Official Journal of the World Water Council
Water Policy

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Water Policy Vol 24 No 7, 1146 doi: 10.2166/wp.2022.011

Impact assessment of land use on water scarcity in urban areas: case of Jaffna Peninsula, Sri Lanka

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ABSTRACT

Urbanization-led land use changes have significant effects on urban water problems as water scarcity is a common challenge for planning of cities today. Chunnakam aquifer in Jaffna, Sri Lanka has been significantly depleted and polluted in the past decade. This study assessed the impact of spatial distribution of land use on water quality and quantity using 44 dug wells. Water scarcity index (WSI), water quality index (WQI) and multiple linear regression (MLR) models were used to explore the spatiotemporal patterns of water quality, quantity and their relationship. Results revealed that 75% of the aquifer faced scarcity problems while 54% was polluted and not suitable for consumption. Moreover, water sources located around agricultural and residential land use were contaminated in line with the spatial distribution of crop types, fertilizer use and domestic waste disposal. Integration of water policy with urban development strategy and multi-stakeholder engagement for water conservation are important findings for ensuring the water security of cities in developing countries. This study can be further expanded by evaluating temporal effects of urbanization on water resources for sustainable spatial planning. Strong water policies must govern the land use change to ensure water security for arid regions in developing countries.

Key words: Land use, Quantity and quality, Urbanization, Water policy, Water scarcity

HIGHLIGHTS

- Evaluation of impact of Urban Development on water resources to support future decision makers.
- Create comprehensive assessment of quality and quantity of water scarcity in cities.
- Support policy makers to integrate multidisciplinary focus areas in water management.
- Statistical assessment to understand the specific parameters leading to the scarcity in urban areas.
- Vitality of aquifer in sustaining the life in arid areas.

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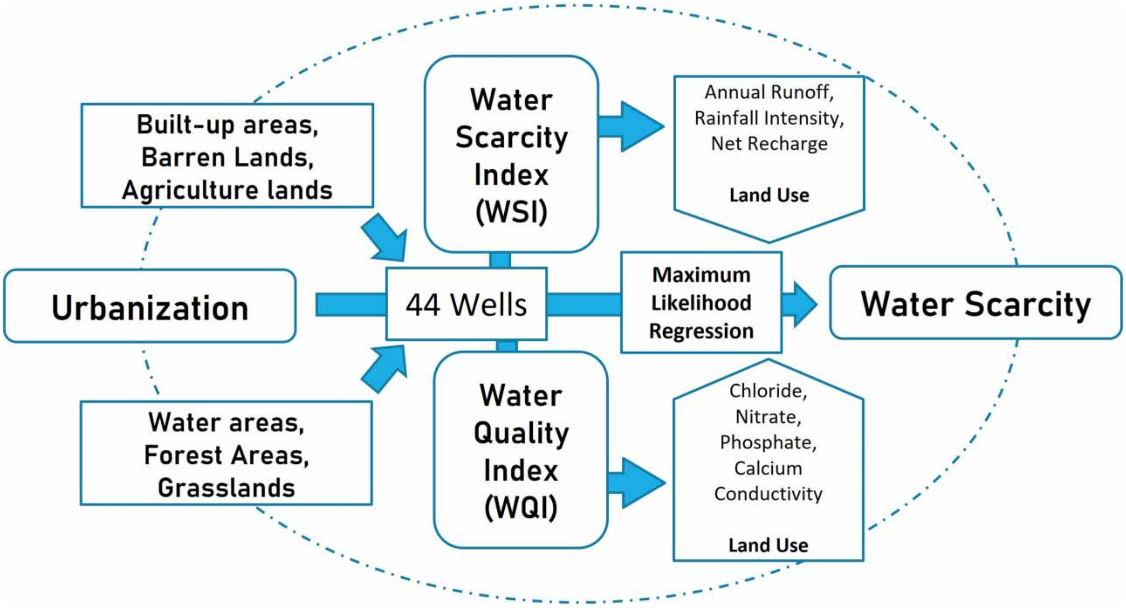
GRAPHICAL ABSTRACT



INTRODUCTION

Water scarcity can be defined as the mismatch of water demand and supply through spatial and temporal dimensions (Savenije, 2000; Long & Pijanowski, 2017). Water scarcity is a major challenge faced by urbanizing cities. Increased global population has resulted in increased water abstraction and consumption in past decades (FAO, 2012). Cities located in arid and semi-arid regions commonly face water scarcity-related issues involved with droughts and groundwater depletion. This is common for developing countries like Sri Lanka where cities located in a dry zone such as Jaffna (a city in the north) face problems in fulfilling the water needs for drinking and agricultural purposes (Balendran, 1969; IWMI, 2013; Gunaalan *et al.*, 2018). In Jaffna, groundwater is the only source for domestic needs and agricultural needs due to non-availability of river basin or related lateral supplies (Rajeevan & Mishra, 2020). Cities and countries in semi-arid regions are most vulnerable for social and economic collapse during drought periods (Falkenmark, 1989). Jaffna peninsula depends on groundwater for all of its needs since the city is not located within any river basin or catchment zone. Also, climate change-induced changes in precipitation patterns have caused residents to be highly dependent on groundwater. Chunnakam aquifer is the main source of groundwater for Jaffna peninsula. However, the groundwater is suspected to be in danger due to overexploitation and pollution caused by excessive usage of agrochemicals and fertilizers (Sayanthan *et al.*, 2015; Prabagar *et al.*, 2020).

Chunnakam is an unconfined aquifer situated in the northern part of Jaffna (Prabagar *et al.*, 2020). It is geographically confined to the north by the Indian Ocean, west by the Palk Strait, and the south and east areas are covered with lagoons. Most of the area is covered with limestone. Spatially, Chunnakam aquifer faces extreme water scarcity issues which can be classified under a few categories. First, salinity intrusion is observed in most parts of the aquifer (Gunaalan *et al.*, 2018). Second, hardness in water is also common due to the limestone bedrock (IWMI, 2013). The third issue is contamination of groundwater and surface water by

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agricultural activities, urbanization and increase of domestic and industrial waste discharge (Harshan *et al*., 2017). This has been worsened by poor water management practices at household level. Owing to these scarcity issues there is a need to manage water demand as well as to increase supply. In Jaffna, approximately 12% of the annual rainfall accounts for recharging the aquifer and over 25% contributes to surface run-off that enters the Indian Ocean via the lagoons and watercourses (IWMI, 2013). Demand for water has increased due to underground water pollution caused by the inappropriate management of lagoons Thondamanaru and Ariyali and improper usage of groundwater resources (Janen & Sivakumar, 2014). In general, coverage of piped water supply to family units is exceptionally low (3.2% have stand posts and 0.5% household connections) (NWSDB, 2016). In this context, studying the relationship between land use and the condition of Chunnakam aquifer is vital to determine the scarcity levels. Since the majority of the population still relies on groundwater through dug wells, the quality and quantity of available water sources need frequent assessment for its suitability for consumption. Due to time and resource limitations, water quality and quantity data were obtained from published reports of the International Water Management Institute (IWMI) (IWMI, 2014). The results obtained through the assessment were verified using professionals in the field including the National Water Supply & Drainage Board (NWSDB), researchers, non-governmental organizations (NGOs) from the water sector and public sector representatives in Jaffna.

Water scarcity has explicitly challenged the community's ability to physically access the resource, while there are different implicit challenges on socio-economic status as well as the infrastructure provision (Ohlsson & Turton, 1999). Access to water-related constraints have resulted on private sector investment flow in northern cities in Sri Lanka including Jaffna (ILO, 2020). Based on the existing policy initiatives and water balance studies, water resources in Jaffna faced severe contamination problems while limited community awareness on water management has caused unsustainable domestic water demand (Sivakumar, 2021). Socio-economic and cultural factors have also created limited options available for improving the water security in this region. Destruction of water sources upstream, and infrastructure projects such as dams and road projects could directly affect water scarcity in a different locality. Excessive population growth and uncontrolled land use changes could worsen the severity of impacts. Jaffna suffered a lengthy civil conflict which kept away population and development for over three decades. With the post war development from 2009, people were settling back in the villages while infrastructure development took place in a rapid phase. The degree of impacts could be a result of the different land use activities within the locality (Gülbaz & Kazezyilmaz-Alhan, 2012).

