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Does Urban Heat Island effect impact Groundwater Levels? A Case Study of Pune District

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Abstract

In the last sixty years, we have seen a massive spike in the process of urbanisation. This spike has been brought about by a 5-fold increase in global population from 750 million in 1950 to 4.2 billion in 2018. The process of urbanisation has spiked significantly over the last sixty years, experiencing almost a 5-fold increase in the global urban population from 750 million in 1950 to 4.2 billion in 2018. While urbanisation has brought about beneficial impacts in terms of infrastructure development, it has also been accompanied with negative consequences for urban residents in particular. As a consequence of the high presence of built infrastructure and sealed surfaces within cities, urban areas often experience elevated temperatures. This phenomenon is particularly evident during the night time and is termed as the Urban Heat Island (UHI) effect. The UHI effect is significantly influenced by location-specific factors, among which land-use change and presence of vegetation have been studied by numerous scholars. However, the impact of the UHI effect of hydrological factors such as groundwater levels is substantially under-researched a topic. In order to bridge this existing gap in literature, the current study aims to investigate the relationship of Land Surface Temperature (LST) with groundwater levels (pre- and post-monsoon) for Pune district. The findings from the study suggest a positive correlation between SUHII and groundwater levels, thereby implying that an increase in land surface temperature is accompanied by groundwater falling further below the surface level.

Keywords: Urban Heat Island effect, Land Surface Temperature, Urbanization, Groundwater Level, Precipitation, Vegetation

1. Introduction

In recent times, developing countries have witnessed urbanisation at an unprecedented rate with almost half the world's population residing in urban areas. In alignment with the trend, urban dwellers in India are expected to increase by 484 million by the year 2050. Such an increase in urbanisation is likely to put pressure on the ecology and infrastructure within cities and degrade land quality as well as natural resources. Combined with an increase in the proportion of impervious surfaces to compensate for the needs of the new urban residents, we are likely to witness an interference with natural environmental processes that take the shape of phenomenon such as the Urban Heat Island (UHI) effect. This phenomenon is particularly evident post sunset in urban areas and is characterised by higher temperatures in the built environment compared to the natural environment (Oke, 1982; Phelan, et al.,2015; Dutta, Gupta & Kishtawal, 2020; Marando, et al., 2019). Among the various categories of UHI phenomenon, the Surface UHI effect is found to have strong correlation with the UHI effect for which Land Surface Temperature (LST) is most commonly used as an indicator. Change in LST is primarily influenced by location-specific factors, among which land-use change and presence of vegetation have been studied by numerous scholars (Feng et al., 2019).

Considering that demographic and environmental changes occurring in urban regions exert substantial influence on water bodies, exploring the relationship between LST and water resources could provide interesting conclusions regarding the often-overlooked impacts of the UHI effect. Nayan, et al. (2020) point out that urbanisation influences water bodies not only at the surface level but also at a volumetric scale. This conclusion led various scholars to explore the relationship between urbanisation and groundwater levels in urban areas. However, literature on the topic is sparse and there exists a lack of consensus regarding the impact of elevated LST on groundwater levels. The current study aims to bridge these gaps in literature by taking Pune district as the study area. The following sections, namely (i) Background; (ii) Materials and Methods; (iii) Findings and Discussion and (iv) Conclusions, Recommendations and Limitations explore the impact and implications of the UHI effect on Groundwater levels in greater detail.

2. Background

Urbanisation has been on a rise across the world, and by 2050, 70% of the global population is expected to reside in urban areas. India alone is expected to add 416 million urban dwellers by 2050, exerting immense pressure upon the availability of resources and the carrying capacity of cities (Department of Economic and Social Affairs, 2019). While urbanisation brings with itself the scope of improvement in the standard of living and better employment opportunities, it is a complex phenomenon that can also give rise to certain negative environmental changes. Scholars point out that urbanisation involves a transformation of natural green surfaces into impervious surfaces, making urban areas emerge as hot spots for negative environmental impacts ranging from increase in air temperature to alteration of natural water levels (Kantakumar et al., 2016; Phelan et al., 2015; Cox, et al., 2018; Mushore et al., 2018). As a consequence, phenomena like UHI effect, which is characterised by higher temperatures in the built environment compared to the natural environment and is particularly prominent during the nighttime takes shape (Oke, 1982; Phelan et al., 2015; Marando et al., 2019). The UHI effect is influenced by several factors but the primary reason behind its occurrence is higher percentage of built-up regions in urban areas that comprise of man-made materials, absorb and store a relatively higher proportion of solar energy as opposed to the countryside areas (EPA, 2020; Phelan et al., 2015; Marando et al., 2019).

When it comes to UHI effect, a crucial concern is that the presence of UHIs can have a detrimental effect on human health and the lives of urban dwellers, as it results in an increase in energy consumption, photochemical smog, deteriorating air quality and the occurrence of heat waves (Dutta et al., 2020; Cox et al., 2018; Feng et al., 2019; Mushore et al., 2018). Considering the recent rise in heat waves in India, particularly in the north-western part of the country, the UHI effect has increasingly become a matter of concern for second-tier cities in the country which have emerged as the hotspots of urbanisation and growth in recent times. Apart from intensifying the impact of heat stressors, the UHI effect can also interfere with local convection currents and result in extreme and unprecedented precipitation events (Shastri, et al., 2017; Dutta et al., 2020; Marando et al., 2019).

Scholars have categorised UHIs into (i) Atmospheric and (ii) Surface UHIs. Atmospheric UHI is measured on the basis of air temperature and is further distinguished into canopy and boundary layer UHI (Estoque et al., 2017). As per the results furnished by Oke (1976), the Canopy Layer UHI (or CLUHI) takes into consideration area from the surface to the mean building height for identifying heat islands. On the other hand, the Boundary-Layer UHI is measured within the Urban Boundary Layer (UBL) that exists above the Urban Canopy Layer (UCL) and is influenced by the urban surface existing below (Oke, 1976; Martin et al., 2015). As the use of air temperature data is hindered by the limited monitoring sites available for its measurement, scholars often rely on Surface UHI (SUHIs) for detecting and measuring the UHI effect for a region. SUHIs are measured through LST which can be retrieved through the means of satellite remote sensing. Existing studies have estimated a high correlation between SUHI and CUHI, thereby making LST a suitable proxy measure for the indirect identification of the SUHI effect (Marando et al., 2017; Dutta et al., 2020).

LST is substantially influenced by location-specific factors, among which land-use change and presence of vegetation have been studied by numerous scholars. He et al. (2007) analysed SUHI patterns for China and found them to be spatially correlated with regional land use and changes in land cover. The presence of vegetation has been repeatedly associated with a cooling as well as humidifying impacts on the surroundings. This is further validated by the fact that the Normalised Difference Vegetation Index (NDVI) which serves as measure for vegetation coverage has been shown to be inversely correlated with LST. Further, this existing negative correlation between NDVI and LST serves as the basis for recommending urban areas to increase the percentage of green spaces in order to mitigate UHI effects (Yue, et al., 2007; Kumar & Shekhar, 2015; Feng et al., 2019; Marando et al., 2019).

Water bodies, being a crucial element of the land cover composition of an urban area, are also influenced by urbanisation and developmental processes. In urban areas with high population density, water bodies are often encroached upon for supporting high-return activities, resulting in frequent water disputes and rising concerns regarding depletion of local water resources (Kalhor & Emaminejad, 2019; Nayan et al., 2020). Mishra et al. (2014) discuss that urbanisation hinders infiltration of water, reducing groundwater recharge as well as storage. A pan-India study conducted by Shiao et al. (2015), also identified that 54 % of the Indian land mass experiences 'high' to 'extremely high-water' stress. According to Nayan et al. (2020), changes due to urbanisation on the land use/cover of a region not only occur at the surface level, but at the volumetric scale as well. Further, their investigation of the relationship between land use patterns and groundwater levels in the city of Hyderabad suggested a positive correlation between land use mix and changes in groundwater level. Further analyses using spatial clustering revealed that regions with mid-rise and low-rise development in peri-urban areas have improved levels of groundwater in comparison to commercial areas with high-rise development which displayed widespread attenuation of groundwater levels.

Patra et al. (2018) identified a declining trend in groundwater levels during pre- as well as post-monsoon periods in Howrah Municipal Corporation (HMC) area and attributed it to higher proportion of urban population and reduced infiltration capacity due to increase in built-up area of an impervious nature. Further, the application of Kendall's Tau Test indicated a significant but inverse correlation between average air annual temperature and annual average groundwater (-0.75) as well as annual average rainfall (-0.77). On the same lines, Mohammed et al. (2019) analysed the relationship of SUHI effect with spatiotemporal factors including groundwater for the city of Ahmedabad, India. Here, the authors observed the Pearson correlation between groundwater table level and SUHI intensity to be around 0.64 during Winter daytime as well as Summer nighttime suggesting that an increase in SUHI intensity is accompanied an increase in the depth of the groundwater table.

Studies conducted on the topic of 'Urban Heat Islands' have primarily focused upon identifying UHIs by measuring the increase in temperature brought about by the Heat Island Effect, and comparing this effect alongside the regional and spatial factors such as weather, location, season, airflow, anthropogenic heat, urban geometry, land use land cover (including agriculture and vegetation patterns), building characteristics (including their size, material and density), urban sprawl and increasing industrial and human activities that are likely to have caused it (Phelan et al., 2015; Estoque et al., 2016; Haashemi et al., 2016; EPA, 2019). Patra et al. (2018) diverged from conventional studies on the UHI effect by looking at the association between built-up area and hydrometeorological factors including groundwater level and precipitation. Similarly, Jaiswal & Jhariya (2020) expanded the focus of their study by taking into consideration the impact of agricultural practices and urbanisation on groundwater levels in addition to investigating the impact of LULC on the heat island effect for the city of Raipur, Chhattisgarh. Changnon (1992) even found evidence for UHI resulting in an increase in seasonal rainfall downward of major cities in his early investigations. Yet there remains little consensus on the impact of heat islands on precipitation and groundwater (Shepherd, 2005; Koomen & Diogo, 2017). In light of the gaps in literature outlined above, the following research looks into the relationship of LST with groundwater levels (pre- and post-monsoon) between 2017 and 2019 for Pune district.

3. Materials and Methods

3.1. Study Area

Pune district, the study area for the research falls within the Deccan Plateau towards the foot of the northern part of the Western Ghats. Home to more than 94 lakh residents, Pune district comprises Pune and Pimpri Chinchwad Municipal Corporations. While Western Ghats surround the district on the West and South, the Indrayani River is located in the North and the Daund tehsil in the East. The study stands at an altitude of 559 metres above the mean sea level with rivers Mula and Mutha running through the centre of the district. The district lies at 18° 32″ North latitude and 73° 51″ East longitude. The mean annual temperature for the district is 25°C, and the mean annual precipitation is 650-700 mm. Being a part of the tropical monsoon land, Pune district shows substantial variation in temperature and rainfall across the year (https://pune.gov.in). Pune district has experienced rapid urban growth and transformation since the last three decades. The region has grown not only with regards to its agricultural sector, but also its industrial and service sectors through widespread industrialisation and provision of eminent educational infrastructure and facilities.

In the near future, the Pune city in particular is expected to progress further as it undergoes the transition envisioned for India’s 100 Smart Cities (https://smartcities.gov.in). However, Pune’s growth stands in utter contrast to the sustainability of its development. A large proportion of the ecological resources, particularly those in peri-urban areas, are overexploited and on the verge of being entirely deteriorated. The region’s land and water resources are often found to be insufficient to meet the increasing demand. Socio-economic polarisation within the region, owing to the lack of suitable urban planning is another developmental concern (Butsch et al., 2017; Kantakumar et al., 2016). As pointed out by Butsch et al. (2017), Pune’s growth and urban expansion trajectory resembles that of various cities across the world, which have experienced substantial urban growth yet continue to struggle with the sustenance of their ecological resources (*Figure 1*). In light of the same, Pune city makes for an appropriate study area for conducting the current research.

3.2. Data Collection & Processing

The methodology for the study entails collection of secondary data for precipitation and groundwater levels for the purpose of understanding their statistical and spatial relationship with LST. Analysis of LST alongside precipitation and groundwater levels has been performed for the entire Pune district. Additionally, Land Use/Land Cover classification has been carried out to facilitate the objectives of this research. LST for estimating the SUHI effect has been retrieved using remote sensing data as combined with Geographical Information Systems as it serves as an efficient yet cost effective method for mapping and analysing spatiotemporal dynamics of urban phenomena (Kantakumar et al., 2016). A land cover/land use map for Pune city has been created using SAGA GIS while data processing and statistical analysis has been carried out using Quantum Geographic Information System (QGIS). Finally, Groundwater Level data has been sourced for wells within Pune district and interpolated for the entire district using QGIS. Provided below is a comprehensive explanation of the data utilised and the procedure followed to obtain the desired output for meeting the objectives of this research.

3.2.1 Land Surface Temperature and NDVI

In order to obtain land surface temperature values, Landsat 8 OLI-TIRS imagery was downloaded from the Earth Explorer of the United States Geological Survey (USGS) website for the metropolitan areas of Pune as well as Solapur (Figure 2, Table 1). The imagery was retrieved for May and October (representative months for summer and winter respectively) between 2017 - 2019 so as to compare LSTs across seasons as well as time periods. Using the Semi-Automatic Classification Plugin available in the open-source software QGIS, Dark Object Subtraction (DOS1) Atmospheric Correction was applied to the downloaded imagery. Thereafter, the formula and methodology recommended by Weng et al. (2004) and utilised by Avdan & Jovanovska (2016) was considered for obtaining LST values from the imagery. The procedure involved applying DOS1 Atmospheric Correction to Landsat bands 4, 5 and 10 using the SCP Plugin in QGIS. Then using Raster Calculator to calculate the At-satellite brightness temperature (Tb). Using the same bands 4 and 5, Normalised Difference Vegetation Index (NDVI) was obtained for the region using the following formula:

$$NDVI = NIR\ (band\ 5) - Red\ (band\ 4) / NIR\ (band\ 5) + Red\ (band\ 4)$$

Using the imagery retrieved for NDVI, the Proportion of Vegetation can be derived. Thereafter, ground emissivity can be determined and finally LST is retrieved in K. By subtracting the conversion factor (273.15) from the same, LST can be converted into °C. Finally, for the retrieval of both NDVI and LST for

Pune district, LST output obtained using the imagery for Pune and Solapur have to be merged and then clipped in QGIS with the Pune district shapefile as the mask layer. The retrieved LST imagery was then classified in order to identify geographical variation in LST. Table 1 represents the dates for which Landsat imagery was acquired for both Solapur and Pune metropolitan areas between 2017 and 2019.

