Water Poverty Index Mapping In Thiruvananthapuram For Identifying Potential Water Harvesting Sites Using GIS

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Abstract

Water poverty is a situation where a nation or region cannot afford the cost of sustainable clean water to all people at all times. Kerala is considered as the land of water resources with high rainfall, rivers, backwaters, lakes and many streams. However, Kerala is frequently facing drought and acute water scarcity in many districts. In the State, majority of people in rural areas are depending on unprotected wells, tanks, rivers and streams for their water needs. The urban areas are also not fully covered by protected water supply services. In 2013, the Union Ministry of Drinking water and sanitation published the State's Economic Review which clearly points out that the available water is mostly heavily contaminated. Kozhikode, Palakkad and Thiruvananthapuram were rated to be the most suffering districts in terms of water quality. This study concentrates on Thiruvananthapuram district, where summer months in the district witness drying up of wells/drastic drop of water level in many parts, water shortage and misery to the people.

The city's elevated areas and coastal stretches also witness water shortage. The calculation of Water Poverty Index and its mapping is done for 4 sub-districts in Thiruvananthapuram district which allows monitoring of a combination of aspects affecting water management, including water sources, access to and use of water, human capacity to manage water and environmental impacts. Thus the highly critical area is identified for the ground water prospect zone mapping. This area with higher runoff potential and less infiltration has major surface water discharge into streams, rendering lower recharge to aquifers. This study presents a methodology or model that can be easily applied to identify suitable sites for rain water harvesting and surface water storage systems by using remote sensing and GIS technologies.

Keywords: Water Poverty Index, Water Poverty Mapping, GIS, Rainwater harvesting

1 INTRODUCTION

"Water is life". It is how water has been characterized in the European Union (EU) Water Policy document. Such characterization is apt, as life on Earth had its origin in water, and life is not possible without water. The world's water resources are locked in to the hydrologic cycle, whereby evaporation of ocean water becomes entrained in to the atmosphere. Precipitation provides water to the lakes, streams and wetlands (surface water). Further, part of the precipitation infiltrates in to the ground and becomes groundwater (sub surface water).

Ultimately, all these continental waters flow back to the ocean and become recycled again. Oceans with 97.2% of all waters dominate the hydrosphere.

There is less than 1% of water that is possibly available to mankind for its various uses. Riverine sources are a meager part of the above. Because of the limited nature of fresh water availability and the increasing demand for various purposes, besides resource depletion due to pollution, water resource estimation had become a major concern of Governments in the developed countries for national planning. Surface water evaluation is relatively easy, whereas ground water recharge estimation requires application of multiple techniques to increase reliability of recharge estimate (Scanlon et al, 2002). Global warming and climate change have all the ingredients to add to the woes of recharge estimation that can offset the water resource projections, affecting life and economy of nations.

Access to safe drinking water means meeting basic human needs. In India, demand for water usage is increasing with its population and economic growth, but, due to lack of infrastructure, the water supply shortage is becoming acute. Further, over reliance on groundwater is lowering the groundwater level and leading to higher content of fluorine, arsenic, and other toxic substances. Also, with a sudden population influx in the urban areas along with industrialization, sewage emission is exceeding treatment which threatens the public health and living environment of local residents. People are heavily relying on groundwater due to a lack of surface water supply, groundwater quality is rapidly deteriorating as sea water permeates the underground water, and therefore development of surface water resources is urgently required.

Kerala is endowed with 44 rivers tanks and wells, backwaters, innumerable rivulets and streams, highest rainfall, yet there is problem related to water throughout the State. The annual yield of water in Kerala in normal year is around 7030 crore CUM. The ground water resource available in Kerala is estimated at 7048 MCM. The total requirement is 4970 crore CUM. Based on this figures, Kerala is being a water surplus state. But at the same time Kerala exhibits a paradoxical situation. It has become the routine in the state that women and children queuing with multi colored buckets and ponds in front of water taps and water supply tankers and the govt. of Kerala declared 7 out of 14 districts in the state as drought prone in 2012. Nearly 40 % of available water resources are lost as run off. Rapid commercialization and when the water becomes paid good, there water become a precious commodity. The declining water availability has become a threat to sustainable development.