For cities located in arid environments, such as Jaffna, water availability is a critical factor for population distribution and development potential. Therefore, spatial planners have focused on sustainable development of urban areas with water security as a prime strategy to support the water–energy–food nexus at city scale (FAO, 2014). In this study, the relationship of existing land use activities and water scarcity was measured since urban land use has a direct impact on water resources due to uncontrolled urbanization (Levin, 2012; Arasalingam *et al*., 2020). Since 2009, many residents have reoccupied their lands and started agriculture which required extensive amounts of water to cater for the demand. Land within Chunnakam aquifer was used intensively for agriculture, and immigration resulted in residential land use conversion (Harshan *et al*., 2017). Hence, it is evident that Jaffna showed hints of groundwater problems, as water quantity and quality has depreciated over the past decade (Amiri & Nakane, 2009). Effects of land use on water quality has been studied by various researchers using statistical methods and land use models (Liu *et al*., 2016; Camara *et al*., 2019). Also, Long & Pijanowski (2017) developed a model to correlate the water quantity with land use change. In this context, use of qualitative and quantitative assessment of water scarcity could provide a comprehensive framework towards water management strategy in Jaffna peninsula.

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METHODS

Study area

Jaffna is one of the rapidly growing cities in northern Sri Lanka with about 1,012 km^2 land area. Chunnakam aquifer is one of the main sources of water for residents due to the non-availability of perennial rivers or reservoirs, and limited rainfall (IWMI, 2013). Total area within Chunnakam aquifer was selected for the study which includes 336.9 km^2 with a residential population of 547,510 in 2019. Figure 1 shows the location of Chunnakam aquifer in Jaffna.

Data

For the assessment of water quality and quantity parameters, 44 dug wells were selected for the sample survey. The wells were selected based on their inclusion within the study boundary and availability of research data in similar fields (Figure 2). Based on the purpose of water extraction, selected wells were classified into three broad categories, namely: public (9) wells used for drinking purposes, domestic (9) wells used for drinking and domestic washing, and agriculture (26) wells for farming purposes. Water quality parameters used in this study

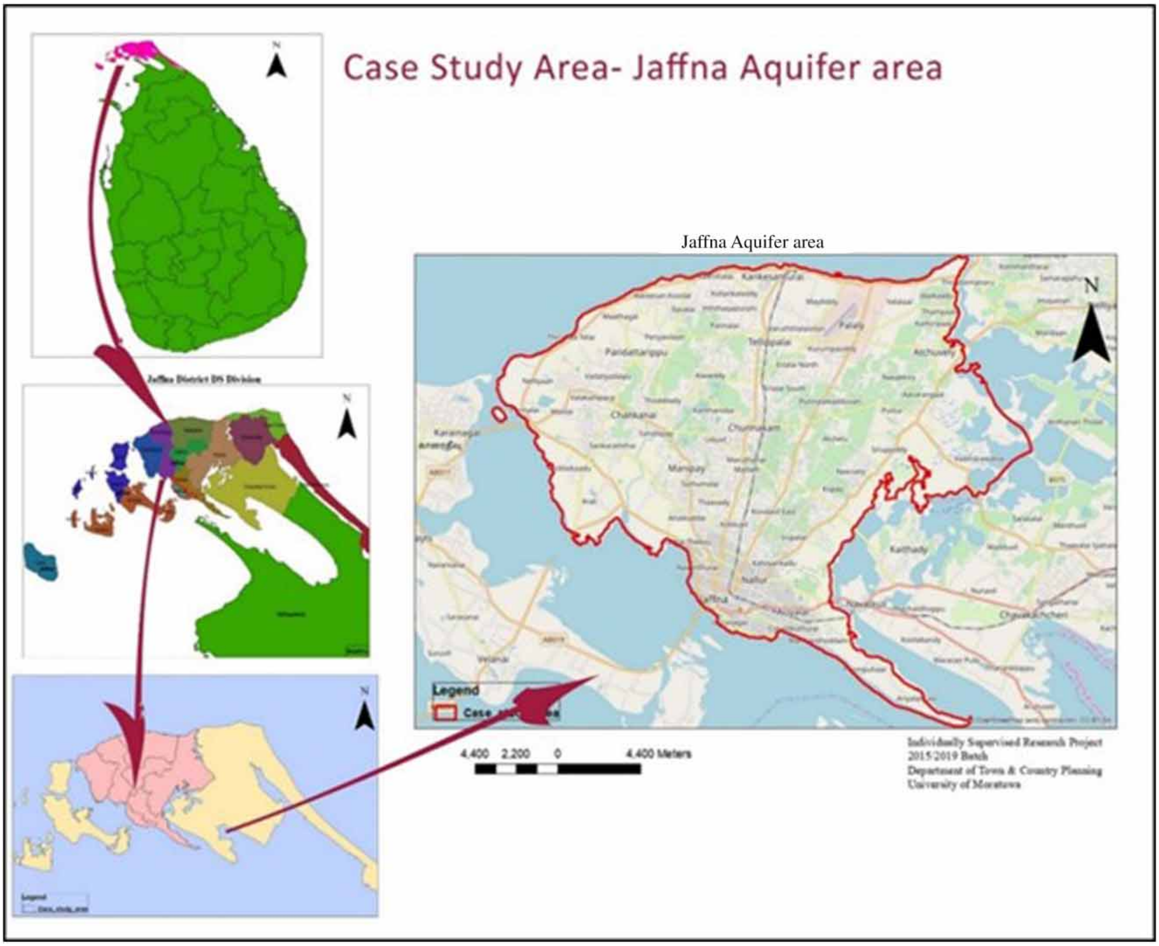

Fig. 1 | Location map of Chunnakam Aquifer, Jaffna. *Source*: Survey Department of Sri Lanka.

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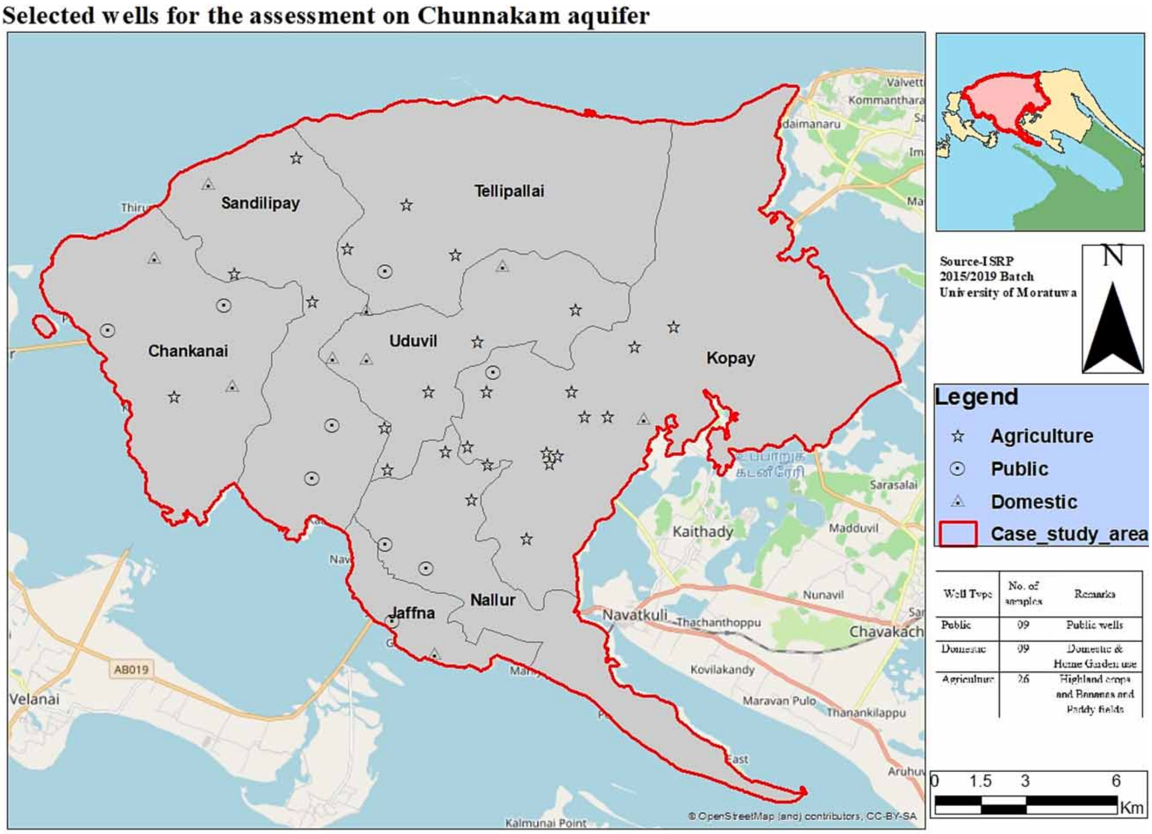