3.2.2. Land Use Land Cover

For deriving the Land Use/Land cover map for Pune city, Object Based Image Segmentation was carried out using SAGA GIS for Landsat imagery for May 2019. The process involved combining neighbouring pixels into a polygon based on the similarity of their spectral and spatial characteristics. After performing the segmentation, objects were classified into the defined land cover categories, namely (i) water; (ii) vegetation; (iii) shrub land; (iv) barren land and (v) built up by creating training polygons and assigning a value to specific land cover classes and supervised classification was carried out in order to obtain the land cover classification for the region of interest. Lemenkova (2020) utilised a similar OBIA procedure and carried it out using SAGA GIS for the purpose of distinguishing urban spaces from other land cover types in the region of Yaoundé, Cameroon.

3.2.3. Groundwater Level

Groundwater level data for Pune district was derived from the data collected by Central Groundwater Board (CWGB) and made available on India - WRIS website (https://indiawris.gov.in/wris/#/DataDownload). Data for pre-monsoon and post-monsoon months between 2017 and 2019 for 48 sites located within the Pune district was retrieved. Using Google Earth Pro, place marks were created for these sites and imported to QGIS. Thereafter, the shape file with place marks was joined with the groundwater data downloaded from India - WRIS. Using Inverse Distance Weighted (IDW) Interpolation, spatial distribution for groundwater levels within Pune district was obtained for pre- as well as post-monsoon. Finally, random points were created for each of the land use/land cover classes, and values for groundwater as well as LST were sampled at each of these points. Using these sampled values, correlation coefficient between LST and groundwater levels was obtained for pre- as well as post-monsoon periods between 2017 and 2019.

4. Results and Discussion

4.1. Seasonal Variation in Surface Urban Heat Island effect

From the descriptive statistics for LST provided in Table 2, it can be ascertained that post-monsoon LST values are substantially lower than pore-monsoon LST values across the years. The average LST prior to monsoon is 33.04 C° in 2017, 41.22 C° in 2018, and 41.75 C° in 2019, suggesting an increasing trend over the years. Mean LST, post-monsoon on the other hand is 20.26 C°, 31.61 C° and 23.46 C° in 2017, 2018 and 2019 respectively. Moreover, the mean LST value for 2017 for pre-monsoon is 33.04 C° which is substantially lower than the mean LST value for pre-monsoon observed in 2018 and 2019 which is approximately 41 C°. However, this trend is not observed for the post-monsoon period wherein mean LST value for 2018 is observed to be 31.61 C° which is considerably higher relative to the mean LST value for 2017 and 2019 which is approximately 23 C°. The difference between mean LST for pre-monsoon and post-monsoon months across a year can be observed to be the highest for 2019 suggesting the increasing influence of factors contributing to a rise in LST.

From *Figure 3*, depicting the spatial variation in LST values, it can be interpreted that areas lying towards the west of Pune district have relatively lower LST values in comparison to the areas lying in the centre of the district, particularly for the pre-monsoon period. The map further suggests presence of cloud cover for the post-monsoon imagery for 2017 and 2019, which is likely to be the reason behind their lower mean LST value derived when compared against the post-monsoon imagery for 2018.

4.2. Relationship between NDVI and LST

During the pre-monsoon season between October to May, agricultural lands are harvested across the country, transforming crop lands into barren lands. This decreases the vegetation cover prior to monsoon and therefore lowers NDVI and evaporative cooling. Reduced evaporative cooling plays a dominant role in contributing towards UHI and is evident in the form of elevated LST. This inference is evident from Table 3 which depicts that mean NDVI is consistently lower during pre-monsoon with respect to post-monsoon months. Similarly, Figure 4 also suggests that during the pre-monsoon period, vegetation (or NDVI) is lower, while UHI effect (or LST) is on the rise. Post-moon, vegetation is replenished which increases NDVI and therefore decreases UHI effect (or LST) in comparison to the pre-monsoon period. Additionally, it can be visually interpreted that areas within the district with greater vegetation, depict a reduced presence of the UHI effect while areas with a lower presence of vegetation, show a strong presence of the UHIs. Further, the correlation coefficient derived for the relationship between NDVI and LST was found to be negative, and having a value of 0.84 particularly for vegetation as land cover during pre-monsoon of 2018. This negative correlation between NDVI and LST was observed to decrease to 0.70 for vegetation considered within the post-monsoon period in 2018 implying that the presence of vegetation had a greater influence on LST during the pre-monsoon period.

4.3. Seasonal Variation in Precipitation and Groundwater Level

From the data extracted through the India-WRIS portal for precipitation within Pune district and depicted using a graph in *Figure 5*, it is evident that Pune district witnessed exceptionally high levels of precipitation in 2017 in comparison to 2018 and 2019, when the region experienced modest levels of precipitation. Precipitation largely occurs between June and September, making a case for the extraction of pre-monsoon LST data in May, and the retrieval of post-monsoon LST in October. On comparing the data for groundwater levels presented in Table 4 with the precipitation graph in *Figure 5*, it is evident that groundwater levels are positively associated with precipitation levels. The mean groundwater level ranges around 6-8 metres bgl prior to monsoon, it rises to 2-5 metres bgl during post-monsoon months implying that water is nearer to the ground post-monsoon when compared against pre-monsoon months due to precipitation in the monsoon months.

Figure 6 further illustrates the fluctuation in groundwater level across monitoring sites within the district and validates the rise in groundwater levels post-monsoon for a majority of sites. Due to the substantial rainfall experienced in 2017, significant variation is found in the pre- and post-monsoon groundwater levels across monitoring sites. Additionally, it is evident from the graph that the monitoring sites of Nimbgaon-Ketke and Otur, groundwater levels were abysmally below the surface across the years. For the site of Kauthe however, groundwater levels worsened considerably in 2019 and went as low as 30 metres below ground level. From Figure 7, it can be observed that some regions within the district, particularly those located towards the western ghats have groundwater located merely 0.01 metres below the ground post monsoon, approximately at the surface level. Areas located towards the northern part of the district on the other hand, experience extremely low levels of groundwater. In the pre-monsoon months of 2019, the groundwater level can be observed to have decreased to 32 metres bgl in the northern regions of the district. The considerably lower value for groundwater observed in the pre-monsoon of 2019 towards the northern part of the district is likely to be representing the dip in groundwater levels for the site of Kauthe and neighbouring areas.

4.4. Relationship between GW level and LST

With regards to the relationship between Groundwater level and LST, it is evident from Figure 8 that prior to monsoon, when LST is high, groundwater levels are lower or groundwater is located further below the ground. On the other hand, post-monsoon, the LST decreases while the groundwater levels are found to rise such that groundwater is found nearer to the land surface. A visual comparison of LST and groundwater levels for Pune district suggests that areas towards the western part of the district experience lower LST levels along with improved groundwater levels, while the northern and eastern parts of the district find strong presence of increased LST and relatively worse levels of groundwater. The highest correlation between LST and groundwater levels is observed for vegetation as land cover post-monsoon in 2018, that is 0.80. This positive correlation between LST (in °C) and groundwater level (in m bgl) implies that for areas with prominence of vegetation, as LST increases, the groundwater levels fall further below the surface level.

5. Conclusion, Limitations & Recommendations

The present study aimed to investigate the impact and implications of the urban heat island effect on groundwater levels for Pune district between 2017 and 2019. The study involved application of GIS techniques for the retrieval of Land Surface Temperature data using Landsat-8 OLI/TIRS sensor and its comparison with presence of vegetation (NDVI) and groundwater levels. Validating results from studies conducted by Marando et al. (2019) and Feng et al. (2019), a negative correlation of 0.84 was observed between NDVI and LST for the pre-monsoon of 2018 suggesting that regions with a higher presence of vegetation observe lower land surface temperature. As recommended by Marando et al. (2019), the negative relationship between NDVI and LST is suggestive of the contribution of green infrastructure towards improvement of cooling capacity of the region. On the basis of this evidence, it can be concluded that increasing the proportion of green infrastructure in the city could serve as a beneficial mitigation strategy for increasing the cooling capacity, thereby minimising the negative consequences of the UHI effect.

With regards to the relationship between LST and groundwater levels, investigations from the study identified a positive relationship with the correlation coefficient as 0.80 during the post monsoon of 2018, particularly for vegetation as a land cover. This implies that regions experiencing higher land surface temperature, observe groundwater levels that are far below the surface level. For regions that experience low groundwater levels year after year, field initiatives targeted towards identifying these areas and studying the impact of rapid urbanisation and land cover dynamics of the region on groundwater levels could pave the way for suitable mitigation strategies. In the context of the rising concerns associated with water scarcity and climate change, adopting adequate mitigation strategies for preventing further deterioration of groundwater levels is likely to become a necessity in the coming years.

By comparing the results obtained for association between LST and Groundwater Level alongside those obtained for LST and NDVI, it can be assessed that presence of vegetation and improved groundwater levels collectively contribute to a decrease in LST. Increase in vegetation cover results in an improvement in groundwater levels by making the land surface permeable and letting water seep down the land surface. Moisture and vegetation collectively reduce LST and therefore decrease UHI intensity. This conclusion further suggests that increasing the presence of vegetation cover serves the dual ecological and economic purpose of replenishing the groundwater sources and mitigating elevated temperatures.

Despite providing valuable insights regarding the often-overlooked factors influencing the Urban Heat Island effect in second tier cities, the current study has certain limitations. In terms of the estimation of spatial variation in LST for Pune district, the retrieved output was subject to the limitations associated with the use of low spatial resolution imagery from Landsat-8 OLI/TIRS sensor. Due to technical constraints with the removal of cloud cover and idiosyncratic factors influencing satellite imagery, only images for the months of May and October were retrieved and assumed to be representative of pre- and post-monsoon fluctuations in LST as well as groundwater levels. Further, the time period taken into consideration for assessing the relationship between LST and groundwater was insufficient to provide an understanding of the influence of LST on groundwater over time. Another concern associated with the research is that correlation coefficient values derived were found to be varying substantially across land cover categories as well as across time periods.

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7. Tables and Figures

Table 1: Acquisition Date for Landsat-8 Imagery downloaded from USGS Earth Explorer

2017			
Pre-monsoon		Post-monsoon	
Path 147 Row 47	Path 148 Row 46	Path 147 Row 47	Path 148 Row 46
15th May	8th May	22nd October	31st October
2018			
Pre-monsoon		Post-monsoon	
Path 147 Row 47	Path 148 Row 46	Path 147 Row 47	Path 148 Row 46
2nd May	11th May	9th October	2nd October
2019			
Pre-monsoon		Post-monsoon	
Path 147 Row 47	Path 148 Row 46	Path 147 Row 47	Path 148 Row 46
5th May	14th May	12th October	5th October

Table 2: Descriptive Statistics for retrieved Land Surface Temperature values in Celsius across Seasons (2017 – 2019)

LST - 2017							
Pre-monsoon				Post-monsoon			
Min	Max	Mean	St.dev.	Min	Max	Mean	St.dev.
-	50.25	33.04	5.24	-	39.20	23.33	5.63
LST - 2018							
Pre-monsoon				Post-monsoon			
Min	Max	Mean	St.dev.	Min	Max	Mean	St.dev.
20	53	41.22	3.85	8	47	31.61	4.21
LST - 2019							
Pre-monsoon				Post-monsoon			
Min	Max	Mean	St.dev.	Min	Max	Mean	St.dev.
23	63	41.75	4.36	6	36	23.46	2.86

Table 3: Descriptive Statistics for NDVI values in Celsius across Seasons (2017 – 2019)

NDVI - 2017							
Pre-monsoon				Post-monsoon			
Min	Max	Mean	St.dev.	Min	Max	Mean	St.dev.
-0.38	0.94	0.39	0.15	-0.21	0.91	0.50	0.19
NDVI - 2018							
Pre-monsoon				Post-monsoon			
Min	Max	Mean	St.dev.	Min	Max	Mean	St.dev.
-0.64	1.00	0.20	0.24	-0.71	0.93	0.27	0.32

NDVI - 2019							
Pre-monsoon				Post-monsoon			
Min	Max	Mean	St.dev.	Min	Max	Mean	St.dev.
-0.45	0.92	0.18	0.21	-0.57	0.97	0.27	0.32

Table 4: Descriptive Statistics for Groundwater Level across Seasons for Pune district (2017- 2019)

GW level - 2017 (in m bgl)							
Pre-monsoon				Post-monsoon			
Min	Max	Mean	St.dev.	Min	Max	Mean	St.dev.
0.6	15.85	6.79	2.17	0.01	10.1	3.08	1.53
GW level - 2018 (in m bgl)							
Pre-monsoon				Post-monsoon			
Min	Max	Mean	St.dev.	Min	Max	Mean	St.dev.
0.085	15.35	6.4	1.91	0.01	14.5	4.45	2.42
GW level - 2019 (in m bgl)							
Pre-monsoon				Post-monsoon			
Min	Max	Mean	St.dev.	Min	Max	Mean	St.dev.
0.011	32	7.94	3.2	0.01	14.52	2.92	1.56

Figure 1: Land Use Map for Pune district – Sourced from 'SWOT Analysis of Pune District' (Department of Agriculture)

Figure 2: Merging of Landsat Imagery for the Retrieval of Imagery for Pune district

