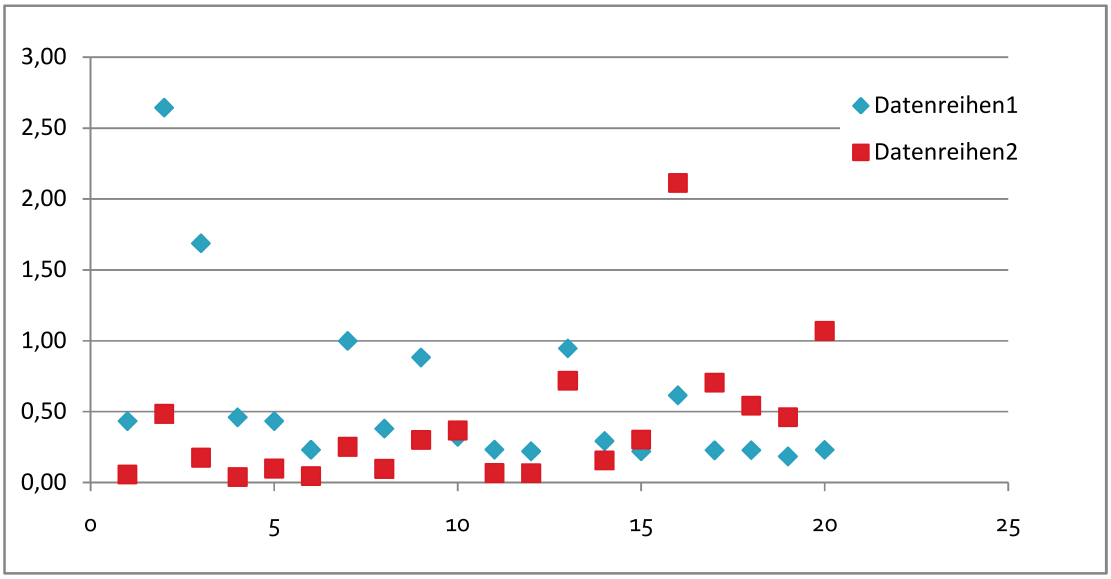

Figure 12: Graph presenting the AVCOR figure (series 1), and showing GDP adjusted water unavailability figures (series 2). Correlation factor is equal to 0.04

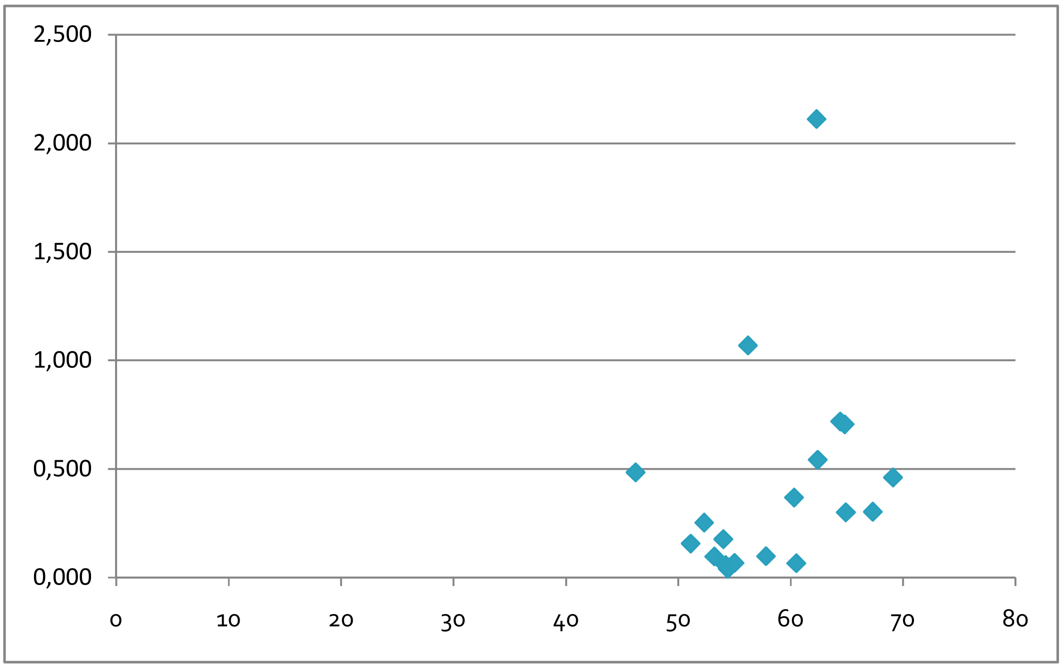

Figure 13: Graph showing correlation between GDP corrected water availability and the Water Poverty Index. Correlation coefficient is 0.31.