Many districts in Kerala are also facing shortage of drinking water. In 2013, the National Sample Survey reiterated that Kerala not only lags behind in comparison to the national figure for accessibility to drinking water, but it also trails behind all the southern states as well. Only 29.5 percent of the rural households have access to drinking water, rest 70% do not have. The immediate neighbor with severe water woes Tamil Nadu has far better figures to its credit – 94 percent accessibility in rural areas. Even other states which trail behind in other indices like Bihar, Uttar Pradesh and Rajasthan fair far ahead in terms of water accessibility. In 2013, the Union Ministry of Drinking water and sanitation published the State's Economic Review which clearly points out that the available water is mostly heavily contaminated. Kozhikode, Palakkad and Thiruvananthapuram were rated to be the most suffering districts in terms of water quality. This scarcity and contamination in a state which receives a healthy share of water from two different monsoon seasons is appalling.

Growth of Thiruvananthapuram, the capital of the of the erstwhile kingdom of Travancore (and present day Kerala) as a prosperous urban centre prompted the Travancore rulers to establish a piped water supply scheme way back in the 1930s. Water was drawn from the middle reaches of Karamana river at Aruvikkara. Commensurate with further growth of the city, the water supply scheme was augmented with storage enhancement by constructing another dam in the upper reaches of the river at Peppara. During a couple of drought years,

even the enhanced storage seemed inadequate to meet the water requirements of the city water supply. Even today, the city water supply is not able to cater to the total demand of the population, and many city wards suffer supply shortage exceeding 41% of the demand.
The main objective of this study is analyzing analyzing water scarcity in Thiruvananthapuram district using GIS and remote sensing technologies and identifying rainwater harvesting sites in most critical block as a mitigation measure.

2. MATERIALS AND METHODS

2.1 Study Area

Trivandrum, the southernmost district of Kerala State, is situated between North latitude of 8° 16’ 59” and 8° 49’ 59” East longitude of 76° 28’ 59” and 77° 16’59”, covers a geographical ambience of 2192 sq. km which house the capital city of Kerala State and falls in Survey Of India degree sheets 58 D and H. The district stretches 76 kms along the shores of Lakshadweep Sea on the west, bordered by Kollam district on the north and with Tirunelveli and Kanyakumari districts of Tamil Nadu on the east and south respectively.

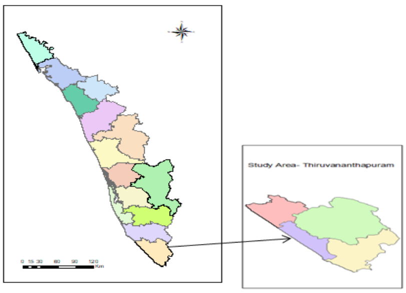


Fig 2.1 Location map of study area

2.2 Calculation Of Water Poverty Index And Mapping

The WPI is a concept, which was first developed in 2000 (Sullivan, 2000, 2002, Sullivan et al. 2003) 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. Such an index makes it possible to rank countries and communities within countries taking into account both physical and socio-economic factors associated with water scarcity. This enables national and international organisations concerned with water provision and management to monitor both the resources available and the socioeconomic factors which impact on access and use of those resourcesUsing the composite index approach, the WPI could comprise various elements:

- Resource: The availability of water taking into account the variations in seasonal and inter annual fluctuations and water quality
- Access: The accessibility of water for human use
- Capacity: Capacity is interpreted in the sense of income to allow purchase of improved water, education and health
- Use: Captures the actual amount of water being used and extracted from the system

2.2.2 Mathematical structure of WPI

Composite Index Approach as developed by Sullivan(2014) was used in the determination of Water Poverty Index WPI) (see equation 1).

$$WPI=(W_rR+W_aA+W_cC+W_uU+W_eE)/(W_r+W_a+W_c+W_u+W_e) \quad (1)$$

Where WPI = Water Poverty Index score of a particular location

R = Resources component (score out of 100)
A = Access component (score out of 100)
C = Capacity component (score out of 100) U = Use component (score out of 100)
E = Environment component (score out of 100)
w = weighting factor for each component

Each of these components is first standardised so that it falls in the range of 0 to 100. The resulting WPI value is between 0 and 100. A score of zero indicates water-stressed situation while 100 score shows water-advantaged situation.