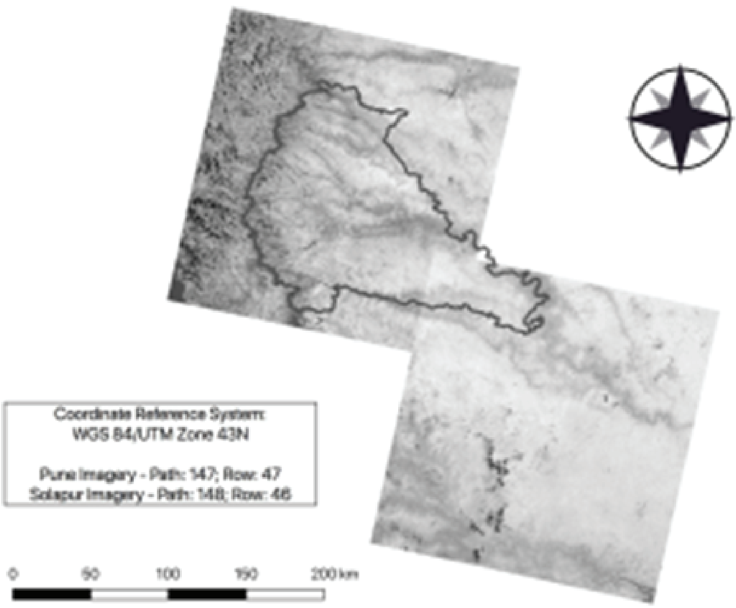


Figure 3: Spatial Variation in Pre-monsoon v/s Post-monsoon LST for Pune district (2017 – 2019)

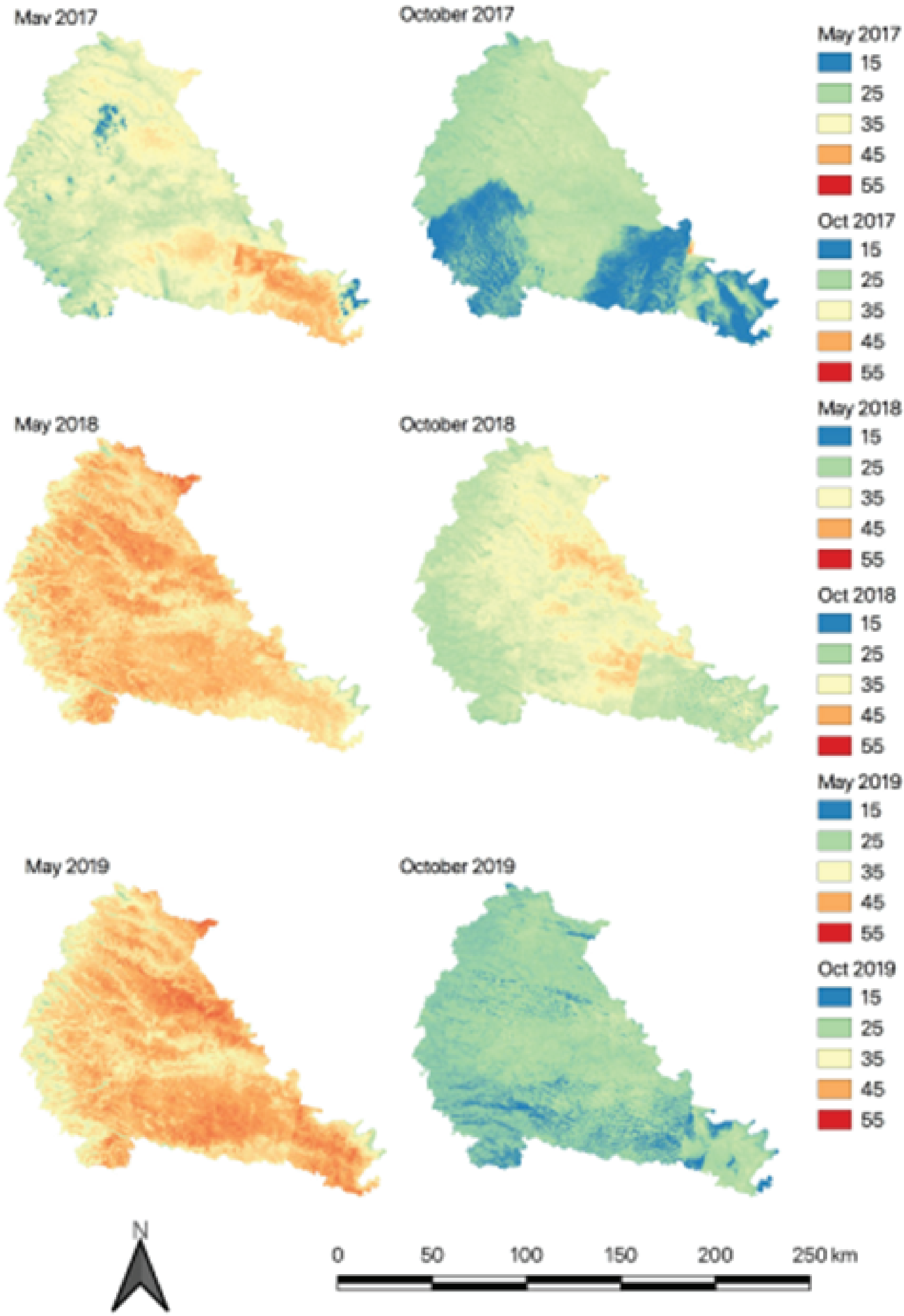


Figure 4: Spatial Variation in Pre-monsoon v/s Post-monsoon LST and NDVI for Pune district in 2018

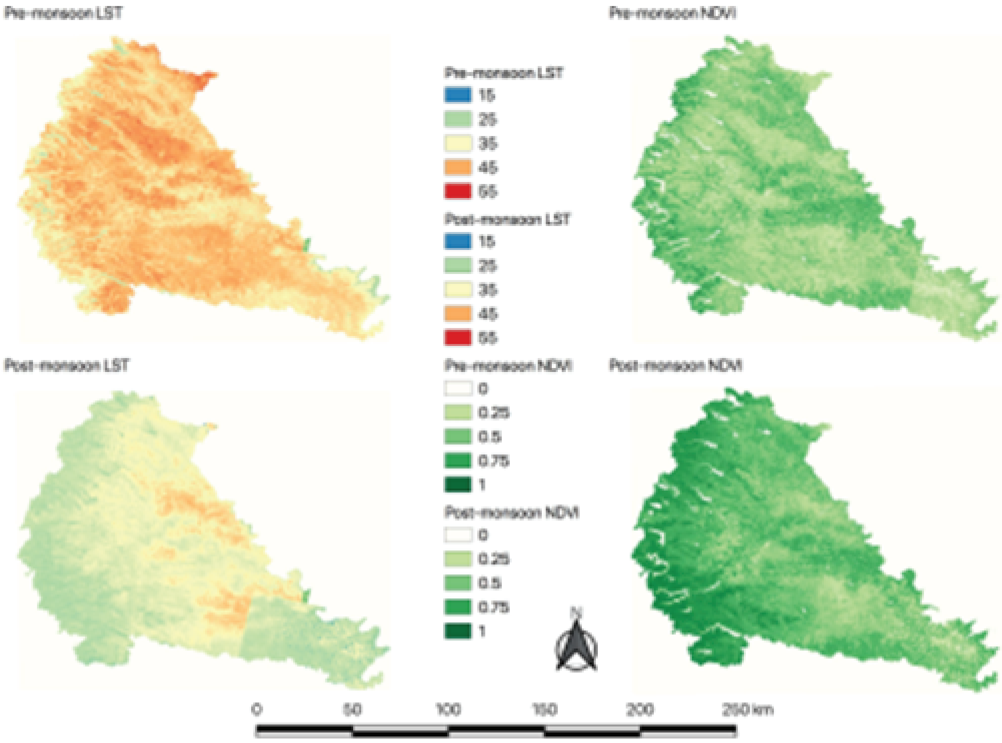


Figure 5: Bar Graph representing Normal v/s Actual Precipitation Levels within Pune district between 2017 and 2019

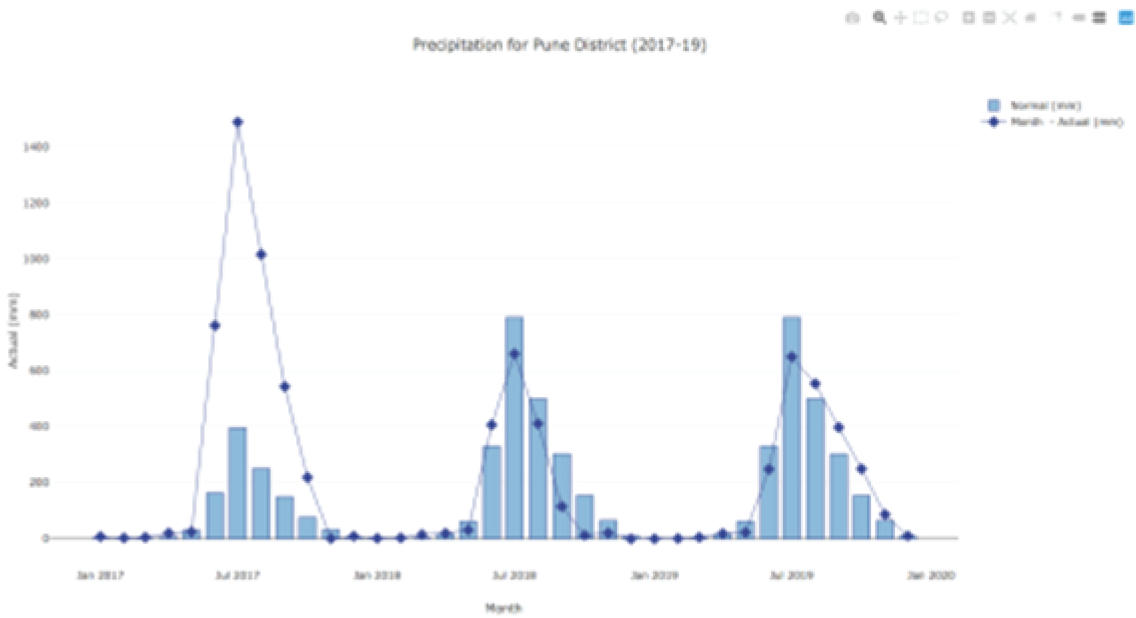


Figure 6: Seasonal Variation in Groundwater Level for Groundwater Monitoring Sites within Pune district (2017-19)

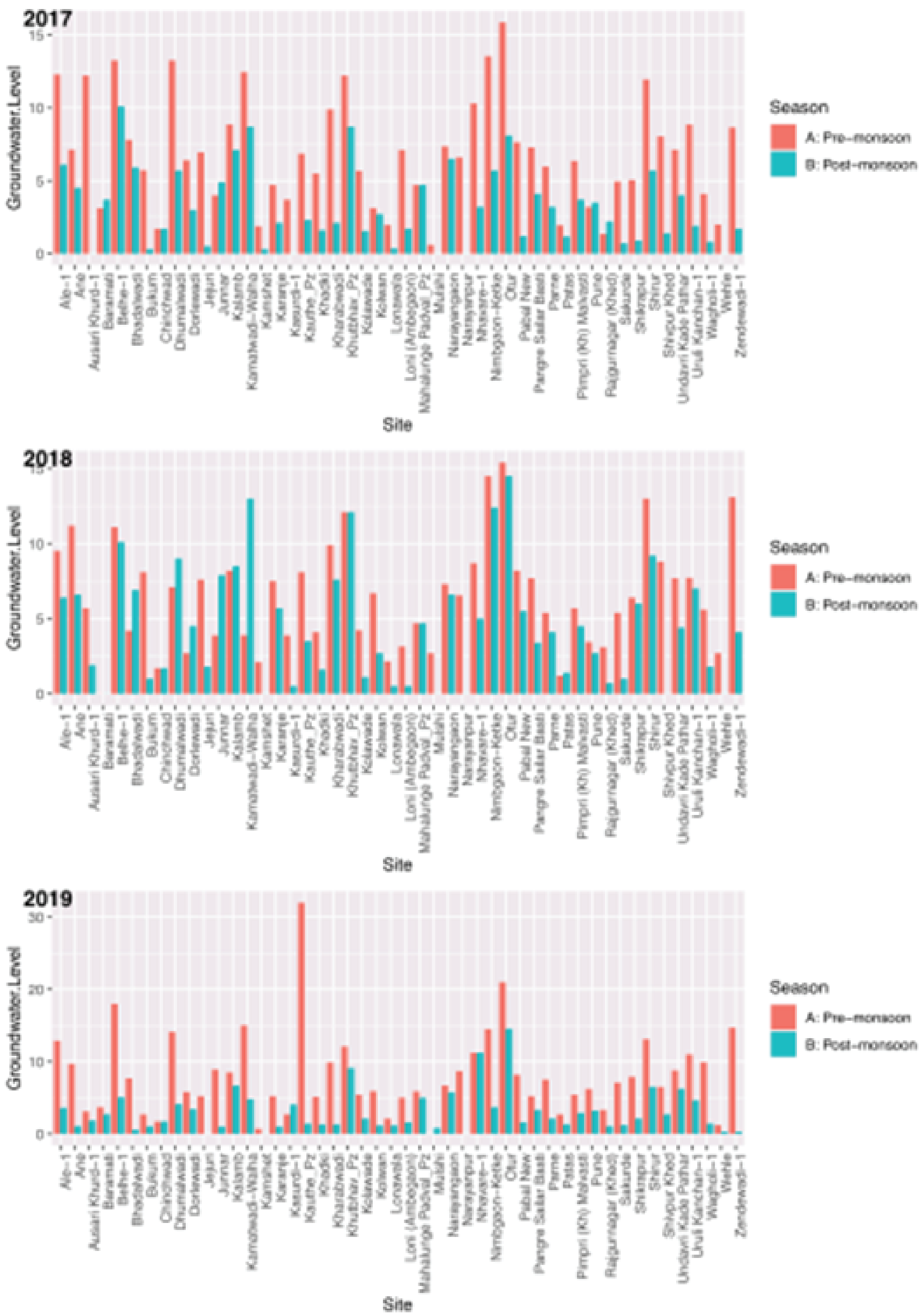


Figure 7: Spatial Variation in Pre-monsoon v/s Post-monsoon Groundwater Level for Pune district (2017 - 2019)