Fig. 2 | Selected wells for the assessment on Chunnakam Aquifer. *Source*: Survey Department of Sri Lanka, IWMI (2013).

were chloride, nitrate, total phosphate, electricity conductivity and calcium content. Water quantity parameters included net recharge of groundwater, rainfall coverage, runoff and evapotranspiration. By using the existing land use categories in Jaffna, supported by the water scarcity assessments of existing research, seven land use categories were identified for the evaluation, namely: agricultural land, forest land, built-up land, grassland, unused land, water, and roads (Lee *et al.*, 2009; Lintern *et al.*, 2018). Statistical methods were used for researchers to investigate the relationship between land use and water quality, such as linear fixed model (Liu *et al.*, 2016) and multiple linear regression (Amiri & Nakane, 2009). Camara *et al.* (2019) conducted impact assessment of different land use (urban land use, agricultural land use and forest) and water quality indicators (physical, chemical, biological and hydrological). In this study, five hydro-chemical parameters, namely, total phosphorus (TP), chlorides (Cl^-), nitrates (NO_3^-), electrical conductivity (EC) and calcium (Ca^{2+}), were used to test the relationship with land use. Spearman correlation analysis was conducted between water quality indicators and land use.

Methodology

The relationship between water quality and land use changes can result in various reliability scores based on the quality of data, type of model and expected depth of analysis. In this study, the relationship between water scarcity and land use were taken separately with quality and quantity criteria. Water scarcity index (WSI), water quality index (WQI) and multiple linear regression (MLR) were sourced for assessing water quality, quantity

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and relationship values. Water scarcity is based on the water requirements by the people, actual use and precipitation. WSI consists of water resources available index (WRI), use-to-resource ratio index (URI) and precipitation index (PI) (Long & Pijanowski, 2017). WRI measures water resources availability per capita, per year, by region. Stress is calculated under four categories coded 0–3 as, no stress, stress, scarcity and absolute scarcity, respectively. URI is the ratio between withdrawals and recharge of water resources on an annual basis by region. URI also has the same coding, 0–3. PI is the annual rainfall measured for the region per year which also ranges from 'no stress' to 'absolute scarcity'. The study considered equal weight for each index in the assessment of scarcity of Chunnakam aquifer region. WSI is calculated using Equation (1).

$$\textit{Water Scarcity Index } (WSI) = WRI + URI + PI \tag{1}$$

According to Equation (1), water scarcity was assessed by using the water demand and supply data within Jaffna peninsula in the previous years. Rainfall intensity was considered along with runoff data in the study area since rain-fed water is the main source for groundwater recharge in Chunnakam aquifer. Groundwater abstraction rates, evapotranspiration and other outflow information was obtained from past studies and water balance scorecards prepared for the study area. The criteria for evaluating each of the parameters to calculate WSI are listed in Table 1.

Accordingly, WSI values were coded as no stress (0), stress (1–3), scarcity (4–6) and absolute scarcity (7–9) as the composite values obtained from analysis.

To evaluate water quality and land use relationship, WQI, MLR and Spearman correlation analysis was used. WQI is a tool used to collect different water quality parameters and convert them into a single standard (Harshan *et al.*, 2017). In this study, five hydro-chemical characteristics (TP, Cl^-, NO_3^-, EC, Ca^{2+}) were selected and applied into WQI, which is calculated by Equation (2).

$$WQI = Antilog\left[\sum_{i=0}^{n} w_i \log q_i\right] \tag{2}$$

where
w_i = *weightage factor of* i^{th} *parameter*
q_i = *quality rating of* i^{th} *parameter*

The MLR model (Amiri & Nakane, 2009) was used to explore the correlation between land use pattern and water quality indicators in the study area. Linear correlation was applied to interpret the results using MLR. The formula of the correlation between water quality of non-point source and land use coverage (%) is expressed

Table 1 | Criteria for calculation of WRI, URI and PI.

Indicator	Index value	WRI (Runoff m^3 per capita/year)	URI (Net recharge) (withdrawals/renewables)/year	PI (Rainfall intensity) (mm/year)
No stress	0	>1,700	<0.1	>1,200
Stress	1–3	1,000–1,700	0.1–0.2	800–1,200
Scarcity	4–6	500–1,000	0.2–0.4	400–800
Absolute scarcity	7–9	<500	>0.4	<400

Source: Long & Pijanowski (2017).

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through Equation (3).

$$NPS = exp\ (\beta_1 \times land_1 + \beta_2 \times land_2 + \beta_3 \times land_3 + \ldots + \beta_n \times land_n) + \alpha \quad (3)$$

where
$NPS = water\ quality\ from\ non\text{-}point\ source$
$\alpha = constant$
$\beta_n = correlation\ between\ water\ quality\ variables\ and\ n^{th}\ land\ use$

RESULTS AND DISCUSSION

Water quantity assessment

Population distribution is a common indicator used to understand the land use changes of any locality. Population density within Chunnakam aquifer is shown in Figure 3 based on the census conducted in 2011. According to the Department of Census and Statistics data of 2012, the population at Jaffna Municipal Council (JMC) was 80,829. JMC has the highest concentration of population in Jaffna (approximately 52 persons per hectare) which has been triggered by the post war development.

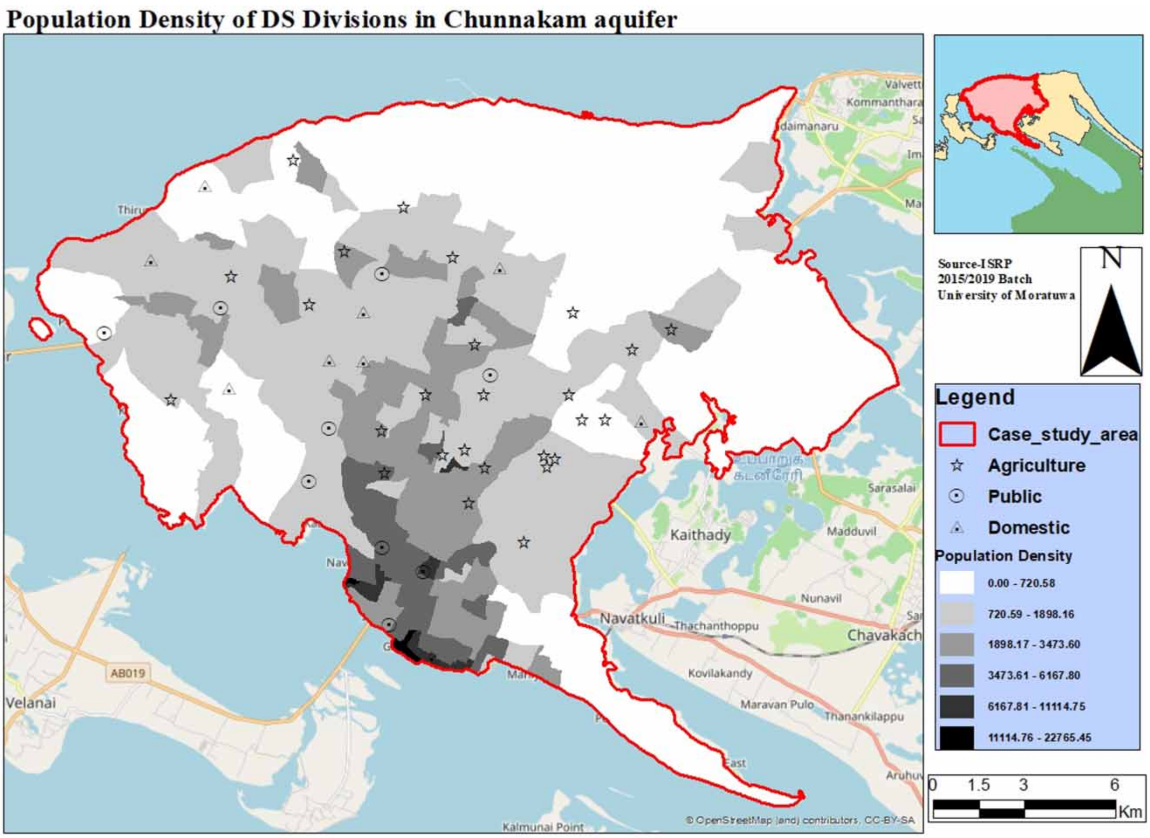

Fig. 3 | Population density in Chunnakam Aquifer area. *Source*: Survey Department of Sri Lanka, IWMI (2013).