4.1 Analysis and Problems of the AVCOR

There is a significant correlation between the Water Poverty Index and the AVCOR, and this correlation that exists is negative (approximately -0.5). There are a number of reasonable explanations for this phenomenon, and these can be directly related to the previous section covering the evident drawbacks of the Water Poverty Index. The difference in results achieved by both indexes will be discussed on a country-by-country basis. This section is comprised of a discussion over the relevant problems and applicability of the AVCOR within the Asia-Pacific region. A number of assumptions will be made in the formulation of a new index, and these include; estimated precipitation from external sources for drinking water within the system boundaries, and also from internal precipitation. A country-by-country analysis will be completed below, in which the final output figure for the AVCOR, the Water Poverty Index, and the GDP corrected data from the AVCOR will be given respectively next to the name of the country.

Bangladesh (0.43, 54.2, 0.057)

The relationship between Water Poverty Index and the AVCOR is positively correlated, and therefore it can be assumed that this relationship is concrete. Despite this the Water Poverty Index suggests that water scarcity does not pose a threat to the population, whereas the AVCOR suggests that there is a considerable threat, given the available resources and the size of the population. Additionally, the high amount of agricultural area (approximately 58%) suggests that a large amount of water is used for irrigation purposes, and this would exacerbate the water shortages to the individual. However, it should be noted that the Water Poverty Index does not account for divergences in water Access for rural and urban population groups, which is a significant factor in the case of Bangladesh, as approximately 74% of the nation’s population live in rural areas. With this in mind, it is highly likely that these rural population groups have less access to water than urban ones. The Water Poverty Index, however, simply attaches a figure of 13.8 for the Access section to Bangladesh, without consideration of this factor. In view of the AVCOR, this figure should be assumed to be lower than 13.8 (which equates to approximately 70% access). Once again, the determinants within the “Access” category are merely functions of GDP, and therefore serve no other purpose than to raise the national water poverty figure in the case of Bangladesh. The GDP corrected figure here is a representation of Bangladesh’s low average income, and details the country’s unavailability to deal with water scarcity.

Cambodia (2.64, 46.2, 0.48)

A comparison of availability/consumption figure, and the GDP corrected figure illustrates a significant difference in these two figures, which can be primarily attributed use of external water resources for drinking water within the AVCOR. Due to the large external flow of water into Cambodia from surrounding regions (25,044 m^3/cap/year), an educated estimate was made as to the percentage of this water used for drinking water (10%). Due to the large number of people living in rural areas, many of whom would no doubt access their drinking water from external flows of precipitation such as from the Mekong River, this estimate seems to be adequate. Additionally, a relatively low amount of land area is utilized for agricultural production (21% by FAO estimates), and this would also give a higher reading for water resources in the country. The amount of water used per capita per day is also extremely low (13 L/cap/day on average), which, in once again discounting the “Access” section which gives a very low figure of 4.9, further accounts for this large figure of 2.64. However, in the event of water scarcity, the average per capita GDP would not be high enough to deal with effective management and allocation of water resources.

Myanmar (1.7, 54, 0.18)

In this example, the correlation between the Water Poverty Index and the AVCOR is quite strong. Myanmar has a significant amount of external water input from neighbouring countries, and this, combined with a large amount of annual precipitation (2091mm/year), accounts for a value that shows no water scarcity in the country (1.7). This, however, is once again dependant on the quantity of water from external sources precipitation to be used as drinking water, which has been estimated at around 5%. Although even if only 2% of precipitation from external sources is used as drinking water, the value given for water unavailability would be 0.88, which still does not show a terrible amount of water scarcity within the country. The GDP corrected figure of 0.18 illustrates the low average annual income of the country ($1,200/cap/year), and suggests that even if there were a severe water shortage within the country, the government would struggle to ameliorate the issue.