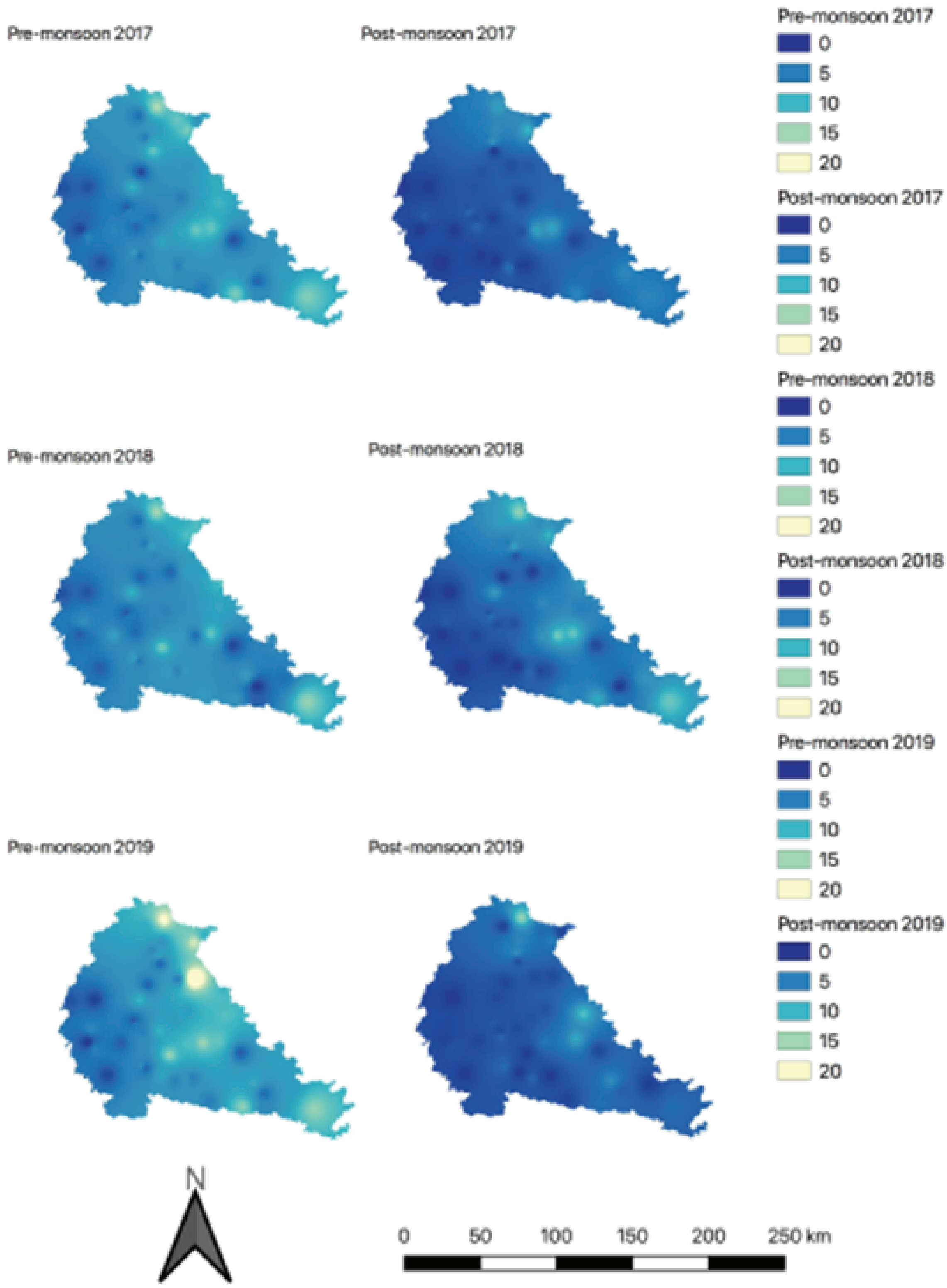
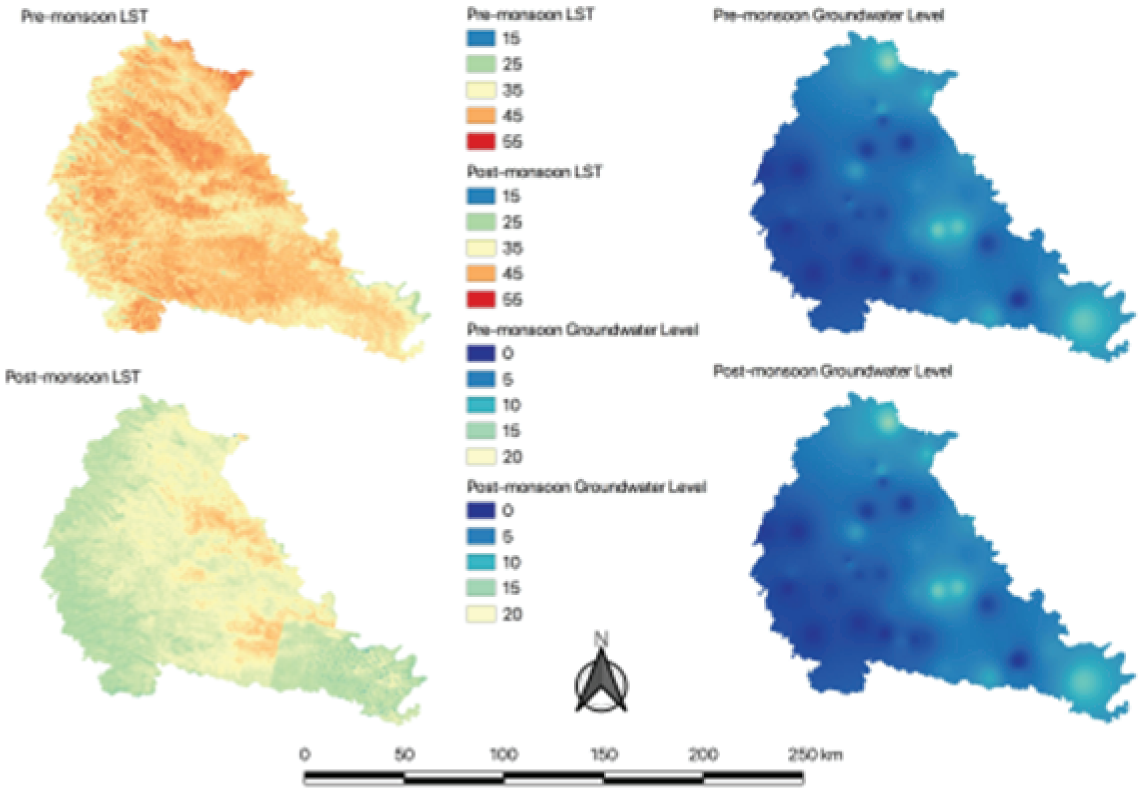


Figure 8: Spatial Comparison between LST (left) and Groundwater Level (right) for Pune district (2018)



Towards a Regulatory Framework for Higher Education Institutions

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Abstract

Today, research on higher education regulation is dominated by higher education scholars and not those working on the regulations itself. This leads to a limited regulatory understanding of higher education sector. As private universities mushroom across developing countries, an adequate understanding of how regulatory frameworks should be developed is important. By drawing ideas from pertinent taxonomy in regulatory studies (Gilad 2010) we evolve an approach through which higher education regulation can be benchmarked, examined and evaluated. To illustrate the design principles of the proposed framework, we use India's higher education sector as the case study.

Keywords: Higher education regulation, privatization of higher education, Global South.

1. Introduction

Scholarship on regulation of higher education (HE) is dominated by HE experts rather than the regulatory experts. This may not be a problem per se, but indeed unusual. King (2007) examines this strange nature of HE scholarship where despite an increasingly rich account of state-university relationship (Clark 1983; Neave 1998), literature has hardly engaged with regulatory theories or emerging regulation tools with sufficient depth. One could have, for argument's sake, gone beyond traditional models and applied the theories of 'responsive' (Ayres and Braithwaite 1992) or 'smart' regulations (Gunningham et al 1998) to sculpt better HE regulatory models. But it is not the case. Often new designs, techniques and even motivation of HE regulation remains untheorized. Even the inflating research on regulation has not been able to subsume HE in its scope.

Developing countries in absence of good quality higher education institutions (HEIs) suffer even more from this lack of scholarship. A robust menu of regulatory designs for HE, that caters to the context of the developing countries can be invaluable. With rapid rise in privatization of HE globally and in Global South, that can potentially have significant implications in universities in Global South, the need for innovative regulatory designs in the sector is increasing (Jamshidi et al 2012; Varghese 2004; Priest and John 2006; Slantcheva and Levy 2007, Robertson and Komljenic, Altbach et al 2019). Thankfully, the rise in available data and countries' growing sensitivity to local contexts have made regulatory science an agile discipline, which can be deployed more creatively (Capano and Pritoni 2019; 2020).

This article is such an attempt. We do this weaving through two important threads. We use prevailing taxonomy of regulatory approach (Gilad, 2010) that suits the context of higher education, and use it to benchmark the Indian HE landscape. Next, we also pick select HE regulations from India and evaluate them through the proposed framework. Adopting Indian-HE as a reference point is useful since it carries significant lessons for the Global South in general.

The rest of the paper is divided as follows. In Section 2, we slice open the concept of 'regulation' and develop its clearer conceptualization in context to HEIs. In Section 3, we discuss the 'purpose' of regulation borrowing ideas from standard theories, and screen Indian HE ecosystem through this framework. In Section 4, we use the categories of prescriptive, outcome-oriented and process-oriented regulation (Gilad 2010) to demonstrate a potential framework and an approach to regulatory design of HEIs. Here again, we run the scope of the Indian HE sector through the evolving approach. Section 5 integrates the purpose and approach and section 6 concludes.

2. The conceptual apparatus of regulation for HE

Regulation, despite its ubiquity in sectoral applications has somehow not been able to sufficiently capture elements and experiences of HE. Much of the scholarship in HE-regulation actually takes place in journals on HE, rather than those on regulation. Of the little excitement there is in the field of HE-regulation, handful number of comparative studies on policy reforms have dominated the intellectual landscape (Broucker 2017; Capano 2011; Capano and Jarvis 2020; De Boer and Van Vught 2015; Gornitzka et al 2005; Huisman 2009). Regulation in HE is predominantly understood in terms of government intervention. There is the Anglo-Saxon world on one-side, where despite a historical tradition of autonomy, governments intervene significantly in HE sector (Schuetze et al 2012, Capano 2015), including in US (El-Khawas 2005, McLendon & Hearn 2009), Canada (Jones 2012), Australia (Pick 2006); and several other jurisdictions. On the other hand, there are countries, where governments prefer a distant monitoring (Lazzaretti & Tavoletti 2006; Huisman 2009), like in western Europe (Paradeise et al. 2009; Capano 2011; Capano & Regini 2014). Since HEIs in developing countries are poor carbon copies of their western counterparts, this is also what we observe in the erstwhile colonies. This distinction observed through extent of government intervention is not only overly simplistic and general but also too binary to create ideas for innovative reforms.

There has been occasional interest in the HE-literature through the lens of New Public Management too (Beliklie 2018, Ferlie et al 2008) although it has not been developed as extensively. Anxieties with respect to rising neoliberal tendencies of HE-governance has also been recognized (Olssen and Peters 2005; Marginson 2009), but even these remain for want of more technical treatment. The recent data-based analysis of European universities' policy trajectories by Capano and Pritoni (2019; 2020) is an admirable effort. But by and large, the field suffers from disappointing scholarly silence.

This may be because of two reasons. *Firstly,* regulation as a concept is traditionally applied on private, for-profit organizations, but universities in many countries are public in nature and non-profit. *Secondly,* the philosophy of any HE organization is predicated on the idea of academic freedom and functional autonomy, while regulation does exactly the opposite (Enders et al 2013, Christensen 2011).

The first reason no longer holds. The overwhelming mushrooming of private universities across the world, particularly in developing countries makes the issue rather urgent (Varghese 2004, Altbach et al 2019, Evans et al 2020). Further, regulation can very well be applied for non-profit organizations (Prakash and Gugerty 2010) so even that skepticism is unfounded. In fact, precisely because universities want autonomies and regulation restrict them, there is all the more merit in examining the tradeoffs. In fact, this very dichotomy between autonomy versus control (freedom versus regulation or state versus civil society) is the very reason the HE-regulatory discourse in inadequate to explain the changing HE-landscape today (Moja et al 1996). A more nuanced approach here can help enrich not only the discourse around regulating an organization with social objectives but also around regulation itself.

2.1. Defining 'Regulation'

To begin thinking about HE regulation, one needs a crystallized understanding of what is regulation to begin with. The effort has been going on for a while. Despite the fact that a precise definition is missing, scholars have made sincere efforts in this direction (Baldwin et. al. 1998; Baldwin et al 2012; Jordana and Levi-Faur 2004; Parker and Braithwaite 2005; Morgan and Yeung 2007; Levi-Faur 2011; Lodge and Wegrich 2012). Mitnick (1980, p. 2) had drawn our attention to the idea of regulation as an *'interference of some sort of activity.'* Since this could mean any activity, so Selznick (1985, p. 363) brought in the idea of control administered by government (public agency) over *'activities that are valued by the community'* (that is why criminal justice system is not regulation because crime is not valued by the community). Later, Black (2002) made the idea more specific, calling it an effort to *'alter the behaviour of others…which may involve mechanisms of standard-setting, information-gathering and behaviour modification.'* Moran (2003, p. 13) brought back the necessary generality by calling is an *'act of steering.'*

Recently, Koop and Lodge (2017) conducted a meta-analysis to synthesize the meaning of 'regulation'. Using concept analysis, they excavate commonalities in the description of regulation as mentioned in the most cited articles in various social science journals. They identify a pattern which can inform an abstract understanding of the concept. The pattern reveals that a 'prototype regulation' is an intervention which (a) is intentional and direct, (b) involves binding standard-setting, monitoring and sanctioning, and (c) exercised by public sector on economic activities of private sector actors.