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Net recharge of the groundwater wells, gross recharge and runoff amounts were the quantity-based parameters used to measure the water scarcity. Further, rainfall intensity, evapotranspiration and land use were used as influencing factors in the analysis. Groundwater level fluctuation method was applied to measure the groundwater recharge. The method has also provided information on the temporal and spatial recharge variations including gross water recharge, net recharge and runoff volume. Rainfall and evapotranspiration data were obtained from published secondary data from IWMI (2014). Data analysis with inverse distance weighting (IDW) tool in spatial interpolation was conducted in geographic information systems (GIS) software.

Land use data were mined from Landsat 7 TM images (USGS, 2017). Six types of land use were classified from the satellite image: water, grassland, forest, built-up area, barren land and agriculture land. Barren lands were considered as the unproductive bare lands with limited vegetation and contamination. The barren lands in Jaffna were the result of heavy fertilizer use on abandoned agricultural lands and geological factors. Grasslands are the areas with grass cover and small shrubs without conversion into other land uses. War-affected lands unclaimed by the original occupants and scrub areas were considered as grasslands in this study. The land use categories were classified using maximum likelihood classification tools in GIS. Land use details are shown as in Figure 4. Extent of major land use categories within Chunnakam aquifer are as shown in Table 2.

Land use categories within 200 m buffer distance of each sample location were considered for evaluation. The land use classes of sample locations were calculated using maximum likelihood classification method through

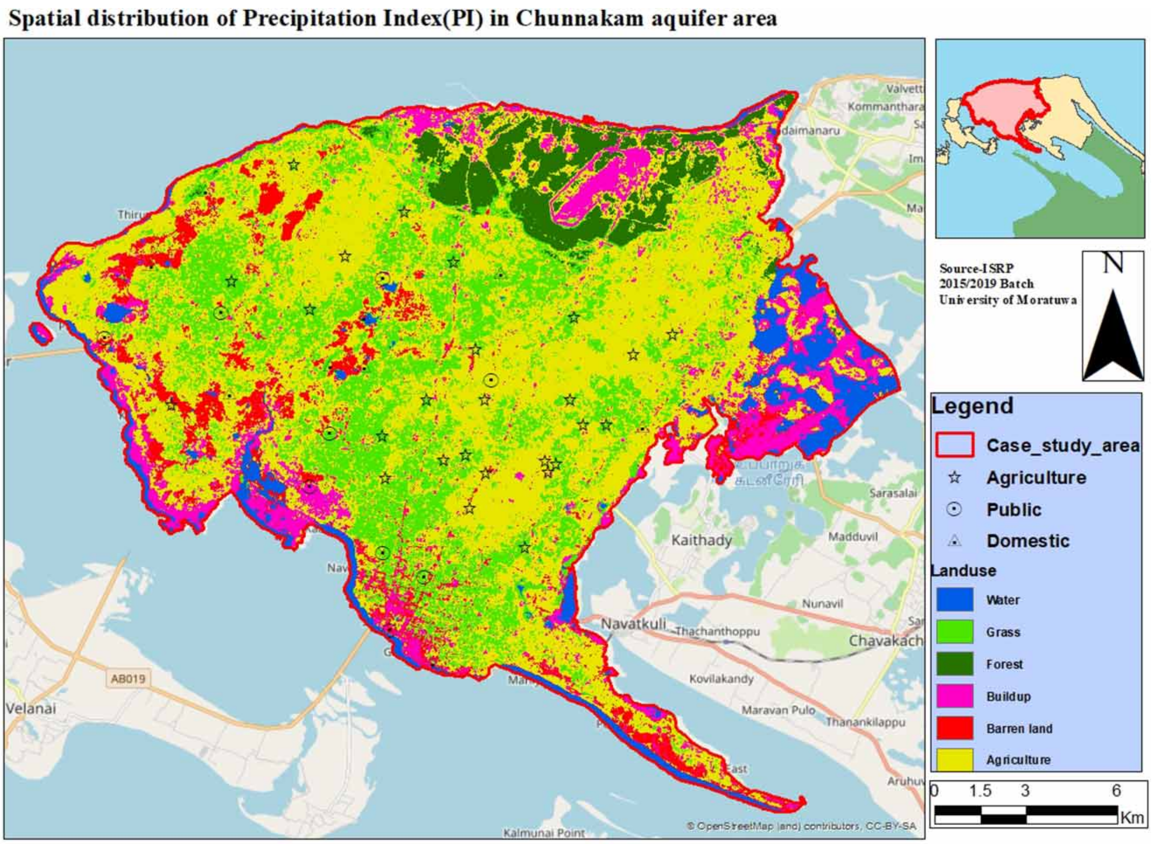

Fig. 4 | Land use map of Chunnakam aquifer area. *Source*: Survey Department of Sri Lanka, IWMI.

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Table 2 | Land use distribution within Chunnakam Aquifer.

Land use type	Water area	Grassland area	Forest area	Built-up area	Barren land area	Agriculture land area
Extent (km^2)	5.22	105.45	0.17	16.91	22.98	185.83

Source: Survey Department of Sri Lanka.

GIS tools. Land use statistical data analysis was carried out using SPSS software and Microsoft Excel software tools. Accordingly, agricultural land accounted for 55% of the total land extent of the sample whereas the proportions of the grassland and built-up areas in the sample location area were about 31 and 5%, respectively. Commercial agriculture is the source of income for over 65% of people, who mainly cultivate red onions, chilies, potatoes, tobacco, bananas, and grapes (Sutharsiny *et al.*, 2012).

Water scarcity index (WSI) consists of three different index analyses to derive the output. IDW tool of spatial interpolation analysis in GIS was applied to measure WRI, URI and PI (Table 1) as depicted in Figure 5 at spatial scale.

Table 3 shows the calculation of WSI by using weighted scoring methods in MS Excel and SPSS software. Accordingly, it is conclusive that the whole study area comes under the scarcity category. Standard deviation of the WSI was 2.36 which explained why the variation of the index was high.

Table 4 shows the range of water within the study area where over 75% of the sample locations fell under the scarcity or absolute scarcity range.

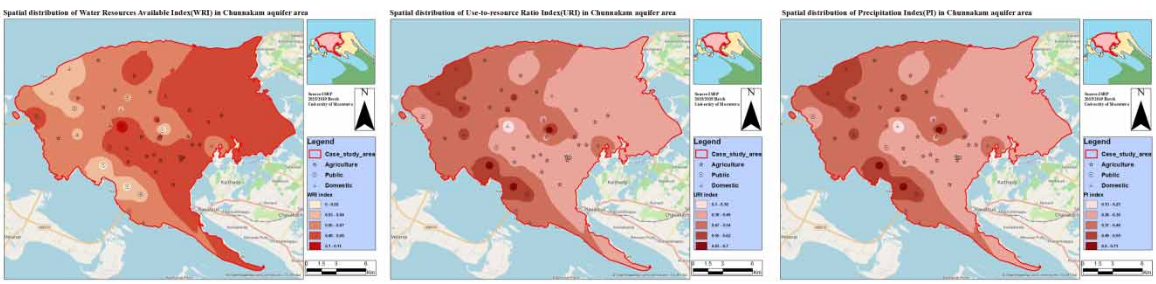

Fig. 5 | Spatial distribution of WRI, URI and PI.

Table 3 | Table of weighted scoring for water scarcity variables.

Description	Descriptive statistics of water scarcity index
Mean	5.34
Median	6.00
Standard deviation	2.36
Range	9.00
Minimum	0.00
Maximum	9.00

Source: Compiled by author.