Nepal (0.5, 54.4, 0.04)

An estimate of 3% of precipitation from external sources was made to achieve this figure of 0.5, and was based balancing the relatively small amount of external renewable water resources with the high percentage of people living in rural areas, which would extract their drinking water from local sources (I.e. Rivers). However, Nepal is still water scarce, as the quantity of both internal and external renewable water resources is relatively low compared to many other Asian countries (1500mm/year). Additionally, the size of the population (about 27 million) exacerbates water stress within the country's borders. Despite this, this figure is counterbalanced by the fact that individuals use a comparatively small amount of water for domestic use (approximately 34 L/cap/day according to FAO estimates), which brings it more in line with the WPI's estimate of 54.4.

Pakistan (0.43, 57.8, 0.1)

The water-scarce status of Pakistan can be derived from two principle sources: precipitation and internal renewable water resources. Pakistan has a relatively low annual average amount of precipitation (494mm/year), and also lacks internal water resources such as lakes and rivers on which it has become dependent. This can be seen from the large quantity of system input (1058 m^3/cap/year), as derived from FAO data. With regard to the Water Poverty Index, Pakistan is surprisingly water-rich, with a value of 57.8. However, sections which received high figures in the Water Poverty Index include the "Access section" which (as previously mentioned) involves a number of determinants, which are merely a factor of GDP. The "use" section also scored 14.0, which suggests that per capita usage of water resources for households, agriculture and industry is seemingly efficient, which is once again reiterated in the AVCOR, in which average per capita domestic usage is approximately 62 L/day. Additionally, agricultural use (548 m^3/cap/year) is also relatively low, but given the yearly precipitation and low water inflow, it is not surprising that this water is scarce.

Papua New Guinea (0.2, 4.5, 0.05)

The AVCOR gives Papua New Guinea a final output figure of 0.2, and a GDP corrected value of 0.05, while the Water Poverty Index cites 54.5 as the final figure for water scarcity in Papua New Guinea. The output figure calculated from Papua New Guinea's water input data is obviously incorrect, given the very large amount of internal renewable water resources (129158 m^3/cap/year), the low amount of agricultural area (2%), high rainfall (3142mm/year), and low population strain – all of which ultimately result in less stress on water resources. The reason for this inaccuracy is due to the data used to detail water withdrawal per person, and water withdrawal for agricultural use. Given the high annual average precipitation in Papua New Guinea, the amount of water used for agriculture would most likely be decidedly less that then 1000 m^3/cap/year implemented by the index. This is a global average, and a lack of availability data concerning this parameter is unavailable, which allows for resulting inaccuracies within the index. This, in combination with a lack of solid data for external renewable water resources, means that this output figure for Papua New Guinea is incorrect. Indeed, the WPI's estimation of 17 for the "resources" section supports this.

Vietnam (1, 52.3, 0.22)

The AVCOR dictates that there is no water scarcity within Vietnam, and this is in line with the conclusion drawn by the Water Poverty Index. However, this figure is once again highly dependent on the amount of external inflow of precipitation from neighbouring countries, which has been estimated at 12 %. This is a reasonable estimate, due to the high rural population, and the large amount of water resources (6087

m^3/cap/year – the majority) coming from external sources. Additionally, yearly precipitation in Vietnam (1821 mm/year) is considerable. Taking all these factors into consideration, this figure could be potentially even lower than 1, as the large population size and daily domestic consumption of 192 L/cap/day can place substantial strain on water resources. Again, the GDP per capita is not high enough to deal with future water shortages.