We find this frame to be particularly useful for our conversation. Relying on this formulation, in order to understand regulation for HE, we will focus on standard-setting, monitoring and sanctioning efforts undertaken directly by government on private universities. Since any activity of university has economic implication, that distinction in the pattern can be ignored. This exercise also implies that the regulation of HE as a concept must focus on private universities alone. Problems of government universities must be tackled through a separate conceptual framework, perhaps by invoking New Public Management. Further, by circumscribing our understanding of HE-regulation in this manner, we arrest the potential confusion often arising between management and regulation of HE.

How can one go about carving out a framework that allows some understanding on 'how' to regulate HE? One way is to draw upon categories and taxonomies that go beyond simple framework of high-low government intervention and see if they can illuminate traditional understanding of HE's regulation. As a preliminary starting point, a taxonomy of regulatory framework types can be worthwhile. Gilad's (2010) formulation in this regard has been fairly comprehensive and also succinct. According to that framework, regulation can be broadly categorized as (a) prescriptive, (b) outcome-oriented, and (c) process-oriented. We discuss each of them in turn.

Prescriptive regulation is the traditional form of regulation itself. That is how regulation in its most basic essence is visualized. The regulator prescribes the input action of the regulatee and the latter is expected to comply with the prescribed actions. By definition, such prescriptions need to be spelt out in specific details, and adherence is strict. For instance, in case of information disclosure in a bank, the regulator may not just expect banks to inform their clients of some deal, but also give them (or approve) a detailed set of documents that the banks should use when engaging with a client. In HE, one could argue that laying out the duty of the Senate in detail could be one example.

Under prescriptive regulation, since the regulator is focused on actions, all the regulatee needs to do is to comply with the action and not the regulatory result. But this also means regulators are confident that the said prescriptions will lead to the desired outcomes. This will work only when the organizations are homogeneous, work in a systematic fashion with few instances of governance surprises and are involved in offering standardized products or services. That is why, despite the overwhelming presence of prescriptive regulations in many countries, this approach has severe limitations in securing desired results for specific, individual situations. Given the real world's complexity, it is unable to manage heterogenous and dynamic systems at work, often resulting in excessive or insufficient levels of regulation (Sunstein 1995, Black 1997). Prescriptive regulation works if there is low likelihood of noncompliant organizations to emerge in the sector (Gilad 2010). Indeed, it will also need the regulator to possess almost complete information about the organization's compliance and also its functional features. The one factor regulator is not concerned, is that of performance. Since one does not need to estimate the performance, one can do so with weak regulatory capacity as long as the rule-book is in place. Further, prescriptions create rigidities, which dilute regulatory learning. Consequently, this approach does not allow regulator or regulatee to innovate. In fact, the same rigidity allows considerable avenues for rent seeking.

Outcome-oriented regulation – as the name suggests – focuses on specifying regulatory outcomes and goals that the regulatee must strive for. These goals can be as specific as pollution emission standards or be as vague in objectives like the full information disclosure guideline. In that sense, one may subdivide outcome-oriented regulation into vague-outcome-oriented regulation and specific-outcome oriented regulation. While this distinction is not found in the literature, we believe it is particularly pertinent in cases of HE regulation because of the nature of industry itself. HE sector serves multiple objectives and regulatory designs can easily be seen to jostle against multiple such parameters. Many of the performance attributes of HE institutions are intangible in nature, and therefore even for an informed regulatory agency, it is difficult to set a specific regulatory goal against it.

Outcome-oriented regulations make sense if the regulator is dealing with heterogeneous organizations in dynamic settings, when it can observe and has access to organization's performance, and more importantly, when the output is a good measure of regulatory performance (Coglianese and Lazer 2003). This is similar to what some scholars call 'performance-based' regulation (Gunningham 1999, May 2003, Coglianese and Lazer 2003) or 'standards-based' regulation (Kaplow 1992, Braithwaite and Braithwaite 1995, Black 1997). When the latter, it is the standard for outcomes rather than prescriptive standards for input actions that is of interest. This approach to regulation also requires that both regulator and regulatee have reasonable understanding of which outcomes can be linked to regulatory performance. But depending upon if the outcomes are vague or specific, requirements and consequences change. For instance, if the outcomes are vaguely specified, the need for regulatory capacity is high, although regulatory rent seeking will also increase (opposite for specific outcomes). At the same time, regulatee and regulators can innovate better in the case when outcomes are vaguely constructed.

Finally, we have the process-oriented regulation. Such type has been invoked through a number of other nomenclatures. For instance, it is similar to what Ayres and Braithwaite (1992) discussed under 'enforced self-regulation', in which the organizations devised their own rules guided by regulatory goals, and regulators examine their compliance with their own internal rules. A similarity is drawn by Gilad (2010) with what is known as 'management-based regulation' (Coglianese and Lazer 2003, Bennear 2006) and meta-regulation (Gilad 2010, Parker 2002). In management-based approach, regulators develop criteria which the regulatees can use to evolve their own set of understanding about their potential failure in achieving regulatory objectives. Regulators also keep an eye on the regulatees' self-installed provision to arrest such derailments. In meta-regulation, organizations are expected to not only devise internal systems of control and monitoring, but also continuously evaluate the efficacy of these internal systems to improve them – some form of double loop learning (Gilad 2010). In that sense, meta-regulation poses considerable requirement for learning and responding to the organizations themselves.

Overall, process-based regulation specifies processes and mechanisms that must be undertaken which identify and control risks/harms within an organization. So, it is like telling organizations to tell themselves about risks and their control, and auditing if they are really installing mechanisms to identify and arrest risks. These approaches become useful when organizations are heterogeneous or dynamic in nature, and when outcome definition is not possible. But indeed, regulators need to have huge capacity to evaluate link between organizations' internal controls and systems and their impact on the desired regulatory outcomes. There will be some indications of rent seeking here but regulatory innovation will be high.

As Gilad (2010) shows, process-oriented efforts have been documented in cases of food safety in US where regulatees are required to analyze the risk of their food processing processes and set their thresholds to minimize it (Coglianese and Lazer 2003). Australian law firms where the regulators expected them to adopt appropriate management systems to self-assess themselves and reduce complaints is another example (Parker 2010). Even in mining industry in Australia industry safety was also enforced to be self-regulated upon the mining industry (Gunningham and Sinclair 2009). Airport security regulations, financial reporting regulations and any industry where vast uncertainty, dynamism and specific-information models exists, will be natural attractors for this type of regulation.

We engage with the three approaches here and attempt to show how can this orientation be applied to HE-regulation. This paper does not make a claim that Gilad's categorization is the most appropriate. Instead, it opens the discourse on how forms of regulatory categorization can help think about the issue. We use the case of HE sector in India to suggest the possible direction this approach can take.

3. Indian HE, and role of Regulation

By sheer numbers, India presents a massive laboratory for regulatory reforms in HE. In 2020, there were 38+ million students enrolled in 42,000+ colleges across 1000+ colleges in India, with an enrolment ratio of 27.1 (AISHE, 2020). From 2000-01, the 8% enrolment ratio, 254 universities and 10,000+ colleges (MHRD 2011) the rise has been rapid (Varghese 2015).

This meteoric rise has been a result of massive privatization of HE in India. More than 2/3 of Indian students go to private institutions (39% of universities and 78% of colleges being private) (AISHE 2020). Yet, despite its dominance, the emergence of private universities in India since the 1990s is not accompanied by rise in quality and excellence in higher education; in fact quite the contrary (Mehta and Kapur 2004,Varghese 2013, 2015, Agarwal 2009). The rise in HEIs has not been accompanied by any careful thinking or foresight on part of the government (Tilak 2018, 2004). In fact, in the initial days, it wasn't clear if the private HE institutions should be allowed to make profits. Even in the judiciary, considerable confusion prevailed between the terms profits, surplus, exorbitant profits bringing judicial 'ambivalence' in the centre of such debates (Kumar 2003). Finally, the sector was cleared to have a non-profit character (Tilak 2005) even though vast majority of these institutions siphon off huge money through unaccounted means (Nagarajan 2019). Some clarity has been afforded by the Supreme Court in a series of cases, but a robust administrative design and policy is missing.

The regulatory design and priorities for private HE today has been a maze of bewildering apparatuses, entirely unsatisfactory in fulfilling its role (Tilak 2014, Varghese 2015, Shah 2015, Varghese and Malik 2016). The apex regulatory body for HE in India is University Grants Commission (UGC) which was set up in 1956, primarily for standard-setting and giving financial grants to universities. In addition to UGC, there are more than 15 governmental councils on disciplines which regulate the courses and manage the programmes run by the universities (for instance, Medical Council of India regulates HE in medicine category, Bar Council of India regulates law schools, and so on). There are two accrediting bodies namely National Assessment and Accreditation Council (NAAC) and National Board of Accreditation (NBA). Each of these bodies have detailed sets of prescriptions, often operating in their own realms. The multiplicity of regulatory bodies, their overlapping functions and changing rules and creates deep regulatory confusion (Shah 2015).

Further, in India, both the centre and the state can legislate on education sector. Many states have their respective state private university acts, through which private universities can be established in these states. These acts are often inconsistent with each other. Then there is this issue of congruence between university acts and UGC regulations. For instance, in 2005, the Supreme Court rescinded the Chhattisgarh state's private university act because it did not follow the regulations stipulated by UGC in 2003. More than hundred universities established in the state between 2002 and 2005 were ordered to be closed. The regulatory response has been more regulation, often with competing priorities and interests leading to even more confusion and policy paralysis (Sudarshan and Subramanian 2012, Kapur and Mehta 2004, Shah 2015, Qamar 2020).

As a result, the goals of quality, excellence and access remains abysmal (Varghese and Malik 2016, Kapur 2012, Nayak 2014, Agarwal 2009, Varghese et al 2017, Kumar 2018, Kumar 2018). Barring a select handful, no Indian university features in the global ranking of universities' lists, in even the top 500.

4. Applying the regulatory taxonomy to Indian HE

One way to evaluate the regulatory framework of Indian HE is to locate it against Gilad's taxonomical framework and understand the various types of regulatory designs it is made up of. Since prescriptive, outcome-oriented and process-oriented categories are not too general to ignore the various layers and nuances prevalent in the HE landscape in a country, nor are they too specific to lose out on the generality of its application, this can be a worthwhile approach. We will make judgments about how Indian HE is perceived regulatorily and slot it in one of the categories. While it looks simplistic, it is the depth of understanding of the sector that will make the insights rich. Note that the task here will not be whether our assessment of Indian HE is accurate or objective (HE scholars can enrich various layers therein in future work). The task is to evolve an approach to find regulatory rubric for HE in a country (like India). Once we have done so, it is easy to identify the gaps against a normative framework that can be separately evolved. In other words, HE scholars need to distil how should the regulation of HE look like normatively. Then, our approach can spell out the gaps, and where is a policy intervention required.

We will do our analysis in two steps. In the first step, we will pick specific HE statute(s) in India and have them passed through Gilad's (2010) taxonomic sieve. In the second step, we look at the overall architecture of HE regulation of India, and draw our judgments about the state of HE regulation from the literature. In other words, here, we go to a large scale insights of Indian HE sector, and have them pass through the same sieve. Both results can be independently understood, and also read simultaneously. We will attempt to do both.

4.1. Indian HE regulation: Specific

For the purposes of experimenting with the approach, we will pick up two private university statutes in India. As discussed, private universities comprise of more than ¾ of all Indian universities today, and it is hard to look at the future of Indian HE without considering the dominant role of private universities playing in it (Varghese and Malik 2020, Tilak 2018). It is important to understand how are private universities in India regulated specifically.

All universities in India are statutory bodies, namely, their establishment originates in an Act passed either in the Parliament or in the State Legislature (India has a quasi-federal structure, where provinces (states) have their own Parliaments called Vidhan Sabha, or State Legislatures). There is one more way to establish a university, namely through the deemed university route, in which the government, through the UGC accords a university status to that HEI which is found to be working with very high standards of quality and work. This route however has been criticized frequently and government has been very reluctant to grant 'deemed to be university' status to HEIs of late. For practical purposes therefore, universities are statutorily constructed. So for instance University of Delhi (a prominent central government university) was established through Delhi University Act 1922. The Guru Gobind Singh Indraprastha University (a prominent Delhi state government university) was established through Guru Gobind Singh Indraprastha University Act 2008.

For private university, the states can either have an overarching State Private University Act, under which, through successive amendments, new universities are added up, or each university can be established as standalone legislations that are passed in the State Legislature. Even in the latter case, the private university's statute does not differ significantly from the state's private university general Act. The private university's Act is then followed by First Statute, and/or Ordinance to get into finer details on university's regulations. For instance, the First Statute will define exact role of the Vice Chancellor, or details on student admissions. The Acts are supposed to offer broad, structural rubrics of the most important building blocks of the University.

A typical private university Act comprises of definitions, establishment clauses, objectives, powers and functions of the university, requirements for setting up a university and the process thereof, officers of the university (chancellors, vice chancellors, registrars etc.), authorities of the university (governing body, board of management, academic council etc.), procedure for promulgating statutes and ordinances, general regulations, funds of the university and accounts/audit considerations, dissolution of the university, and miscellaneous provisions. Going through these statutes can therefore allow a deeper understanding of regulatory attitude that Indian universities are subjected to.

We selected the private university acts of two large and populous Indian states, namely Gujarat and Rajasthan, which have the largest number of private universities in any Indian state (50 and 52 respectively). We examine each section of their statutes, one by one, namely the Gujarat Private University Act 2009 and Rajasthan Private University Act 2005, and identify the regulatory design underlying against them. We divide these sections under some broad clause-categories. These clauses are then seen through Gilad's (2010) framework to get a sense of whether the clauses are prescriptive, outcome oriented of process oriented. This yields a bigger picture about India's HE regulatory frameworks. Typically, each private university act in Indian states can be divided into these very clause-categories, with each containing several sections. Discussing these clauses for the two states will offer a fairly general impression of private university regulation across India as a whole. The idea here is, in addition to deep diving in Indian regulatory framework, to evolve an approach of undertaking a regulatory analysis in higher education.