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Table 4 | Frequency distribution of level of scarcity.

Level of scarcity		Frequency	Percentage (%)	Cum. percentage (%)
0	No stress	3	6.8	6.8
1	Stress	8	18.2	25.0
2	Scarcity	22	50.0	75.0
3	Absolute scarcity	11	25.0	100.0
Total		**44**	**100.0**	

Source: Compiled by author.

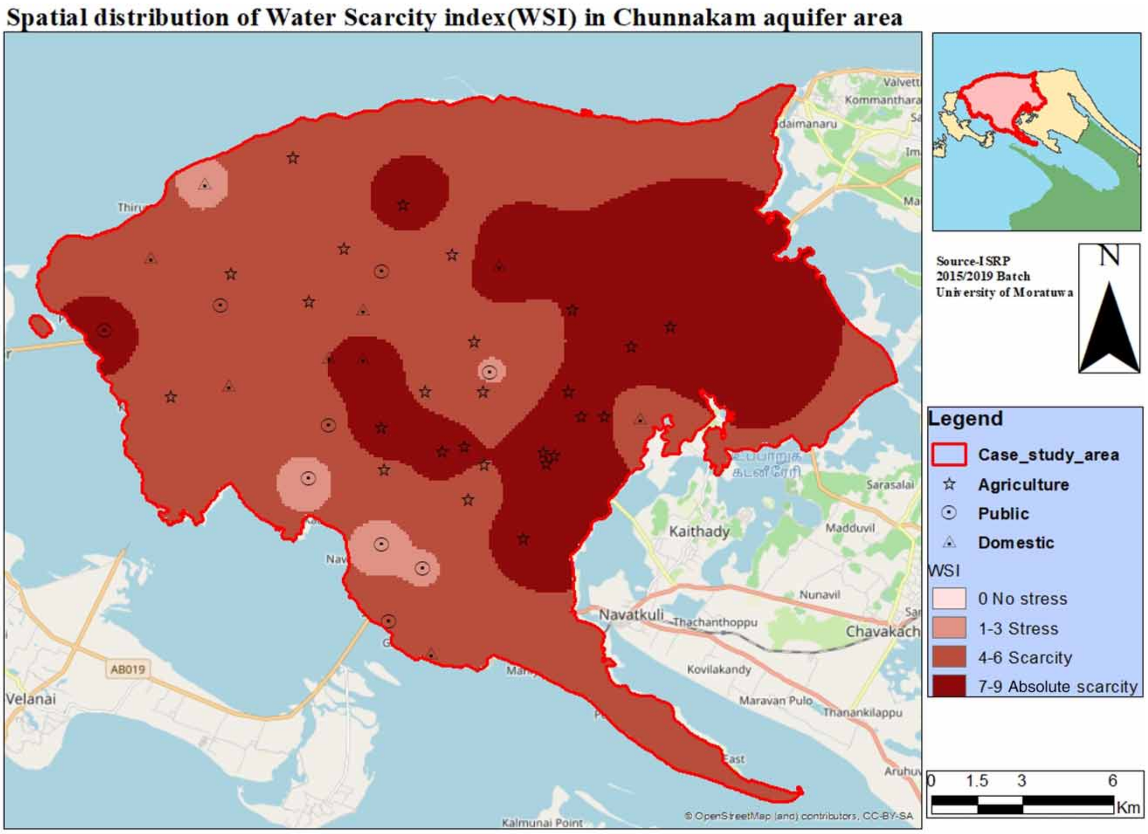

Fig. 6 | Spatial distribution of WSI in study area. *Source*: Compiled by author.

Spatial distribution of water scarcity was illustrated through spatial interpolation analysis in GIS. Figure 6 shows the spatial distribution of water scarcity in Chunnakam aquifer. Accordingly, agricultural areas and highly populated residential areas are located within the highest levels of scarcity values (scarcity or absolute scarcity).

The land use statistical data and water quantity parameters were analyzed using SPSS. For modeling, the econometric model explained in Equation (3) was rearranged to correlate WSI and land use data within

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Chunnakam aquifer as shown in Equation (4).

$$WQ_N = exp(\beta_1 \times land_1 + \beta_2 \times land_2 + \beta_3 \times land_3 + \ldots + \beta_n \times land_n) + \alpha \quad (4)$$

where WQ_N equals the water quantity parameters in Chunnakam aquifer, β reveals coefficient of the percentage change in land use activity. $\beta_n > 0$ implies a positive impact on the characters of water quality while $\beta_n < 0$ implies a negative impact. Table 5 illustrates the interaction between water quantity and land use types rendering to the analysis results from multi-regression correlation in SPSS statistical software.

Built-up area was the most significant land use type contributing to water scarcity with a significance level less than 0.01 ($P < 0.01$). Barren lands and agriculture lands have significance levels less than 0.05 ($P < 0.05$). At the 95% confidence level, it can be concluded that built-up area shows the most significant correlation with water scarcity in the Chunnakam aquifer area while barren lands and agriculture lands show positive relationships at the same level. Multi-regression correlation (MRC) can then be described by Equation (5).

$$ln(WSI) = -0.415 - 0.374Water + 1.855Grass + 0.66Forest + 3.064Builtup + 2.395Barren + 2.092Agri \quad (5)$$

Equation (5) revealed that the highest positive relationship to water scarcity was shown by built-up areas (3.064), barren lands (2.395) and agricultural areas (2.092) while grasslands and forest areas have also shown minor positive relationships. By applying the log-linear model interpretation, one unit of increase in built-up area could result in over 21.4% increase in overall WSI results. Similarly, barren lands and agricultural lands contributed to significant increases of WSI results. Therefore, potential impact of land use activities, especially the built-up areas, is significant in water scarcity in Chunnakam aquifer region. This has been proven by the statistical data on urbanization trends and decline of water availability in the past decade. Moreover, contribution of agricultural land uses to groundwater depletion was also visible since over 50% of spatial form has agriculture land uses.

Figure 7 shows the curve estimation between different land uses on water scarcity. Built-up area and agricultural land use show a positive log-linear relationship with WSI that has the highest amount of water extraction. Grasslands and barren lands show comparatively mild positive growth for WSI while forest cover

Table 5 | Correlation results between log-metric water scarcity index and land use type (%).

	Unstandardized coefficients[a] LN(WSI)		Standardized coefficients		
Model	***B***	***Std. Error***	***Beta***	***t***	**Significance (*p*)**
Intercept (Constant)	−0.415	0.991		−0.419	0.678
Water area (%)	−0.374	1.073	−0.108	−0.349	0.729
Grassland (%)	1.855	0.976	0.747	1.900	0.065
Forest (%)	0.660	0.973	0.102	0.678	0.502
Built-up area (%)	3.064	1.063	0.817	2.882	0.007
Barren land (%)	2.395	1.062	0.528	2.255	0.030
Agriculture land (%)	2.092	0.985	1.039	2.125	0.040

Source: Compiled by author.

[a]Dependent variable: Ln (WSI).