India (0.4, 53.2, 0.1)

The AVCOR gives India a final output figure of 0.4, and a GDP corrected value of 0.1, while the Water Poverty Index cites 53.2 as the final figure for water scarcity in India. India, being one of the most populous countries in Asia, exerts a huge strain on its national water resources in order to provide its citizens with adequate water supplies. However, India simply does not have enough water to account for its massive population: the country has a mediocre total renewable water supply per capita of 1647m^3, and only 1083mm of rainfall per year. In addition to this, the average domestic water usage per capita is (by FAO estimates) 142 L/day, which is not insignificant, the WPI assumes only 50L per day. The percentage of land used for agricultural purposes equals around 52% of the country's entire landmass, which means that more water will be wasted in inefficient irrigation and water-intensive practices. It is for this reason that an availability/consumption analysis of India returns a figure of only 0.4. The WPI's figure of 53.2 seems extremely high, given this previous information. This can be mostly attributed to the "use" category – which evaluates industrial and agricultural efficiency with regard to water use – but this is once again a factor of GDP and is a very generalized figure given the large divergences in population groups (rural and urban) within the country. An AVCOR of 0.4 suggests that there are severe problems in counteracting this water shortage, and effective policy measures need to be introduced to solve this. Despite this, a corrected GDP figure of 0.1 means that the finances required to do this (given the GDP in PPP per capita) are limited. It would be interesting to perform this analysis for different population groups on a more localized level.

Indonesia (0.88, 64.9, 0.3)

Indonesia's final availability/consumption output figure of 0.88 suggest that the country is water scarce, although not severely. In the Water Poverty Index, Indonesia obtained a figure of 64.9, which suggests a reasonable status for water resources in the country. However, this is not the case. The Water Poverty Index allocated 15.7 out of 20 for "use", which suggests efficient use of water in industry and agriculture. It does not, however, allow for the fact that the majority of water used in industry at least is non-consumptive, and thus this determinant is void. Precipitation in the country is quite high due to the tropical climate of the country (2702mm/year), and total and internal water resources (12400 m^3/cap/year) are considerable. Despite this, the heavy burden the large population places on the country's water supplies is considerable. An assumed 5% of exogenous precipitation sources was assumed, but in the event that this figure is higher (e.g. From bordering Papua New Guinea, which has substantial water resources), then this would negate the water scarcity issue. However, even without water scarcity, Indonesia would struggle to deal with the problem due to low GDP, giving a GDP corrected figure of 0.3.

Iran (0.32, 60.3, 0.37)

The AVCOR gives Iran a final output figure of 0.32, and a GDP corrected value of 0.37, while the Water Poverty Index cites 60.3 as the final figure for water scarcity in Iran. Iran also shows conflicting positions between the AVCOR and the Water Poverty Index. The figure of 0.32 as calculated from the AVCOR displays water scarcity, which is not surprising given the low amount of annual precipitation on a national scale (228 mm/year). The total renewable water resources (a total of 1957m^3/cap/year) are also not very substantial considering the total population of the country, which is just over 70 million. The figure cited by the WPI (60.3) is boosted mainly by the "capacity" and "access" determinants, both of which have previously been shown to be inadequate in assessing water poverty, as they contain indicators which are merely factors of GDP (which was also included in these groupings). The GDP adjusted output figure of 0.37 is a solid figure (given the country's national average GDP in PPP of $13100), but still shows an inability to tackle water scarcity in the country given its grave status.

Mongolia (0.23, 55, 0.07)

The AVCOR gives Mongolia a final output figure of 0.23, and a GDP corrected value of 0.07, while the Water Poverty Index cites 55 as the final figure for water scarcity in Mongolia. This suggests water scarcity, although there is no concrete data with regard to actual water used for agricultural production, or for total water withdrawal per capita. Additionally, the FAO suggests that there is no input water into the system, despite the fact that Mongolia is a land-locked country. With this in mind, the results returned for Mongolia should be considered not entirely accurate. Despite this, the low amount of rainfall within the country (241 mm/year), combined with the relatively low estimate given by the Water Poverty Index, suggest that the average agricultural water footprint (estimated at 1000 m^3/cap/year) may not be too far from the mark, although this is merely speculation and requires further development.

Philippines (0.22, 60.5, 0.07)

The AVCOR allocates the Philippines a final output figure of 0.22, and a GDP corrected value of 0.07, while the Water Poverty Index cites 60.5 as the final figure for water scarcity in the Philippines. A concrete output figure cannot be allocated to the Philippines, as there are, once again, inaccuracies in the calculation of the AVCOR within countries with no external water input, and whose water footprint (total per capita, and for agricultural purposes) has not yet been calculated. With this in mind, it is therefore better to use the value given by the Water Poverty Index (60.5), which is, until the application of new data on these parameters can be applied, the best means by which to assess water scarcity in the country. This data given by the AVCOR, therefore, should not be entirely trusted.