Table 1 is illustrative; the overall architecture of the university statutes in India is overwhelmingly prescriptive in nature. It is interesting to note, that even something like 'Objectives' of a University, the regulatory attitude is prescriptive, with no expectations on outcomes or self-installed processes by the University.

4.2. Indian Higher Education: General

One wonders if this approach can be generalized to a greater degree. Surely, if the clauses of private university acts can be called as isomorphic in some sense, the general regulatory attitude in Indian higher education would also be carrying similar patterns. In other words, can we not extend this analysis from specific statutes to a more generic and prevailing discourse that explains the large-scale insights of Indian higher education? If we can generalize that the private university acts of the states of Gujarat and Rajasthan are predominantly prescriptive, can we not say the same thing about the overall architecture of Indian higher education? We think this is indeed possible. Gilad's (2010) formulation can surely work for specific legislative text, but should also be applicable across a discourse. Put differently, just like a statute can be categorized as prescriptive, one should be able to make such a claim about the regulatory framework of the entire industry too.

This is a question tackling multiple layers, and will require a much larger research project to be undertaken. At this stage, we rely on studying the relevant literature extensively and drawing out the prevalent discourse. We start by identifying the factors that explain Gilad's (2010) formulation, and then from the literature, attempt to map the factor for Indian higher education regulatory landscape, and then offer the preferred mode based on the formulation. For instance, the organization-type is an important factor in the framework. If the organizations are fairly homogenous, one would prefer prescriptive regulation. Literature indicates that Indian universities (organizations in question) are fairly diverse, thus calling for an outcome or process-oriented regulation. Further, if the HE sector in India operates under uncertainty (perhaps as anywhere else given the pressures of technology and cultural diversities) comprised of heterogeneity, dynamic, then outcome-oriented regulation or process-oriented regulation is more appropriate.

We see the results in Table 2. In general, it appears that higher education regulatory attitude in India should be outcome oriented or process based. This may vary from university to university, but a large-scale insight here is instructive. Note that there are various design features of HE regulation in India which can be classified under process-oriented regulation, even though more closely aligned with management-based-regulation rather than meta-regulation. These would include regulators' emphasis on criteria for selecting students, examination and assessment, ensuring an appreciable faculty-student ratio, sometimes perhaps faculty recruitment, for example. One also needs to see whether and to what extent is the outcome-oriented regulation vague, and/or specific. Similarly, the high stress on the regulator to gathering information of performance of the HE institutions in India (given the large size) indicate the suitability of process-oriented regulation, since this type of regulation does not impose heavy regulatory burden on the regulator. Similarly, if the need for regulators' innovation and learning curve is high (which we believe is, given the changing dynamics of HE landscape in India), then process-based and outcome-oriented regulations will suit best.

5. Discussion

Regulation in HE needs to recognize that universities are diverse in every sense of the word (more so in India where a boundless cultural diversity alloys with respective university goals). HE institutions respond to their local conditions and demands, operate on varying levels of budget and carry a plurality of responsibilities. Modern, aspirational and younger universities sit alongside the traditional, older ones and despite similar purpose, their specific goals and targets are very different. Moreover, the regulatory body for HEIs recently introduced the "University Grants Commission (UGC) Regulations, 2023," aimed at overseeing the establishment and functioning of Foreign Higher Educational Institutions (FHEIs) in India. This further calls for a nuanced and layered understanding of HE sectoral regulation for India. Prescriptive, handholding regulations meant for some also need to give way to recognition of agile, adaptable and innovative rules that govern many other universities. This implies that regulatory frameworks for a university must be capable of absorbing a range of diverse priorities universities have in India. In some sense, this calls for process oriented and the outcome-oriented regulation to step in.

The three categories are not watertight at all, and same organizational features can function under all three types of regulations depending on which level of the organization are we looking at. The overall evaluative framework for regulation of HEs allows us to do a categorization of any HE regulatory approach, synthesized in Table 1 and 2 using Indian HE as an illustrative case. A combination of these factors can be organized alongside the existing ones to make the analysis richer. Once the characteristic factors are decided, the subsequent regulatory approach appears on its own.
It is frankly, not important whether we have identified the characteristics of Indian HE appropriately. This is indeed where the HE scholars can come in, as this offers a meaningful space for collaboration between HE scholars and regulation experts. But what is important is that once the characteristics of a society's HE institutions and landscape is adequately captured, one can begin deducing the approach of regulation one is implementing or one ought to implement. For instance, based on our own assessment of Indian HE, the general impression is that characteristics of Indian HE demands outcome and/or process-based regulations as the most effective regulatory approaches. As the constructs of Indian HE institutions change, the consequent policy approach desired will also need to change. The model is dynamic.

The idea to use Gilad's (2010) formulation is a useful entry point to bring in HE and regulation scholars on the same table. Surely, this may translate into another set of categorizations, for instance, procedural and substantive regulation (McLendon 2003, Ogus 2004). The idea was to introduce a useful approach in this interdisciplinary field of inquiry and any other category of regulatory framework should suffice. Gilad's (2010) work is perceptive and somehow exhaustive enough to be able to capture the nuances in HE. If in the spirit of taking a more dynamic view of regulation as emphasized by Jordana and Levi-Faur (2004), we take Dassler's (2006) call for intertwining regulatory intervention with regulatory governance seriously, then this may well be a valuable effort.

6. Conclusion

HE sectors in most part of Global South are characterized by institutionalized mediocrity. In attempting to unravel the causes for the malaise, one is confronted with a vastly overwhelming paths of regulatory prescriptions in the country, often credited to be sourced in colonial governance. In an attempt to understand this regulatory maze, we realized that HE regulations are often characterized by a lack of sincere effort in understanding regulatory characteristics and design philosophies, because the discourse is dominated heavily by HE-scholars rather than regulation-scholars. This article is an attempt to fill this gap, and hopefully to trigger an interest of regulation scholars towards HE.

We picked up a neat definition of regulation to begin with. We drew upon a prominent taxonomic approach to categorize different types of regulatory framework. By sweeping through the experience and structure of Indian HE regulation experience, we were able to identify the desired strategy of approach. For India, our preliminary findings suggest that outcome based and process based regulatory approaches will work most appropriately, even though the regulatory architecture in HE is dominated by prescriptive regulations.

Several limitations remain. While the formulation of the approach in the categories of prescriptive, outcome-oriented and process-oriented seemed meaningful to us, other scholars may find alternative approaches more useful. That is indeed welcome. For us, the contribution of the article does not lie as much in our understanding of a country's HE regulation (India in this case), but in proposing an approach for helping in that understanding. Further, we have used a very specific definition of 'regulation' and avoided the whole gamut of regulatory issues that the government universities go through. The dynamically changing meaning and characteristics of regulation (Jordana and Levi-Faur 2004) necessitate that the scope of this work must expand. Finally, our inferences on what India HE regulatory architecture looks like needs to be complemented by more surveys, meta-analysis of literature and more HE experts writing about it.

With an ever increasing numbers of private HE institutions, and the increasing noise from these institutions demanding higher levels of autonomy, the scope is considerable. Rise of online education owing to the Covid-19 pandemic has also push for institutional reforms and rejigging regulatory frameworks in many countries, including in India. The traditional models of understanding regulation will need new approaches. It is here that the intersection of regulatory and HE experts will be most productive.

7. References

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8. Tables & Figures

Table 1: Regulatory taxonomy (Gilad, 2010) applied in Indian context, for two states' private university regulations.

Clauses	**Gujarat**	**Rajasthan**
Establishment	Prescriptive	Prescriptive
University to be self-financed	Outcome oriented	Outcome oriented
Objectives[a]	Prescriptive	Prescriptive

Clauses	Gujarat	Rajasthan
Powers & Functions	Prescriptive largely[b]	Prescriptive (captured under the Objectives)
Requirement for setting up the University	Prescriptive	Prescriptive
Affiliating/Setting up colleges	Process oriented	Prescriptive
Officers of the University	Prescriptive/Process Oriented	Prescriptive/Process Oriented
Authorities of the University	Prescriptive/Process Oriented	Prescriptive/Process Oriented
Statutes and Ordinances[g]	Prescriptive	Prescriptive
Committees	Process oriented	Process oriented
Accreditation	Outcome oriented	Outcome oriented
Funds of the University[j]	Prescriptive	Prescriptive
Dissolution of the University	Prescriptive	Prescriptive
General Provisions	Prescriptive	Prescriptive
Admissions	Prescriptive	Prescriptive
Fee	Prescriptive/Process Oriented	Prescriptive/Process Oriented

[a] *Barring 5% of the clauses in this section, all the others are prescriptive in nature.*

[b] *Of the 38 clauses, two (concerning discipline and expenses) are process-oriented, the others are prescriptive.*

[g] *While the clauses give Universities freedom to make their own statutes and ordinances, all these documents have to be approved by the government.*

[j] *The audit requirement here is process oriented (which is obvious).*

Table 2: Indicative Typologies of regulation of higher education in India

		Regulatory Mode					
	Factors	**Prescriptive**	**Outcome-oriented**	**Process-oriented**	**Indian HE State**	**Description if the state of Indian HE**	**Preferred mode of Regulation, as contributed by the Factor[a]**
Characteristics	Emphasis	Action	Results	Self-governed processes	Action	Rigid regulations, with focus on action (Kumar 2018, Varghese and Malik 2016, 2020 Agarwal 2006, 2009)	Outcome and Process
	Nature of rules	Specific	Output	Design	Specific	Laws remain very specific and detailed (Shah 2015, Kumar 2018, Varghese and Malik 2016)	Output and Design
	Regulatory intervention	Ex ante	Ex post	Ex ante and ex post	Ex ante and ex post	Depending upon the type of university, it varies (Shah 2015, Goyal 2019, Varghese and Malik 2016)	All three
Conditions	Market/environmental uncertainty	Low	Low	High	High	Markets and priorities changing at rapid pace (Kapur 2012, Kumar 2018, Kumar 2017, Varghese and Malik 2016, Tilak 2018)	Outcome /Process
	Organization's type	Homogeneous	Heterogeneous	Heterogeneous	Heterogeneous	Universities and colleges are hugely diverse (Kapur 2012, Kumar 2018, Varghese and Malik 2016, 2020)	Outcome /Process
	Organizational State	Static	Dynamic	Dynamic	Dynamic	HE is dynamic in nature (Kumar 2018, Varghese and Malik 2016, Tilak 2018)	Outcome /Process
	Organizational information with regulator	High	High	Low	Low	Regulator has low information (Shah 2015, Varghese and Malik 2020)	Outcome /Process
	Regulatory capacity	Low	Low	High	Low	Indian regulatory capacity is weak (Shah 2015, Varghese and Malik 2016, 2020, Agarwal 2006, Goyal 2019)	Outcome /Process
	Frequency of rule adaptation	Low	High	Low/High	Low	Changing HE rules is not so easy nor desirable (Shah 2015, Varghese and Malik 2016)	Outcome /Process
Consequences	Burden of gathering compliance information	High	Low	Low/High	High	The HE sector in India is large, and hence burden is high (Shah 2015, Agarwal 2009, Varghese and Malik 2020)	Process
	Burden of gathering performance information	Low	High	Low/High	Low	It is easier to fill in outcome variables through AISHE (Shah 2015, Agarwal 2006, 2009)	Process

		Regulatory Mode					
	Factors	**Prescriptive**	**Outcome-oriented**	**Process-oriented**	**Indian HE State**	**Description if the state of Indian HE**	**Preferred mode of Regulation, as contributed by the Factor[a]**
Consequences	Regulator's Learning	Low	Low	High	Low	There is little learning across HE regulatory bodies which is staffed with bureaucrats and not academics generally (Shah 2015, Goyal 2019, Agarwal 2006, 2009)	Process
	Regulator's rent seeking	High	Low/High	Low	High	HE in India has high rent seeking (Kapur 2012, Shah 2015, Goyal 2019, Varghese and Malik 2016, 2020)	Outcome
	Regulatee's capacity to innovate	Low	Low/High	High	Low	Regulatees must be allowed to constantly innovate (Kumar 2018, Agarwal 2006, Kumaer 2017, Tilak 2018)	Outcome, Process
	Regulatee's commitment to regulation	Low	Low	High	High	HE requires regulatees to be committed to regulation; also have some self-regulation (Kapur 2012, Agarwal 2009, Kumar 2017, Kumar 2018, Tilak 2018)	Process
	Regulatee's autonomy	Low	High	High	Low	HE demands high levels of autonomy (Agarwal 2009, Kapur 2012, Kumar 2017, Kumar 2018, Tilak 2018)	Outcome /Process

Notes: Select chapters from the books referred here: Varghese and Malik (2016, 2020), Kumar (2018), Tilak (2018).

[a] *Preferred Mode is merely only indicative and does not purport to make a defensible claim.*

Population Ageing in India: Assessing Inter-State Variations

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Abstract

With the rapid decline in fertility and improving life expectancy at all ages in India, ageing populations are projected to increase substantially in the future. Given India's rapidly growing population, this translates into a large number of elderly individuals in terms of absolute numbers. Further, due to substantial variations in economic growth, income and wealth distribution, health infrastructure as well as the pace of the demographic transition across Indian states, understanding the differentials in population ageing across states becomes imperative for targeted resource allocation from a policy perspective. This study used data obtained from secondary sources such as the Census of India, Sample Registration System, and the United Nations World Population Prospects (2015 Revision) to provide a comprehensive overview of the trends and variations in population ageing across Indian states over the years using a range of indicators. The findings revealed a relatively higher proportion of elderly populations in southern states with Kerala reporting the highest proportion of elderly population, old age dependency, median age as well as life expectancy (at birth and old age). This is followed by other southern states and Punjab, Maharashtra and Odisha. In contrast, Uttar Pradesh, Rajasthan and Madhya Pradesh reported the biggest lags in experiencing bulging elderly populations. Findings also indicated an increase in the range (highest minus lowest) of elderly share in the total population implying significant differences in the timings at which states will experience a bulge in their old age populations.