$$\mathrm{WPI} = \sum_{i=0}^{n} \mathrm{Wi} \,/ \sum_{i=0}^{n} \mathrm{W}$$

2.2.3 Design of the Index

The methodology adopted for its calculation is the one applied by the authors of the index (Cullis and O'Regan, 2004; Sullivan et al., 2006; Sullivan 2005) implementing it at community level; ie, the composite index approach. Using survey data and national statistics, each variable of the WPI is obtained by aggregating a set of sub-components using composite index approach. The variables are then standardized on a scale of 0 to 100 before they are aggregated by weighted average, giving a low score of the WPI indicate a high level of water poverty (Sullivan,2005).

2.2.3.1 The variable - Resources

The report submitted after an assessment of surface water and groundwater availability of the district by central groundwater board Government of India in 2007 it is reported that the district receives on an average 2001.6 mm of rainfall annually and net annual groundwater availability in MCM is 304.74. In the study area water available both as surface water and groundwater are not enough to meet the daily demand hence optimum extraction is assumed.

2.2.3.2 The Variable - Access

The access component value is calculated as

A =(Total Households) /(Households With Access To Secure Water)

A secure water source is defined as access to clean water as a percentage of households having tap water source from treated source or covered well. The data regarding the total number of households and those with the safe water source is obtained from Department of Economics And Statistics Thriuvanthapuram, prepared using Census data 2011. The minimum bench mark level for access is 0 percentage and the maximum benchmark level is 100 percentage.

2.2.3.3 The Variable - Capacity

The capacity index is a function of the level of education and income level. It is computed here at household level by first fitting a model to the proxy parameters to determine the income level and further introducing the level of education to get the capacity value. Income level is considered as the households above poverty line and education level is taken as the literate people in the area. Both of these data is obtained from Census data 2011

The education capacity value is calculated as

EC= (Literates)/(Population)

and income capacitor value is calculated as

IC= (Households above poverty line)/ (total households)

The two sub components used for the capacity component have been assigned equal importance (Cullis 2002; 2005). The Capacity component value is there for merely average of two sub components and the calculated as

C = (EC + IC) /2

The minimum benchmark for capacity is 0 percentage and the maximum level 100 percent

2.2.3.4 The Variable Use

As Per The Central Public Health And Environment Engineering Organisation (CPHEEO) recommended water supply levels in the area provided with water supply is 150 l/p/c/d and water required for an average Indian towns 270 l/p/c/d

The use component value is calculated as

U={(Direct requirement urban)/ (population)}*{10^9/365} l/c/d (litres/capita/day)

2.2.3.5 The Variable – Environment

The 'environment' important is very complex combining variables such as biodiversity, environmental degradation, soil erosion and water quality. This is desugned to represent the degree of maintenance of ecological integrity needed to ensure ecologically sustainable development. In this study it was difficult to capture the idea of ecological integrity, as data to adequately represent the environmental situation where not widely available in Thiruvananthapuram, as environmental protection is not high on our country's agenda

For this study, data on vegetation cover were incorporated into the WPI since it is the best indicator of water availability in tropical regions. The minimum benchmark for environment is 0 and maximum level is 5. The environment component score is then calculated by multiplying the component value with 20, as this expresses the component as a score out of 100 and therefore as a percentage.It has a range of 0 to 5, with 0 indicating very poor ecological state and 5 a perfect ecological state.

2.2.4 Weighing of the Variable

The WPI index is a composite index made of combination of five variables described above. For each variable and an index is calculated from the values of indicators of parameters identified. In any case of aggregation weighted average is the method used. The weights are chosen to sum to 1 so that a trade-off is created between the criteria. The standardization is done on a scale of 0 to 100 with a low score of WPI indicating a high level of water deprivation (Sullivan et al, 2006) In the concept of WPI, it is recommended that the values of Wi be set by stakeholders relevant to the considered level of water poverty through a multi criteria decision analysis process

2.2.5 Index calculation

After calculating each of the individual component scores, the weighing have to be used to calculate the final WPI for each taluks, the least value of WPI indicates more water scarcity in the area.