Thailand (0.9, 64.4, 0.72)

The AVCOR gives Thailand a final output figure of 0.9, and a GDP corrected value of 0.72, while the Water Poverty Index cites 64.4 as the final figure for water scarcity in

Indonesia. Thailand obtained a relatively high score in the Water Poverty Index (64.4), but the highest ranking figures came once again from the “use” and “capacity” sections. The output availability/consumption figure calculated for Thailand is more likely: approximately half of the country’s water resources come from external sources (the Mekong River); rainfall in the country is only mediocre (1622mm/year), given the size of the population (around 63 million). What stops the ratio returning an even lower figure, however, is the fact that the majority of the country’s population lives in rural areas (and thus are assumed to consume less water); domestic usage per capita is relatively low (98L/day), and only a small amount of agricultural area (3%). The use of precipitation from exogenous sources for drinking water has been estimated at 15%, but this could be higher, which would in turn augment the output figure for the AVCOR. Increasing this 20% would give an output of 1.2, showing no water scarcity. However, this is difficult to estimate. The GDP corrected figure of 0.72 illustrates Thailand’s low-middle income status, and reduced ability to deal with water shortage.

China (0.29, 51.1, 0.16)

China’s status is similar to that of India’s: a huge population, and relatively low precipitation. However, China is even more water scarce than India, due to a lower annual average amount of precipitation (629mm/year), and lower amount of external renewable water resources. Compared to India, China also has a higher proportion of urban dwellers (42%), which would use more water and therefore exacerbate the water scarcity issue, although it has a lower domestic daily consumption per capita (90L). This, however, is still not enough to counteract the huge strain the population places on water resources within the country. Within the Water Poverty Index, the seemingly high figure of 51.1 originates from the “capacity” section (13.2), which has previously been discounted, and should therefore be lower. Given the GDP corrected figure of 0.16, water resources reallocation and management could serve to be a significant issue in the future.

Malaysia (0.2, 67.3, 0.3)

The AVCOR allocates Malaysia a final output figure of 0.2, and a GDP corrected value of 0.3, while the Water Poverty Index cites 67.3 as the final figure for water scarcity in Malaysia. Despite the fact that the AVCOR portrays Malaysia as a water stressed country, an analysis of the water resources of this country shows that this cannot be the case. Malaysia has approximately (22211 m^3/cap/year) of internal renewable water resources, and this, in combination with high average annual rainfall (2875mm/year), shows that the country's population is not suffering from water scarcity. In view of the per capita domestic water usage of the country (179 L/day), these internal water resources should be more than enough to supply the population with adequate water. Within countries such as Malaysia that have a high amount of rainfall, it is unlikely that the standard 1000m^3/cap/year can be applied, as it is doubtful that this amount of water would have to be withdrawn for agricultural purposes. Therefore, more information regarding per capita water usage for agricultural production is required to ascertain if the country is really water scarce or not, however, without the appropriate data, this cannot be accomplished.

Australia (0.62, 62.3, 2.11)

The AVCOR gives Australia a final output figure of 0.62, and a GDP corrected value of 2.11, while the Water Poverty Index cites 62.3 as the final figure for water scarcity in Australia. A breakdown of Australian States and their relative water AVCOR has been previously shown, however this section will show Australia's national AVCOR, and explain why this is so. Calculation of this ratio gave a total output figure of 0.62 for Australia, which illustrates the water scarce nature of the country, due to low rainfall (534mm/year) and high urban population (88%). Additionally, the quantity of domestic water used per capita (501L/day by FAO estimates) is very high, which further aggravates the water scarcity issue. By the same token, however, Australia's high per capita GDP shows that the country is well equipped to deal with this shortage, and should therefore assign more financial resources to combat this increasingly serious problem, and ameliorate allocation and management of water resources. This can be seen from the GDP adjusted figure of 2.11 as computed for Australia. Once again, within the Water Poverty Index, the sectors augmenting the figure of 62.3 as allocated to Australia are the “Access” and “Capacity” sections (13.7 and 17.6 respectively), which are not relevant in the new index.