1. Introduction

According to United Nations (World Population Prospects 2017), the share of elderly population (60+ years) in India has increased from 5.4% in 1950 to about 9% in 2015 and is further projected to cross 20% in 2050 and 34% by the end of this century. Although India does not fit into the United Nations' definition of ageing countries (above 11%) with its current proportion of elderly (9%), having the second highest population base in the world, the estimated number of old people in India is about 103 million (Census of India, 2011). This is further projected to increase manifold in the future. With the rapid decline in fertility and persistent increase in longevity at all ages, the absolute figures for old age population (330 million) will outnumber the child population (326 million) by 2050 (UNWPP, 2017). Given the intrinsic demographic differentials across Indian states, the timing and pace of population ageing, its implications are also expected to vary across regions (Subaiya & Bansod, 2011; Visaria, 2001).

Existing studies have assessed the variations in the fertility and mortality transition across states in India (Alagarajan, 2003; Alagarajan & Kulkarni, 1998; Bongaarts, 2003; Casterline, 2001; Guilmoto & Rajan, 2001). In addition, there are widely known and acceptable differences across states in terms of economic growth, income and wealth distribution, poverty and deprivation, literacy and educational levels, employment levels, nutritional status and health infrastructure (Deaton & Dreeze, 2002, 2009; Jayaraj & Subramanian, 2015; Navaneetham, Mishra, & Joe, 2008; Sen, 1972, 1973). Additionally, the pace of change in the age structure of the population – the phenomenon commonly known as demographic transition – also varies substantially across states (Goli & Arokiasamy, 2013; Lee & Reher, 2011). Recent studies have also proposed a novel method to measure the pace of population ageing termed "Prospective measures of ageing" (or characteristics-based ageing measures) (Sanderson & Scherbov, 2010, 2013, 2015). With the valid argument that the age-specific characteristics of the population tend to change overtime, they asserted that being young and old are relative notions and therefore the threshold for old age should be determined based on certain health characteristics (like blood pressure) rather than chronological age. Besides, they further argued that conventional measures of ageing (mainly the proportion of elderly (65+ years) in total population) are solely based on number of years already lived (i.e., retrospective phenomenon) which can potentially ignore the overtime improvements in the length of life.

However, there is a dearth of studies on understanding the variations in the pace of population ageing across Indian states using recent data. A thorough understanding on the interstate variations in population ageing can offer valuable insights for effective allocation and distribution of resources primarily from the targeting perspective. Therefore, this study aims to understand the differentials in population ageing across major states in India via examining conventional measures of ageing. The study also attempts to understand the current and future policy implications of interstate variations in ageing indicators.

2. Data and Methodology

Data

The present analysis is based on data obtained from secondary sources including Census of India, Sample Registration System and United Nation's World Population Prospects (UNWPP) (2015 revision). To understand the overtime trends and interstate variations in various ageing indicators across Indian states, this study focuses on 15 major states (Andhra Pradesh, Assam, Bihar, Gujarat, Haryana, Karnataka, Kerala, Maharashtra, Madhya Pradesh, Odisha, Punjab, Rajasthan, Tamil Nadu, Uttar Pradesh and West Bengal) which comprise about three-fourth of the Indian Population. The data from Census is available on decadal basis; mainly for five time points i.e., 1971, 1981, 1991, 2001 and 2011. Further, Census projections based on 2001 population (as base years) are available on five-yearly basis up to 2026. The data on projected life expectancy and age specific population for India has been taken from UN World Population Prospects (2015th Revision) on five-yearly basis for the period of 1950 to 2100. Further, information on life expectancy (five yearly moving average) is taken from SRS (Sample Registration System) abridged life tables from 1970-75 to 2011-15. It is also to be noted that the Census wasn't conducted in Bihar and Assam in 1981.

3. Outcomes

To understand the trends and variations in population ageing across Indian states, this study focuses on a range of demographic indicators including age-specific population growth rate, age composition of population (proportion of elderly and very elderly population i.e., 60+ years and 70+ years), old age dependency ratios, median age, and life expectancy (at birth, at 60 years, and at 70 years).

4. Analysis

The overtime trajectory in ageing indicators across major Indian states and regions is presented through simple cross tables and bar graphs along with differences between highest and lowest observations. Further, box-and-whisker plots are used to further the understanding on the variations in population ageing across Indian states for different time-points. Box plots are non-parametric and are used to display variations in samples of a statistical population through quartiles. The line inside the box shows median of the population. The size of the boxes reflects the variations across the populations and tails at the top and bottom of boxes show the range or skewness in the population. The position of the boxes in the plot region shows the range of sample overtime. This section is followed by the results describing the trends and variations in each indicator.

5. Results

Elderly Population in India

The growth rate of population by broad age groups for India is presented in Table 1. While there is substantial increase in the share of adult and elderly population, the growth rate of child population has been declining in India since 1971. It can be observed from the table that the growth rate of elderly cohort is highest across all age groups. For instance, the decadal growth rate of elderly population in India has increased from 32.3% in 1971 to 35.5% in 2011. Similarly, the decadal growth rate of adult (15-59) population has also increased from 21.8% to about 25% during the period 1971 to 2011. However, since 1991 the growth has been declining from 29.6% in 1991 to 25.9% in 2001. Contrastingly, the decadal growth in child population has declined substantially from 27.9% to just 0.4% between 1971 and 2011. Since last decade, only elderly population have experienced higher growth rate in 2011 as compared to child and adult population.

Figure 1 shows the percentage share of elderly group in total population by regional zones in India for 2011. In 1981, the share of elderly population was highest (6.87%) in the northern region. According to Census 2011, the proportion of elderly are clearly highest in the southern zone with total share of 10.25% in population. This is followed by western zone with second highest share (8.71%) of elderly in total population. Importantly, relative growth in the share of elderly population have been consistently higher among southern states compared to other regions. Central and north zones have relatively lower proportion of elderly in their state.

Further, Figure 2 depicts the percentage distribution of elderly population across major regions in India for 2011. The estimates from Census 2011 data clearly display that more than a quarter of total elderly population in India are agglomerated in southern states. However, contrary to expectations, northern states also have more than one fifth of total elderly population. Besides, the share of western zone in India's total elderly population is about 20.59% in 2011.

Table 2 shows proportion of old age (60+ years) population for selected Indian states from 1981 to 2011. According to the Census 2011 estimates, about 12.57% of total population in Kerala is old (60+ years) and has the highest proportion of elderly population. In addition to this, the proportion of elderly cohort is significantly high in Tamil Nadu (10.42%), Punjab (10.35%), Himachal

Pradesh (10.26%) and Andhra Pradesh (9.88%). On the contrary, the share of elderly population in 2011 is much lower in Arunachal Pradesh (4.60%), and Assam (6.66%). Interestingly, the proportion of old age population in Uttar Pradesh is about 8% in 2011.

Kerala has experienced highest increase in the share of old age population of about 5 percentage points (7.51% to 12.57%) between 1981 and 2011 (Table 2). However, most-part of this increase in Kerala is experienced between 2001 and 2011. In addition to this, substantial rise in the old age population can be observed in Tamil Nadu (4.01 percentage points), and Maharashtra (3.53 percentage points).

However, most of the states have experienced an increase of about 1 to 2 percentage points in the share of old age population over the last four decades. Interestingly, the difference between the state with the highest and lowest share of elderly population have increased overtime from 3.05 percentage points in 1981 to 7.97 percentage points in 2011.

The interstate variations in the share of child population (0-14 years), adult (15-59 years) and elderly (60+ years) population is presented through box plots. Figure 3 shows the same for the child populations via box plots. It is apparent from the Figure 3 that the interstate variation in the share of child population across Indian states have increased between 1981 and 2011. Further, the median share of children in total population across states have shown a clear and substantial reduction. It can be also be observed that the skewness in the share across states have also increased overtime.

Figure 4 displays the box plots for the share of adult population across Indian states between 1981 and 2011. Clearly, the median share of adult population has increased notably from about 55% in 1981 to about 63% in 2011. Further, decrease in the size of boxes overtime clearly indicates that interstate variations in the share of adult population have decreased significantly since 1981. It may be noted that the overall share as well as variation in the share of adult population across states have been increased significantly between 1991 and 2001.

Figure 5 displays the box plots for the share of old age population across major states in India for 1981, 1991, 2001 and 2011. Unlike child and adult population, the median share of elderly cohort has increased persistently from about 6.5% in 1981 to above 9% in 2011. The increasing size of the box plots clearly suggests that interstate variations in the share of old age cohort in India has increased significantly between 1981 and 2011. However, not much change in the skewness is observed during same period of time. While the median share of elderly population has been increasing persistently since 1981, a substantial rise in the median share can be observed between 2001 and 2011.

6. Old age Dependency Ratio

The old age dependency ratios for India from 1950 to 2015 are depicted in Figure 6. Clearly, the dependency ratio for elderly has increased substantially from 9.4% in 1950 to 14.3% in 2015. A major increase in dependency ratio is evident during 2010 (12.7%) and 2015 (14.3%) indicating a higher pace of ageing in coming decades. On the other hand, Arunachal Pradesh has least proportion of dependent elderly (7.7.%) (Table 3).

Table 3 displays the dependency ratio for elderly across major states in India for 1981, 1991, 2001 and 2011. Expectedly, Kerala with the highest share of elderly population has highest elderly dependency ratio (19.6%) followed by Himachal Pradesh (16.1%) and Punjab (16.1%) in 2011. Besides, according to Census 2011, the old age dependency ratio is significantly higher for Tamil Nadu (15.8%), Maharashtra (15.7%) and Andhra Pradesh (15.4%). It is worth noting that dependency ratios for elderly is also higher for populous states like Uttar Pradesh (13.9%). Evidently, Kerala experienced highest increase in the old age dependents (6.6 percentage points) between 1981 and 2011. However, in 1981, Himachal Pradesh had the highest elderly dependency ratio of about 14.2%, which increased to about 16.1% in 2011. In addition to this, Tamil Nadu (4.9 percentage points) and Maharashtra (4.1 percentage points) have also experienced a significant in rise the elderly dependency ratio between 1981 and 2011.

7. Median Age

The estimated and projected median age for Indian states is presented in Table 4. Estimates from Census 2011 shows that the median age of population in Kerala is highest at 31.8 years followed by Tamil Nadu (31.1 years). In addition to this, median age of population in several states like Haryana, Himachal Pradesh, Odisha and Andhra Pradesh is close to 30 years. In fact, the median age of Tamil Nadu's population is notably lower than populous states like Uttar Pradesh (21.9 years).

Table 4 clearly shows that the median age across all major states in India is increasing since 2001 and is further projected to rise in coming decade as well. According to the Census projections, by 2026, the median age of population in Kerala will remain highest (37.7) in the country followed by Tamil Nadu (37.3 years). Additionally, median age of Uttar Pradesh's Population is projected to be lowest (26.9 years) across all the major states in 2026. Besides, most of the major states are projected to experience a rise in median age by about 10 years between 2001 and 2026. While the median age for several states like Kerala, Tamil Nadu, Himachal Pradesh and Andhra Pradesh is already above 35 years, states like Gujarat, Karnataka, Maharashtra, Odisha and West Bengal are their loggerheads.

8. Life Expectancy at Birth

Table 5 presents estimated and projected life expectancy at different ages for India. According to the United Nations World Population Prospects (2017 Revision) estimates, the life expectancy at birth for India has increased from 36.6 years in 1950-55 to 69.1 years in 2015-20 and is further projected to increase to 76.9 years and 84.6 years by the mid and end of this century respectively. It is however important to note that in last 60 years, life expectancy at birth in India has almost doubled.

Table 6 displays life expectancy at birth for major Indian states in India for the period of 1975-80 to 2011-15. Kerala has the highest life expectancy at birth (78.2 years) in 2011-15 at birth followed by Punjab (74.2 years). On the other hand, Uttar Pradesh has lowest life expectancy birth at 65.6 years for 2011-15.

It is evident from Table 6 that almost all the major states in the country have experienced a significant increase in the life expectancy at birth between 1975 and 2015. Demographically backward states like Uttar Pradesh have experienced highest increase (by about 52%) in life expectancy at birth from 43 years to 65.6 years between 1975 and 2015. The life expectancy at birth for Kerala has increased by about 25% from 62 years in 1970-75 to about 78.2 years in 2011-15. Besides, some southern states have experienced substantial increase in life expectancy at birth between 1975 and 2015. For instance, life expectancy at birth has increased by about 47% in Tamil Nadu and 46% in Andhra Pradesh. It can be observed from table 6 that the jump in life expectancy at birth has been highest between 2006-10 to 2011-15 across all states. It is important to mention here that demographically backward states like Uttar Pradesh have experienced highest increase (by about 52%) in life expectancy at birth from 43 years to 65.6 years between 1975 and 2015.

Evidently, the difference between the highest and lowest life expectancy at birth across states has decreased, which clearly implies that states are persistently converging in terms of longevity. For instance, Table 6 displays that the difference between the highest and lowest life expectancy for 1970-75 was about 19 years which has decreased to about 21.6 years in 2011-15. The range in life expectancy at birth across states has fallen considerably higher since 1996-2000. However, further regression analysis is required to test whether the states are converging in life expectancy after adjusting for regional heterogeneities in terms of population size, socioeconomic conditions, and human capital. It is also imperative to mention that Odisha have also shown noticeable improvements (by about 50%) in life expectancy at birth between 1970-75 and 2011-15.

Figure 7 depicts the box plots for the life expectancy at birth across major Indian states for 1981 to 2011. It is clear from the figure that the median LE at birth has increased substantially between 1975 and 2015. Besides, it is also evident from the plots that interstate variations in the life expectancy at birth is decreasing and therefore states are converging in terms of expected longevity at birth. Also, skewness and range in distribution of life expectancy at birth across states is lower in 2011-15 compared to previous years.