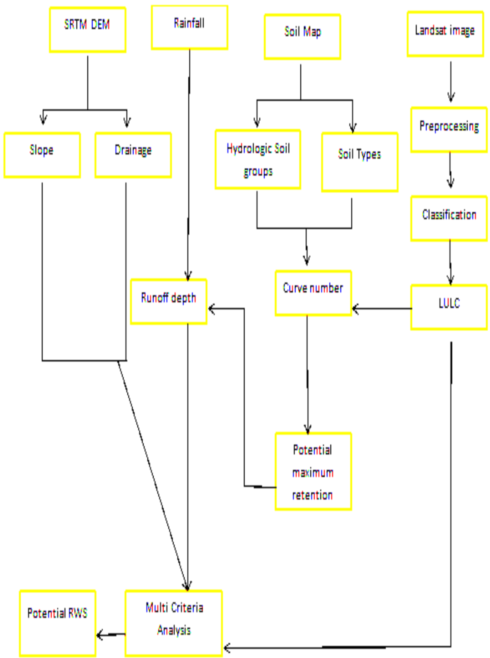
2.2.6 Software Used

Softwares used for the analysis as follows

1. ArcGIS 10.2 for GIS Analysis
2. Erdas imagine for image classification

2.3 Site Suitability Analysis For RWH Structures

The overall process of identifying RWH sites is illustrated in Figure . The SRTM DEM was used to extract the land slope and drainage characteristics of the study area. Satellite image (Landsat OLI) data were used to produce an LULC cover map of the study area. This map was then used with the soil map to produce the CN layer. The CN layer was in turn utilized to estimate the runoff depth in the study area. All the produced layers were combined with the weights from the literature to produce the RWH potential suitability map



3. RESULTS AND DISCUSSIONS

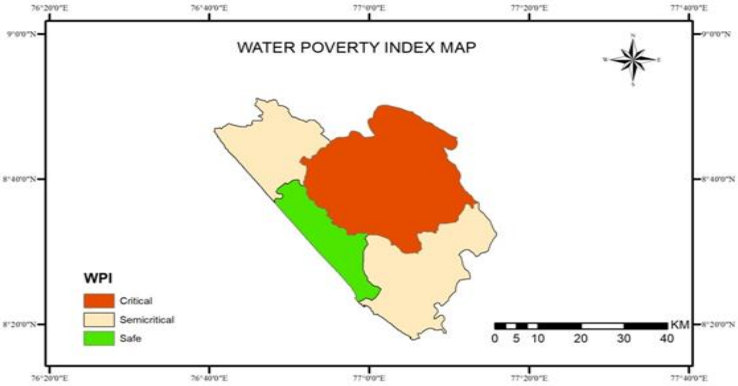
WPI Calculation

A WPI of 100 indicates that there are no water related problems in an area. The worst WPI that an area or region can have is 0, which indicates that there are numerous water related problems nd that a lot of time and money will have to be spent in an effort to rectify the situation.. The four taluks in the study come in the middle range (50-75).

	Resource (w=1)	**Access (w=2)**	**Capacity (w=2)**	**Use (W=1)**	**Environment (w=1)**	**WPI**
Chirayinkeezhu	100	34.97	72.38	51.06	50.5	59.46
Negumangad	100	23.34	71.19	62.34	33.28	55.11
Thiruvananthapuram	100	68.84	80.07	82.4	27.7	72.56
Neyyattinkara	100	36.43	76.27	73.87	31.73	61.57

3.3 Water Poverty Mapping

After the calculation of WPI,the next step in the study is to construct water poverty map. The mapping was done using ArcGIS 10.2 and fig 3.1 shows different indices in different colours. The map shows that Nedumangad taluk is critical in condition



GIS BASED APPROACH FOR IDENTIFYING POTENTIAL WATER HARVESTING SITES

Millions of people throughout the world do not have access to clean water for drinking purposes. In many people throughout the world do not have access to clean water for domestic purposes. In many parts of the world conventional piped water is either absent, unreliable or too expensive. Rainwater harvesting (RWH) has thus regained its importance as a valuable alternative or supplementary water resourse, along with conventional water supply technologies.