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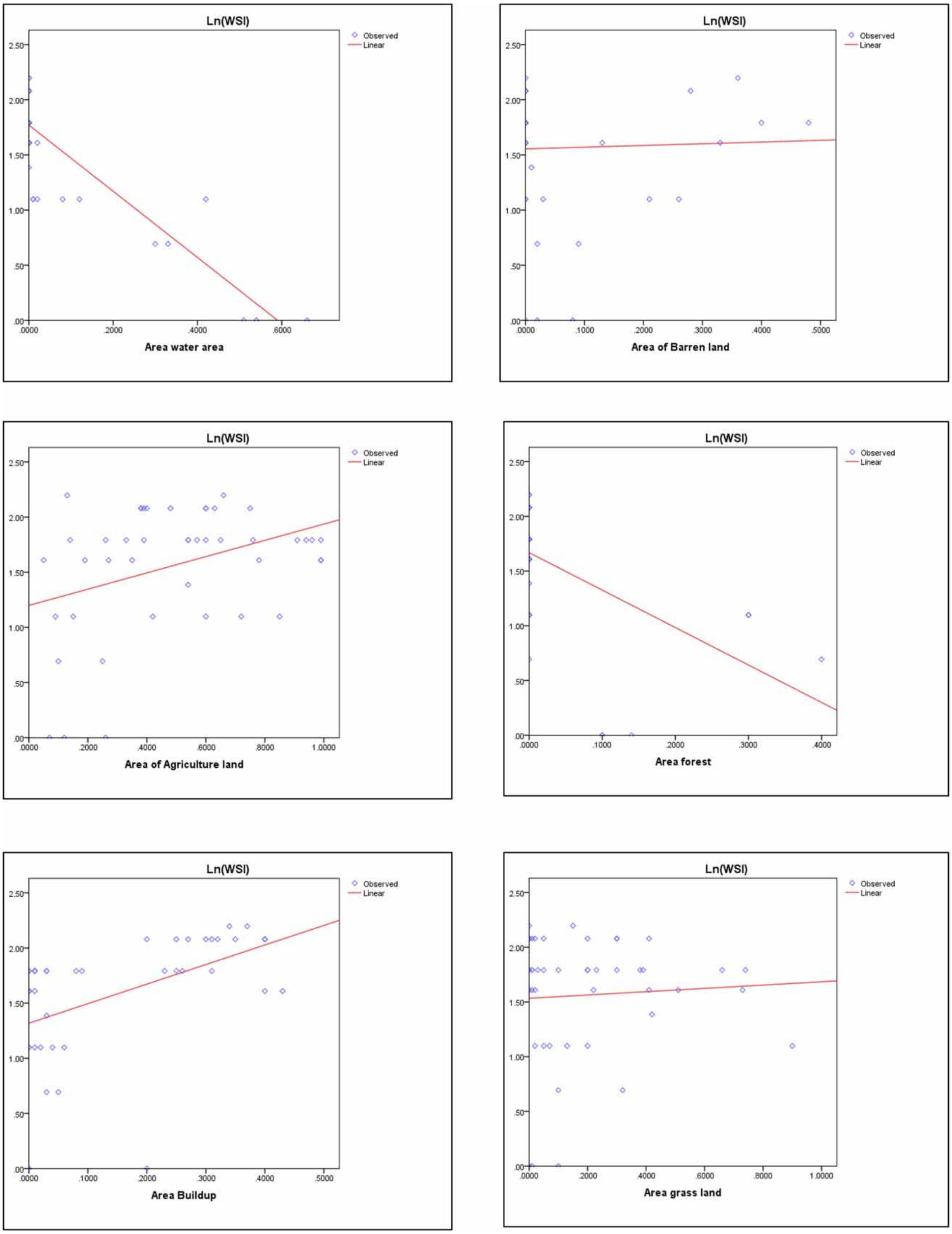

Fig. 7 | Curve estimation between WSI and land use type (%). *Source*: Compiled by author.

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and water bodies displayed negative correlation with WSI. It is evident that urbanization and related land use changes contributed the most to the water scarcity in Chunnakam aquifer region.

Water quality assessment

Based on the availability of data and to suit study objectives, selective types of water quality parameters were analyzed in the case study area. First, water quality parameters from different locations were gathered based on existing published data. Second, the value of chemical characteristics was measured by using WQI. Third, statistical information of land use changes was identified in the exact location. Fourth, correlation was conducted with the WQI and land use change using the model.

The processes of water quality assessment were measured under standard SLS 614 of the Sri Lanka Standards Institution (SLSI). Spatial distribution maps for different parameters were developed using the inverse distance weighting (IDW) in spatial interpolation technique in ArcGIS software. The maximum permissible levels of chemical parameters in water are shown in Table 6.

Spatial distribution of results of water quality parameters in Chunnakam aquifer area are shown in Figure 8.

Table 6 | Standards for water quality with maximum permissible limits.

Water quality parameter	Permissible level
Chloride (Cl^-)	1,200 mg/l
Nitrate (NO_3^-)	10 mg/l
Total phosphate (TP)	2.0 mg/l
Electrical conductivity (EC)	3,500 μS/cm
Calcium (Ca^{2+})	240 mg/l

Source: SLS 614, Sri Lanka Standards Institution.

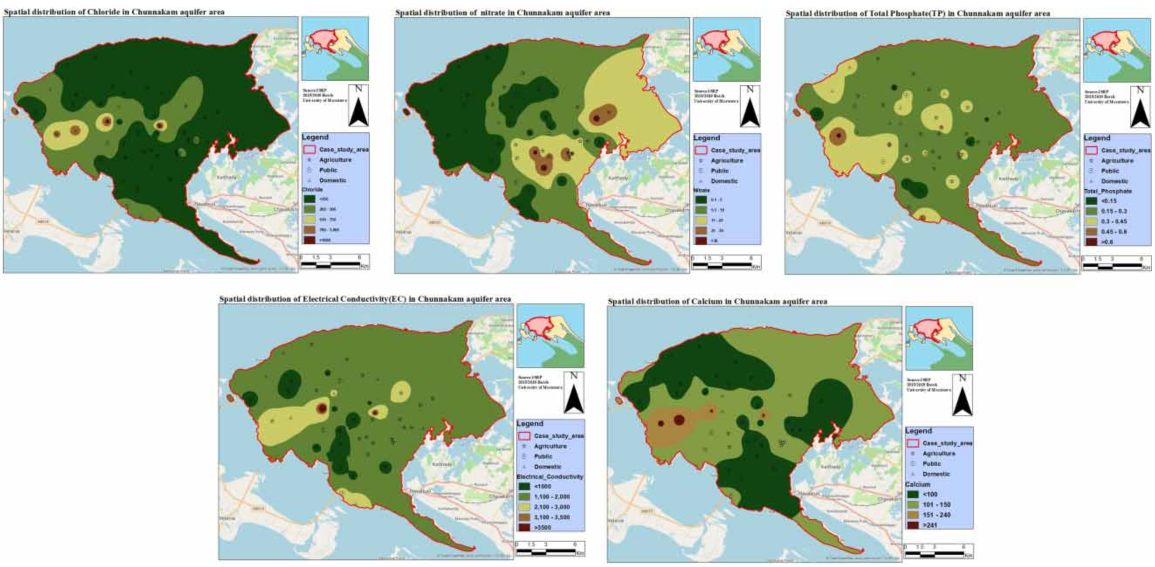

Fig. 8 | Spatial distribution of chloride, nitrate, phosphate, electrical conductivity and calcium within Chunnakam Aquifer. *Data source:* IWMI (2013). Please refer to the online version of this paper to see this figure in colour: http://dx.doi.org/10.2166/wp.2022.011.

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The concentration of chloride in water varied between 61 mg/l and 1,115 mg/l. High chloride concentration of 1,115 mg/l was observed in a public well. Of the 44 wells measured, 74% had chloride content less than 250 mg/l and 24% were within the range of 250–1,200 mg/l. The nitrate concentration ranged from 0 to 35 mg/l within Chunnakam aquifer. All values from domestic and public wells were acceptable for drinking purposes as the nitrate values were below the limit of SLSI drinking water guidelines (10 mg/l). Among the agriculture wells monitored, 38% exceeded the limit of 10 mg/l and were not suited for drinking purposes. The concentrations of total phosphate ranged from 0 to 2.75 mg/l. Two wells were above SLSI permissible levels of 2.0 mg/l, so it is conclusive that phosphate-based pollution is not significant based on the results. Electrical conductivity (EC) values ranged from 320 μS/cm to 4,320 μS/cm. Based on SLSI guidelines for drinking water, 95% of the wells were within the limits of SLSI permissible levels of 3,500 μS/cm. Therefore, saltwater intrusion has not affected Chunnakam aquifer to disrupt water quality. The calcium concentration varied from 49 mg/l to 286 mg/l. The results showed that 95% of the measured wells were below the SLSI permissible level (240 mg/l). The dark brown color in Figure 8 indicates the most polluted areas while the dark green color represents the least polluted areas for each water quality parameter.

Land use data was analyzed from the satellite images provided by USGS as six types of land uses were classified to conduct WSI. Water quality indices aimed at giving a single value to the water quality from multiple variations of all parameters. Five water quality parameters were selected to compute WQI as shown in Equation (6).

$$WQI = Antilog\left[\sum_{i=0}^{n} w_i \log q_i\right] \tag{6}$$

where
$w_i = weightage\ factor\ of\ i^{th}\ parameter$
$q_i = quality\ rating\ of\ i^{th}\ parameter$

$$w_i = \frac{k}{v_i}$$

where
$k = constant\ proportionality$
$v_i = standard\ value\ of\ i^{th}\ parameter\ for\ Sri\ Lankan\ standard$

$$q_i = \left(\frac{v_a - v_s}{v_i - v_s}\right) \times 100$$

where
$v_a = actual\ value\ obtained\ from\ laboratory\ analysis\ of\ i^{th}\ parameter$
$v_i = standard\ value\ of\ i^{th}\ parameter\ (Sri\ Lankan\ standards)$
$v_s = ideal\ value$

The outcome of WQI was categorized into a five scale classification as shown in Table 7.