Japan (0.23, 64.8, 0.71)

The AVCOR gives Japan a final output figure of 0.23, and a GDP corrected value of 0.71, while the Water Poverty Index cites 64.8 as the final figure for water scarcity in Japan. Japan possesses a comparatively low amount of total and internal renewable water resources (approximately 3361 m^3/cap/year), and also has an annual average rainfall of 1668mm/year. However, a large proportion of the population lives in urban areas (66%), and therefore consumes more water than rural inhabitants. Despite this, domestic water use per capita in Japan is quite low for a developed country (375L/cap/day). The rationale for the water AVCOR allocating such a low number for Japan most likely lies in the population size of the country, comparable to water resources available, which would give a water-scarce reading. However, the Water Poverty Index’s output figure of 64.8 is very high, considering the above information. Japan scored very highly on the Access and Capacity sections, which (once again) are irrelevant in the formulation of the new index and should therefore be disregarded. Without these figures, Japan would also be considered water scarce. The GDP corrected figure of 0.71 suggests that, in being significantly than the availability/consumption figure, Japan’s average per capita GDP is high enough to deal with this water shortage.

Republic of Korea (0.23, 62.4, 0.6)

The Republic of Korea is in a similar situation to Japan, although has a smaller population which therefore places less stress on water resources, and accounts for a similar output figure even given lower available water resources. The Republic of Korea possesses total renewable water resources of 1451 m^3/cap/year, and 1274mm/year precipitation. Additionally, an estimated 1% of precipitation from external sources (i.e. from North Korea) was estimated. With 81% of inhabitants occupying urban areas (and are of course higher water consumers), and an average domestic consumption of 388L/day, the Republic of Korea can be viewed as a water scarce country. Once again, within the WPI, the Republic of Korea obtained high scores for “access” and “capacity”, which are not counted in the new index. Once again, the Republic of Korea’s average annual GDP of $27,100 means the country is well positioned to implement legislation regarding rectification of water scarcity and reallocation of water resources.

New Zealand (0.19, 64.9, 0.46)

Once again, the data output figure for New Zealand should be viewed with caution, as given the amount of internal water resources within the country, water scarcity should not be an issue. The WPI’s estimate of 64.9 is undoubtedly closer to the mark, given all the pertinent information contained within the index. This availability/consumption figure, however, is mostly to do with an unavailability of data – particularly, in this case, with regard to water used for agricultural purposes.

Singapore (0.23, 56.2, 1.07)

Singapore returned much the same results as New Zealand; however, they seem to be much more in line with the water-scarce situation of the country. Singapore relies on water input from neighbouring countries such as Malaysia in order to sustain its citizens’ water needs due to an insufficient amount of water (Segal, 2004). Due to the low amount of internal water resources (137m^3/cap/year), the low amount of agricultural land (only 1%), and the moderate rainfall in the country (2497mm/year), this result may not be too far from the truth. However, with no further information regarding exogenous water input from other neighbouring countries, and exact information about water withdrawal per capita, this cannot be certain, and thus the results of the index should be viewed with caution.

5 Conclusion

Given the above comparisons between the Water Poverty Index and the AVCOR, it is clear that this new index adds some additional and pertinent information to assess water poverty to individual population groups within countries, and also on a more localised scale. However, the Water Poverty Index is not completely incorrect in its formulation, and although it has many drawbacks – such as containing irrelevant information – it still gives a good overview of situations of water stress in certain countries. It is very possible there are also divergences in data as used by the Water Poverty Index, and that used by the AVCOR, however this has yet to be confirmed. This, of course, would account for discrepancies in the results obtained between both indices. The primary reason for the differences in results, as can be seen above, is that the AVCOR discounts the importance of such factors such as "Access", "Capacity" and "Environment", which are in many cases responsible for the high output value for the countries analysed above. This new index focuses more on actual water scarcity, and ability to deal with this, and avoids over complication by use of indicators, which are not in themselves mutually exclusive.