Identification of potential sites for RWH is an important step towards maximizing water availability and land productivity in Nedumangad Taluk. However, selection of appropriate sites for different RWH technologies on a large scale presents a great challenge since the necessary biophysical dat and infrastructure are lacking. In this study the site suitability for different water harvesting structures are dterermined by spatially vartying parameters like runoff potential, slope and landuse.

3.4.1 Slope

The slop of the area affects runoff, recharge and movement of surface water and is one of the important parameter for site selection.

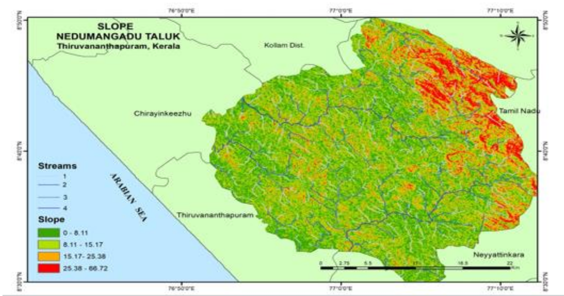


Fig 3.2 Slope Map

3.4.2 Runoff Coefficient

High runoff coefficient indicates the area with high volume of runoff, which is highly suitable for constructing runoff storage structures.

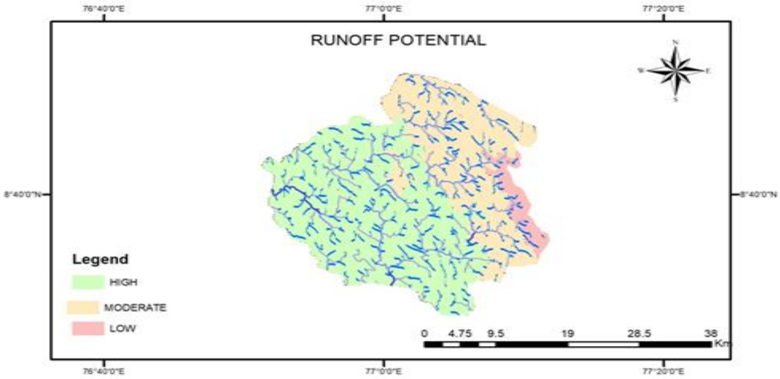


Fig 3.3 Runoff Coefficient

3.4.3 Land Use Map

Land use maps are prepared using LANDSAT 8. Information on land use pattern and their spatial distribution is one of the criteria selecting curve number