The spatial distribution of the water quality index is shown in Figure 9. WQI is categorized into five groups ranging from excellent quality to unsuitable for drinking. Eight wells were classified as excellent while two wells were identified as unsuitable for drinking.

Out of all 44 wells, about 46% were in good or excellent condition for drinking purposes while poor quality water was available in predominantly agriculture-based land use categories. Poor water quality around the

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Table 7 | Water quality index classification range for assessment.

Interpretation (WQI)	Standard value (Canadian scheme)
Excellent	0–5
Good	6–20
Poor	21–35
Very poor	36–55
Unsuitable for drinking	55–100

Source: Harshan *et al*. (2017).

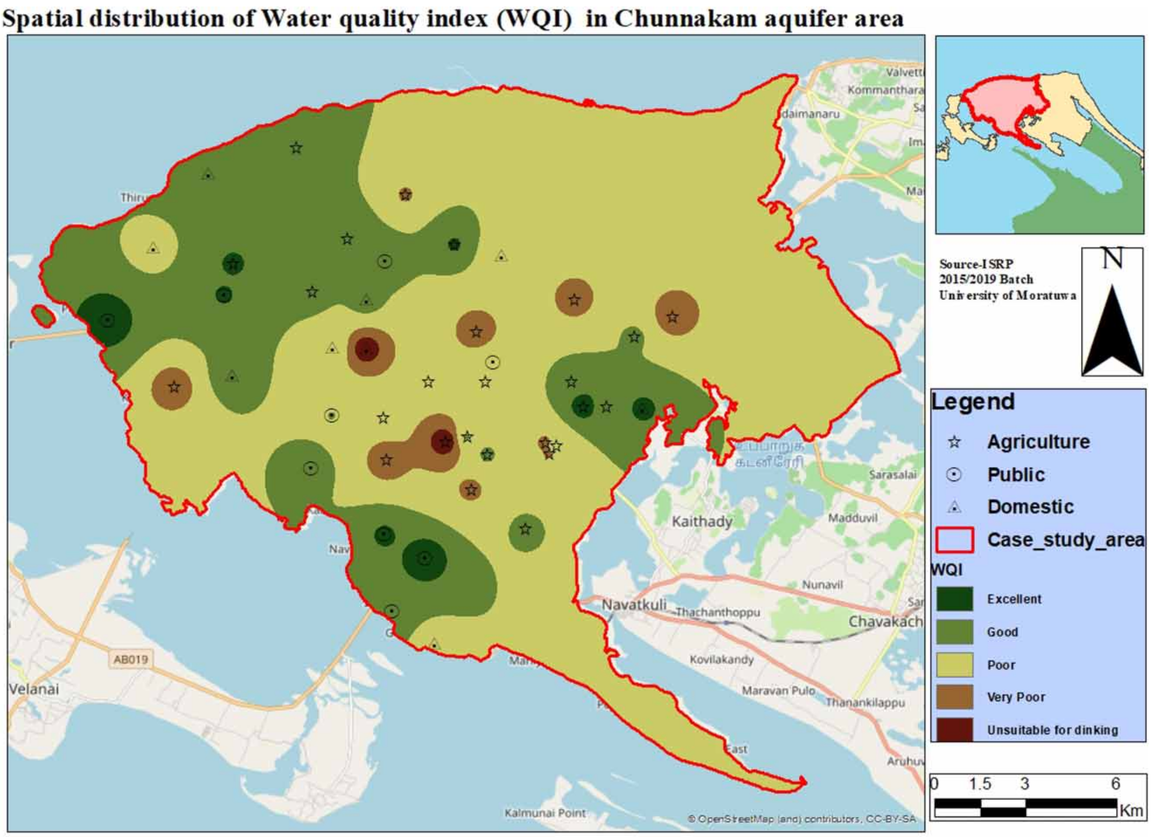

Fig. 9 | Spatial distribution of WQI within Chunnakam Aquifer. *Source*: Compiled by author.

agricultural wells was in line with the intensive use of chemical fertilizer within the study area. Out of all agricultural wells, about 54% were within poor or very poor quality according to the WQI calculations. Even though a major part of public and domestic wells contained good or excellent water quality, Chunnakam aquifer had poor water quality throughout. The land use categories that gave different WQI values were studied as the next step.

Land use statistical data and water quality parameters were analyzed by using SPSS software with the use of an econometric model on water quality parameters. The modified equation to correlate WQI and land use is shown

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in Equation (7).

$$WQI_L = exp(\beta_1 \times land_1 + \beta_2 \times land_2 + \beta_3 \times land_3 + \ldots + \beta_n \times land_n) + \alpha \quad (7)$$

where WQI_L means the change in water quality parameters within Chunnakam aquifer, β means the correlation between water quality parameters and land use area (%). $\beta_n > 0$ implies that land use type n has a positive impact on the characters of water quality while $\beta_n < 0$ shows a negative relationship. α is the intercept of the equation. The panel data has been used to explore the relationship between the water quality and land use types within Chunnakam aquifer. MRC was used to calculate the interaction between water quality and land use types and results are shown in Table 8. Accordingly, nitrate (NO_3^-) showed a significant variation around mean value over 44 wells in the study while other parameters did not show similar variation in comparison. Correlations between each of the land uses with water quality parameters were tested and the logarithmic value of correlation coefficient revealed that built-up area had a significant effect on water quality of Chunnakam aquifer.

According to Table 9, a positive relationship is visible between built-up areas and concentration of water quality parameters. Similarly, barren lands and agriculture lands are positively correlated with chlorides, nitrates, calcium ions and electrical conductivity. Barren lands were a contributing factor for urban run-off and wash-off fertilizer to water sources affecting the groundwater quality in the study area. Grasslands and forest cover showed negative correlation with nitrates and phosphate concentration in the water due to absorption of the dissolved nitrogen and phosphorus. Heavy use of inorganic fertilizer for commercial crops (onions, tobacco, potatoes) and sewage leachate from settlements were major inputs of nitrates to the ground.

Table 8 | Descriptive statistics of water quality parameters.

Variable	N	Minimum	Maximum	Mean	Std deviation
Ln (Cl^-)	44	4.38	7.05	5.2911	0.67455
Ln (NO_3^-)	44	−2.30	3.56	0.6448	2.02960
Ln (TP)	44	−4.61	−0.48	−1.4991	0.75328
Ln (EC)	44	5.99	8.35	7.1859	0.54160
Ln (Ca^{2+})	44	3.91	5.66	4.5993	0.37598
Ln (WQI)	**44**	**−0.64**	**4.89**	**3.7102**	**0.96430**

Source: Compiled by author.

Table 9 | Correlation coefficients between water quality variables and land use.

Variable (land use)	Ln (chloride) coef.	Ln (nitrate) coef.	Ln (TP) coef.	Ln (EC) coef.	Ln (calcium) coef.
Grassland	3.077	−14.941	−2.937	3.478	2.368
Forest	3.350	−7.662	−3.248	3.260	2.567
Built-up area	1.549	20.290	3.017	2.262	1.927
Barren land	2.970	16.349	1.977	3.091	2.532
Agriculture	2.098	16.574	−2.394	2.868	1.873
Constant	2.958	−9.483	−0.791	4.233	2.546

Source: Compiled by author.