Additionally, the AVCOR avoids making unnecessary assumptions – such as the domestic water use in developing countries – as the Water Poverty Index does. However, one primary assumption made within the index was the quantity of precipitation from exogenous sources (i.e. Precipitation from system input) which was used for drinking water within the system borders. This is very difficult to estimate, and educated estimations were made given the quantity of system input water, and the quantity of water in bordering areas. This estimate, however, significantly altered the final output figure for water scarcity, and more research and data need to be analysed in order to correct this. Furthermore, standardised data was implemented in certain situations. Examples of this include; total water footprint per capita (average) and agricultural water per capita (also an average). This information is also not available for every country, only a selection. This lack of data resulted in some considerable faults, the largest one being the functioning of the index when two simultaneous instances occur: when standardised data was applied in the case of the water footprint, and when there was a lack of system input. In this case, the index did not function properly. This problem, however, could be remedied in the event that data pertaining to these parameters was present (unfortunately, this is not the case, and therefore standardised data was applied). It is for this reason that final output figures for countries such as Malaysia, the Philippines, and New Zealand was not correct. The most sensitive parameter causing inaccuracies in these cases is the indicator relating to water for agricultural use; as in countries with high rainfall, less water withdrawal for agriculture is generally needed. However, for these countries, no data was available, and the standardised figure of $1000m^3$/cap/year was applied (which seems too high for countries such as Malaysia and New Zealand, both of which have high quantities of rainfall). However, this inaccuracy is not relevant for the Australian case study, as data pertaining to external and internal water resources for each state was not implemented into the index.

Additionally, the AVCOR would function much better when applied on a localised scale, where concrete data concerning actual differences in consumption, use and financial means of the population group could be obtained. For example, the index would be more accurate if the exact GDP of the population group being assessed was known, rather than just applying generalised data. The same conclusion can be drawn for water consumption; where divergences in water use between population groups would be known. This, in itself, is one of the primary downfalls of the new index. However, this is more to do with a lack of availability of data, rather than an intrinsic drawback of the index itself, and is also the case in the Water Poverty Index. Indeed, this is the same for any index – the more information that is known, the more effective it is. With regard to the GDP corrected data, it is also important to note that this would comparative analysis would function better on a more localised scale. The aim of this thesis was to formulate an index, which accurately assesses water availability within a defined system area, and to cross-reference this figure with the population's average GDP in order to ascertain the population's capacity to deal with eventual water shortages. In view of the above analysis and comparison with the previously established Water Poverty Index, this aim was, at least to some extent, successfully attained.

Despite uncertainties in results occurring from lack of data, the establishment of a water AVCOR can be seen as a relative success. In averting over complication and other inaccuracies that are present in previous indices of this nature, this new index gives a more comprehensive overview of water poverty. The results of this index, while occasionally surprising, become clear upon close analysis. In addition to this, the system allows for the introduction of temporal determinant, which can be applied to illustrate water poverty in monthly intervals. The Water Poverty Index, and many other indices, do not have this determinate, and thus are forced to generalise water poverty on an annual basis. The AVCOR, therefore, is able to calculate water poverty on a more localised, and specific, basis – which will in turn provide invaluable information to policy makers as to how to implement effective water management and allocation policies.

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Annex 1

Country	Availability/Consumption Ratio	WPI	GDP Corrected Ratio
Bangladesh	0.43	54.2	0.057
Cambodia	2.64	46.2	0.48
Myanmar	1.69	54	0.18
Nepal	0.46	54.4	0.04
Pakistan	0.43	57.8	0.10
Papua New Guinea	0.23	54.5	0.05
Vietnam	1.00	52.3	0.25
India	0.38	53.2	0.10
Indonesia	0.88	64.9	0.30
Iran	0.32	50.3	0.37
Mongolia	0.23	55	0.07
Philippines	0.22	50.5	0.07
Thailand	0.95	64.4	0.72
China	0.29	51.1	0.16
Malaysia	0.22	67.3	0.30
Australia	0.62	62.3	2.11
Japan	0.23	64.8	0.71
Korea	0.23	62.4	0.54
New Zealand	0.19	59.1	0.46
Singapore	0.23	56.2	1.07