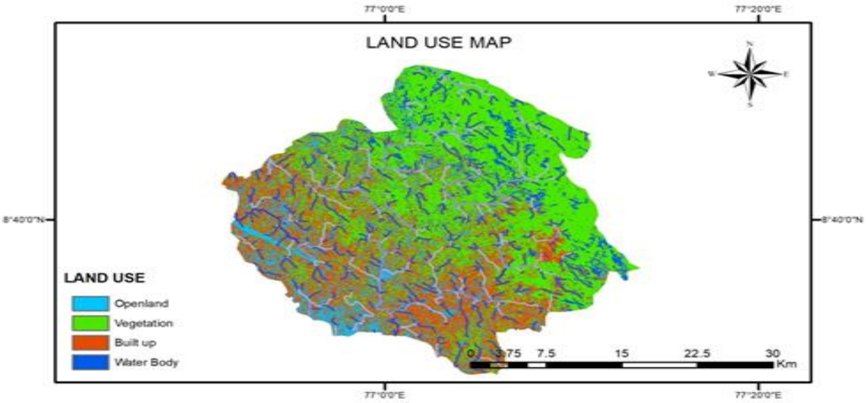


Fig 3.4 Landuse Map

3.4.4 Drainage Map

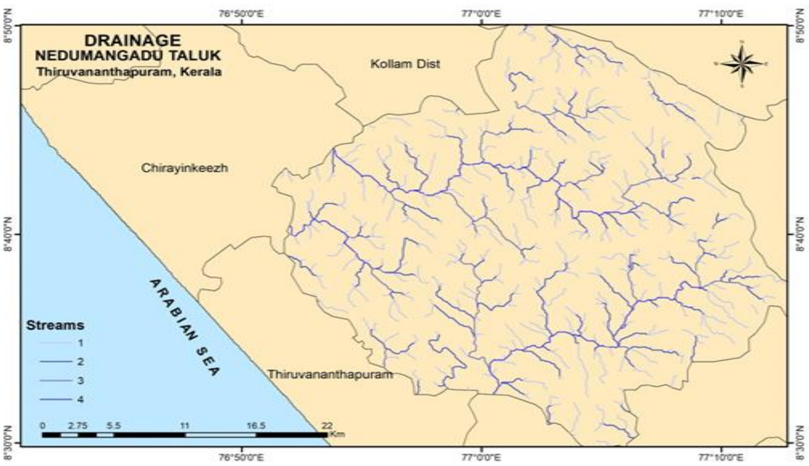


Fig 3.5 Drainage Map

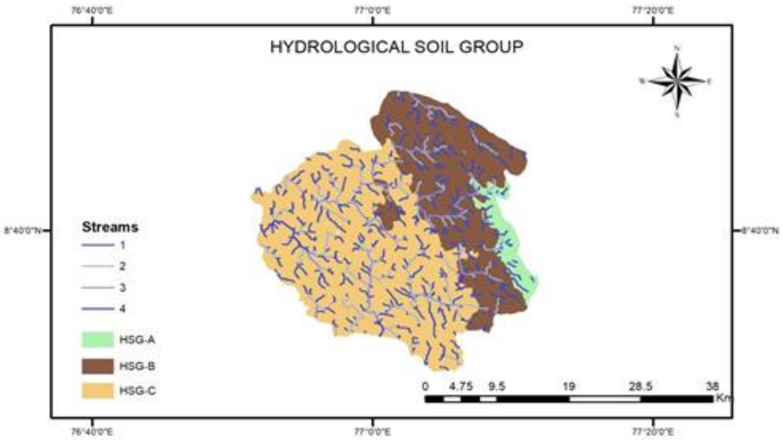


Fig 3.6 Hydrologic Soil Group Map

By implementing decision rules or sire suitability criteria, layers are prepared by combining stream order, slope, land use, soil, runoff maps using overlay in analysis tools.

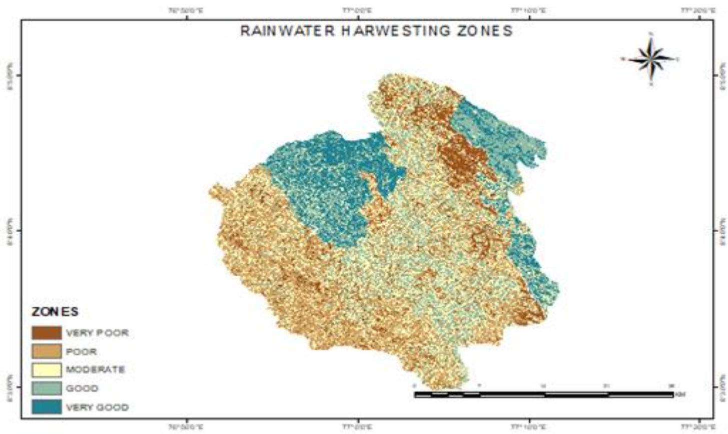


Fig 3.7 Potential Sites For Rainwater Harvesting

This map shows suitable sites for different harvesting and storage structures that can be constructed in Nedumangad Taluk to enhance the aquifer depth.

4. CONCLUSIONS

In this study, WPI for the four taluks in Trivandrum district, scarce has been calculated and indicated in a map. A water poverty map that has been constructed on a sufficient scale and with the correct subcomponents can be very helpful for the management of scarce water resources. This helps local governing bodies to prioritize the places based on their importance and introduce some policies and allocation of water on the basis of their needs. Using Water Poverty Index it is clear that Nedumangad taluk is critical and requires more analysis and attention. Therefore an attempt has been made to delineate suitable sites for rainwater storage for the highly critical area.

A GIS approach has been utilized for identification of suitable runoff harvesting sites in the area located in the semi-arid region. Site selection for water harvesting is carried out by overlying the slope, soil permeability, land use/ land cover, and stream order maps. TBased on integrated GIS modeling, „suitability maps" have been developed for potential runoff harvesting sites. The GIS approach for locating suitable sites for runoff harvesting, helps to reduce the extent of the area to be investigated, for effective runoff harvesting, by identifying specific areas that are potential sites for runoff harvesting.

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