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Out of all the assessed parameters, electrical conductivity, chloride and calcium were influenced by geomorphological elements. Naturally, Jaffna peninsula has saltwater intrusion and limestone bedrock (IWMI, 2013; Harshan *et al*., 2017). Therefore, Chunnakam aquifer is prone to high electrical conductivity and chloride content due to salt water, and high calcium due to calcium carbonate ($CaCO_3$) bedrock. However, land use activities contributed positively to escalate the saltwater intrusion through uncontrolled mining of low-lying areas and unregulated construction work. The regression results have proved that human interventions were more significant than natural causes as indicated in the analysis. However, multicollinearity between water quality variables and confounding factors affecting the water quality parameters could affect the results of each parameter. Statistical results show a significant negative correlation between chloride and calcium levels, which can be justified with the limestone bedrock and related geomorphological characteristics. Multiple regression correlation results obtained from Table 9 are indicated in Equation (8).

$$\begin{aligned}
&\ln(Cl) = 2.958 + 2.477\text{Water} + 3.077\text{Grass} + 3.350\text{Forest} + 1.549\text{Builup} + 2.970\text{Barren} + 2.098\text{Agri}\\
&\ln(NO_3^-) = -9.483 + 18.008\text{Water} - 14.941\text{Grass} - 7.662\text{Forest} + 20.290\text{Builup} + 16.349\text{Barren} + 16.574\text{Agri}\\
&\ln(TP) = -0.791 + 3.360\text{Water} - 2.937\text{Grass} - 3.248\text{Forest} + 3.017\text{Builup} + 1.977\text{Barren} - 2.394\text{Agri}\\
&\ln(EC) = 4.233 + 3.244\text{Water} + 3.478\text{Grass} + 3.260\text{Forest} + 2.262\text{Builup} + 3.091\text{Barren} + 2.868\text{Agri}\\
&\ln(Ca^{2+}) = 2.546 + 2.099\text{Water} + 2.368\text{Grass} + 2.567\text{Forest} + 1.927\text{Builup} + 2.532\text{Barren} + 1.873\text{Agri}
\end{aligned} \tag{8}$$

As shown in Table 9, nitrate concentration in the wells has the highest positive correlation results compared with other water quality parameters. This revealed that nutrient inflow is significantly high into the Chunnakam aquifer from the land use activities. Proportional change in WQI can be obtained by the percentage change in built-up areas by using log-transformed elasticity coefficient calculations. These results further coincide with the pollution levels of Chunnakam aquifer conducted in the past studies. Therefore, residential activities dominated built-up cover and fertilizer-intensive agricultural practices could pose a significant threat unless regulated within Jaffna peninsula. Also, the significant pollutants such as excessive release of nitrates and phosphates should be controlled through sustainable agricultural practices and effective sewage and solid waste management mechanisms.

DISCUSSION

Jaffna peninsula showed a growing water demand caused by land use changes that resulted in a sharp decline in groundwater quality and poor management of water quantity in recent years. This study used water scarcity index (WSI) and water quality index (WQI) to assess the relationship with land use activities in the study area using 44 spatially distributed dug wells. WSI proved (mean=5.34) that over 50% of the wells face significant water scarcity problems. In addition, approximately 60% of agricultural wells were categorized in the scarcity or absolute scarcity range showing the problem of excessive water extraction for agriculture within the Chunnakam aquifer. WQI indicated 54% of the wells in Chunnakam aquifer have poor or very poor water quality, unsuitable for consumption purposes. Moreover, this accounts for over 50% of agricultural wells as influenced by the heavy use of chemical fertilizer and poor land management practices in agriculture. Prabagar *et al*. (2020) identified the contribution of nitrate to the pollution caused by the agricultural activities including potatoes, paddy and tobacco cultivations within Chunnakam aquifer.

Correlation coefficients of built-up areas, barren lands and agricultural areas showed strong positive correlation on the water quantity-based scarcity in Jaffna, which validates the water quality deterioration caused by

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resettlement projects in the post war development in Jaffna (Gunaalan *et al.*, 2018). Barren lands indicated the contamination and run-off effects on groundwater resources. Improving water and forest areas can contribute towards water conservation efforts in Jaffna. Moreover, results supported the hypothesis by revealing the negative effects of built-up areas and agricultural land use and the positive effects of grasslands and forest cover on the water quality-based scarcity. Therefore, effective planning interventions are necessary to conserve existing water resources and manage the land use changes in arid regions like Jaffna by prioritizing the water management perspective in planning of urban areas and agricultural lands. Although new reservoirs and desalination projects are being considered by NWSDB to manage water scarcity problems, strict control measures to mitigate groundwater pollution are necessary because over 60% of water demand is still met within Chunnakam aquifer.

Lack of knowledge of citizens, cultural reasons and land ownership disputes were considered as bottlenecks for the implementation of comprehensive water policy in the area. Therefore, it is pivotal to improve awareness among residents and farmers on the risks associated with the excessive use of chemical fertilizers in agriculture while promoting the use of bio-fertilizers. Efficient irrigation water management practices can prevent the leaching and buildup of nitrates in the aquifer while water-saving irrigation practices and new technologies are essential to manage the dry-season water demand and availability. Estimation of dry-season subsurface runoff is essential to model their implications on seawater intrusion, and a detailed study is required to verify the dynamics between freshwater and seawater interface with the pattern of dry-season groundwater extraction. Spatially distributed rainfall recording stations are essential to estimate spatial variation of groundwater recharge and to develop a regional agricultural water management plan.

CONCLUSION

Urbanization-led spatial growth patterns increase the demand for food and water in cities as resource constraints and pollution risks pose critical issues when planning urban settlements. Chunnakam aquifer, located in Jaffna, is one of the arid regions in Sri Lanka that has faced water scarcity problems in the recent past due to poor water management practices in agriculture and residential development. This paper studied the water scarcity problems influenced by land use activities, which highlighted the need for a water policy-led sustainable urbanization model in arid regions in developing countries like Sri Lanka. Traditionally, urban planning and water resource management are disjointed sectors handled by different agencies within overlapping spatial and temporal zones. Therefore, collaboration for future planning of cities must be in line with water resource management practices to avoid water scarcity problems in forecasted scenarios. Moreover, policy makers must consider the significant water scarcity scenarios for future residential and agricultural growth to meet the demand from rising urbanization. Land use policy must be laid with the priority focus on critical conservation efforts where planning agencies must simulate future land use changes and their consequences on the groundwater extraction in dry zones. This study can be further expanded to simulate the carrying capacity of land and water resources to accommodate sustainable land use changes as a development model for arid regions such as Jaffna, Sri Lanka. In addition, deep implications of water scarcity and land use relationship can be studied by identifying confounding variables which are transboundary in nature. Also, the temporal variations of water quality and quantity could reveal an improved view of water scarcity to foresee the future policy measures. Urban development plans can use these variations as a catalyst for building community resilience to future development challenges. Moreover, machine learning-based quantitative models can be assisted to better predict impacts of urbanization on water resources while scenario-based qualitative evaluations are necessary to implement participatory water policy in water scarce arid regions.

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LIMITATIONS OF THE STUDY

This study used WSI and WQI multivariate regression for the assessment of water quantity and quality parameters within Chunnakam Aquifer, Jaffna. Due to the time and resource limitations, the authors used published information to calculate the water resource variables, which are dependent on the reliability and accuracy of datasets. Based on the published dataset quality and potential variations within groundwater quality, the results could not be used to generalize the water scarcity levels of arid regions, which needs context-specific, spatial and temporal variations of the selected variables. Moreover, a fresh study is required to assess the temporal changes of the selected sampling locations (44 wells) to identify the variance of impacts in contextual spatial scale. Three distinct limitations were identified based on comparison of results with the seminal work in the same field, and progressive analytical frameworks on water quality and quantity parameters. First, this study did not assess the confounding nature of impacts on water quality (i.e. other land use types and natural phenomena occurred within the region). Second, multicollinearity between water quality parameters were not assessed comprehensively which can vary significantly based on temporal variations. Third, errors in data collection, analysis and interpretation of the sample dataset could affect the overall results of the model due to dependency on the published database. Sources used for the water quality measurements need to be expanded with temporal measurement of selected parameters to improve the results for long-term policy implications. Active participation of communities in Jaffna is necessary for policy making dialogue while developing an awareness program at the grassroots level of society. Physical barriers to accessing the wells for verification and lack of cooperation from the farming community was another limitation to the in-depth evaluation of the causal factors of water quality and quantity.

DATA AVAILABILITY STATEMENT

All relevant data are included in the paper or its Supplementary Information.

CONFLICTS OF INTEREST STATEMENT

The authors declare there is no conflict.

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First received 8 January 2022; accepted in revised form 20 May 2022. Available online 22 June 2022

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