9. Life Expectancy at 60 (Elderly Life Expectancy)

The estimated and projected elderly life expectancy (at 60 years) for India from 1950-55 to 2095-2100 is depicted in table 5. Elderly life expectancy in India is projected to increase from 12.1 years in 1950-55 to 18.1 years in 2015-20 and further to 20.9 years and 26.7 years by the mid and end of this century respectively (Table 5). Projected increase in elderly life expectancy in India is higher for the next two to four decades.

Table 7 displays elderly life expectancy (at 60 years) for selected major Indian state for 1970-75 to 2011-15. Clearly, the life expectancy at 60 is highest for Karnataka and Kerala at 22.1 years for 2011-15 followed by Punjab (21.4 years). On the other hand, the elderly life expectancy is estimated to be lowest in Bihar at 17 years followed by Assam (17.3 years) and Uttar Pradesh (17.5 years). While the elderly life expectancy in 2011-15 is estimated to be lowest in Bihar at 17 years, it was lowest in Odisha at 11.4 years in 1970-75.

There are substantial improvements in elderly longevity across all the major states in India between 1970-75 and 2011-15 (Table 7). Interestingly, the improvements in elderly life expectancy are estimated to be highest in Odisha (by about 64%) from 11.4 years in 1970-75 to 18.7 years in 2011-15. In 1970-75, life expectancy at 60 was highest in Punjab (16.3 years) followed by Haryana (16.0 years), whereas Kerala has the highest elderly life expectancy at present. The life expectancy at 60 in populous states like Uttar Pradesh has also improved by about 28% (i.e. from 13.6 years in 1970-75 to 17.5 years in 2011-15). Besides, Gujarat has also experienced about 48% rise in elderly life expectancy between in last 4 decades. Further, it is clear from Table 7 that range of elderly life expectancy across states have decreased overtime signifying the convergence in elderly longevity across states.

To further identify the interstate variations in elderly longevity, Figure 8 displays the box plots for life expectancy at 60 across Indian states for 1970-75 to 2011-15. The decreasing area of box plots across time period indicates that states are converging in terms of elderly life expectancy. Also, it can be observed that the median life expectancy has increased significantly overtime.

10. Life Expectancy at 70 years

To further the understanding on the interstate variation in ageing prospects, it is imperative to identify the trends in longevity at very old age (70 years) (Table 8). At very old age, Kerala (14.3 years) has the highest life expectancy followed by Punjab (14.1 years) and Haryana (14 years). On the contrary, Assam (11 years) has the lowest life expectancy at 70 followed by Madhya Pradesh (11.1 years) and Uttar Pradesh (11.3 years). Surprisingly, life expectancy at 70 in Rajasthan is estimated to be high at 13.5 years.

Clearly, there is a diverging trend across states in terms of longevity at higher ages (Table 8). For instance, the difference between highest and lowest life expectancy (at 70 years) has increased from 4 years in 1970-75 to about 10.8 years in 2011-15. Further, all the major states have experienced significant improvements in the elderly longevity since 1970-75. Improvements in life expectancy at 70 are estimated to be highest in Odisha (80%) between 1970-75 and 2011-15. However, states like Gujarat (56%), Punjab (47%) and Kerala (46%) have shown noticeable increase in life expectancy at very old age between 1970-75 and 2011-15.

The box plots for life expectancy at 70 years for selected major Indian states in Figure 9 clearly show a significant increase in the median life expectancy (at very old age) in the last four decades. However, there is no evidence of clear trends in the interstate variations in the distribution of life expectancy at 70 across states between 1970-75 to 2011-15.

11. Discussion and Conclusion

The present study aims at identifying trends and trajectories in population ageing across major Indian states using secondary information on a range of demographic indicators from several sources. Additionally, the study also compiles and presents evidence for interstate variations in population ageing using a similar set of indicators. It is important to mention that the only intent of this study is to provide a comprehensive description of trends and variations in ageing indicators across states. However, a detailed analysis on demographic and social factors driving the pace of population ageing is also desirable.

The evidences clearly suggest that population ageing in southern states is relatively higher compared to other regions in India. Across all major states, Kerala has the highest proportion of elderly population, highest old age dependency ratio, median age and highest life expectancy (at birth as well as old age). Following this, Karnataka, Tamil Nadu and Andhra Pradesh also have a substantially higher share of elderly population and median age. Along with the demographically advanced states in southern India, population ageing is considerably rapid in states like Punjab, Maharashtra, and Odisha. In contrast, populous states like Uttar Pradesh, Rajasthan and Madhya Pradesh are yet to experience bulging of elderly population. However, it may be noted that the distribution of elderly population (60+ years) across Indian states shows that a large proportion of total elderly population are from the northern and eastern zones.

Importantly, the box plot suggests increasing interstate disparities in the proportion of elderly group (60+ years) in the total population. Further, the range (highest – lowest) of elderly share in the total population has also increased significantly across major states implying significant differences in timing at which states will experience a bulge in their old age populations.

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13. Tables and Figures

Table 1: Decadal Growth Rate of Population by Age Groups for India: 1971-2011

Year	0-14	15-59	60+
1971	27.91	21.81	32.34
1981	14.27	25.90	32.04
1991	18.72	29.59	31.31
2001	16.41	25.99	35.18
2011	12.43	24.66	35.53

Source: Compiled by Author from Census Rounds

Table 2: Percentage Share of Elderly (60+) for Major Indian States: 1981-2011

State	1981	1991	2001	2011
Andhra Pradesh	6.65	6.80	7.61	9.88
Arunachal Pradesh	4.76	4.37	4.55	4.60
Assam	**	5.35	5.86	6.66
Bihar	6.80	6.32	6.45	7.37
Delhi	4.49	4.68	5.20	6.84
Gujarat	4.98	6.42	6.91	7.95
Haryana	6.34	7.70	7.52	8.66
Himachal Pradesh	7.50	8.15	9.03	10.26
Karnataka	6.63	7.10	7.69	9.49
Kerala	7.51	8.84	10.48	12.57
Madhya Pradesh	6.45	6.69	7.11	7.88
Maharashtra	6.39	7.01	8.74	9.92

State	1981	1991	2001	2011
Odisha	6.39	7.24	8.27	9.52
Punjab	7.81	7.88	9.03	10.35
Rajasthan	6.03	6.31	6.78	7.49
Tamil Nadu	6.41	7.48	8.89	10.42
Uttar Pradesh	6.84	6.91	7.07	7.85
West Bengal	5.55	6.08	8.50	8.49
Range (H – L)	**3.05**	**3.51**	**5.93**	**7.97**

Source: Census of India-1981, 1991, 2001, 2011

*** Census was not conducted in Assam and J&K in 1981*

Table 3: Old Age Dependency Ratio (%) across major states, India, 1950-2015

State	1981	1991	2001	2011
Andhra Pradesh	12.1	11.9	12.6	15.4
Arunachal Pradesh	8.5	7.9	8.3	7.7
Assam	**	9.9	10.3	11.0
Bihar	13.2	12.0	12.4	13.8
Delhi	7.5	7.7	8.4	10.4
Gujarat	9.0	11.1	11.5	12.6
Haryana	12.2	14.5	13.3	14.1
Himachal Pradesh	14.2	14.5	15.1	16.1
Karnataka	12.3	12.6	12.7	14.8
Kerala	13.0	14.4	16.5	19.6
Madhya Pradesh	12.3	12.4	13.1	13.4
Maharashtra	11.6	12.2	14.8	15.7
Odisha	11.8	12.7	14.1	15.4
Punjab	14.1	13.8	15.2	16.1
Rajasthan	11.7	12.0	12.8	13.0
Tamil Nadu	10.9	12.1	13.9	15.8
Uttar Pradesh	13.3	13.2	13.6	13.9
West Bengal	10.0	10.7	11.9	13.2
Range (H – L)	**6.6**	**6.7**	**8.2**	**11.9**

*Source: Census of India-1981, 1991, 2001, 2011, ** Census was not conducted in 1981*

Table 4: Estimated and Projected Median Age for Selected Indian States

State/Year	2001	2006	2011	2016	2021	2026
Andhra Pradesh	24.2	26.0	28.0	30.1	32.3	34.6
Assam	21.3	22.8	24.5	26.5	28.6	30.8
Bihar	19.1	20.1	22.1	24.2	26.6	29.1
Delhi	23.4	25.2	27.1	28.7	30.1	31.4
Gujarat	23.6	25.3	27.2	29.1	31.3	33.3
Haryana	21.7	23.4	25.3	27.4	29.6	31.9
Himachal Pradesh	24.4	26.4	28.4	30.6	32.9	35.1
Karnataka	24.1	26.0	28.0	30.0	32.2	34.4
Kerala	28.1	29.9	31.8	33.8	35.8	37.7
Maharashtra	24.2	25.6	27.3	29.1	31.0	32.9
Madhya Pradesh	20.7	21.8	23.3	24.9	26.8	28.8
Odisha	23.9	25.4	27.2	29.1	31.3	33.6
Punjab	24.2	26.1	28.0	30.1	32.4	34.8
Rajasthan	19.9	21.3	23.0	25.0	27.2	29.5
Tamil Nadu	27.2	29.1	31.1	33.2	35.3	37.3
Uttar Pradesh	19.4	20.4	21.9	23.4	25.1	26.9
West Bengal	23.8	25.6	27.8	29.9	32.2	34.5
Range (H – L)	**9.0**	**9.7**	**10.0**	**10.4**	**10.7**	**10.8**

Source: Ministry of Health and Family Welfare, Govt of India

Table 5: Projected Life Expectancy for India: 1950-2100

Year	e_0	e_{60}	e_{80}
1950-1955	36.6	12.1	4.8
1955-1960	39.7	12.7	5.0
1960-1965	42.7	13.2	5.3
1965-1970	46.0	13.7	5.5
1970-1975	49.4	14.2	5.6
1975-1980	52.6	14.7	5.8
1980-1985	55.0	14.7	5.8
1985-1990	56.8	14.8	5.8
1990-1995	59.2	15.5	6.1
1995-2000	61.6	16.3	6.4
2000-2005	63.6	16.7	6.6
2005-2010	65.5	17.1	6.7

Year	e_0	e_{60}	e_{80}
2010-2015	67.5	17.7	7.1
2015-2020	69.1	18.1	7.3
2020-2025	70.5	18.5	7.4
2025-2030	71.7	18.9	7.5
2030-2035	72.9	19.3	7.7
2035-2040	73.9	19.8	7.9
2040-2045	74.9	20.4	8.1
2045-2050	75.9	20.9	8.3
2050-2055	76.9	21.4	8.5
2055-2060	77.8	22.0	8.7
2060-2065	78.7	22.5	9.0
2065-2070	79.6	23.1	9.3
2070-2075	80.5	23.7	9.5
2075-2080	81.4	24.3	9.8
2080-2085	82.2	24.9	10.1
2085-2090	83.1	25.6	10.4
2090-2095	84.0	26.2	10.8
2095-2100	84.6	26.7	11.0

Source: UN-World Population Prospects, 2015 revision

Table 6: Life Expectancy at Birth for Selected Indian States: 1970-2015

State	1970-75	1976-80	1981-85	1986-90	1991-95	1996-00	2001-05	2006-10	2011-15
Andhra Pradesh	48.8	53.1	58.4	59.1	61.8	62.7	65.0	65.8	71.2
Assam	45.5	51.1	51.9	53.6	55.7	57.4	59.2	61.9	66.2
Bihar	**	**	52.9	54.9	59.3	60.5	64.2	65.8	68.3
Gujarat	48.8	52.4	57.6	57.7	61.0	64.4	65.7	66.8	71.6
Haryana	57.5	54.8	60.3	62.2	63.4	64.4	66.5	67.0	71.9
Karnataka	55.2	56.3	60.7	61.1	62.5	64.5	66.1	67.2	70.9
Kerala	62.0	65.5	68.4	69.5	72.9	71.6	73.6	74.2	78.2
Madhya Pradesh	47.2	49.0	51.6	53.0	54.7	57.1	59.7	62.4	66.5
Maharashtra	53.8	56.3	60.7	62.6	64.8	65.9	68.0	69.9	73.9
Odisha	45.7	49.4	53.0	54.4	56.5	58.3	60.8	63.0	68.3
Punjab	57.9	60.5	63.1	65.2	67.2	66.5	68.8	69.3	74.2
Rajasthan	48.4	51.9	53.5	55.2	59.1	62.1	64.5	66.5	70.4
Tamil Nadu	49.6	53.4	56.9	60.5	63.3	64.8	67.2	68.9	73.0

State	1970-75	1976-80	1981-85	1986-90	1991-95	1996-00	2001-05	2006-10	2011-15
Uttar Pradesh	43.0	46.2	50.0	53.4	56.8	58.6	59.8	62.7	65.6
West Bengal	**	**	57.4	60.8	62.1	64.3	67.2	69.0	71.8
Range (H-L)	**19**	**19.3**	**18.4**	**16.5**	**18.2**	**14.5**	**14.4**	**12.3**	**12.6**

*Source: Sample registration System, Census of India **Census was not conducted.*

Table 7: Life Expectancy at age 60 years for Selected Indian States: 1970-2015

State	1970-75	1976-80	1981-85	1986-90	1991-95	1996-00	2001-05	2006-10	2011-15
Andhra Pradesh	12.8	14.3	15.1	14.7	14.9	15.9	17.6	16.8	19.4
Assam	11.6	13.2	13.4	13.6	14.7	15.0	15.5	15.9	17.3
Bihar	**	**	15.1	14.6	16.6	16.5	17.2	17.3	17.0
Gujarat	13.8	16.0	16.4	15.0	15.2	17.5	17.9	18.0	20.4
Haryana	16.0	15.2	17.2	17.3	18.0	18.7	19.4	18.8	20.5
Karnataka	15.8	15.6	16.6	16.8	16.5	17.3	17.9	17.7	18.5
Kerala	15.8	16.3	17.9	17.1	19.4	18.0	19.1	19.4	22.1
Madhya Pradesh	14.3	14.6	14.5	14.9	15.0	15.4	16.3	16.3	17.8
Maharashtra	14.3	14.8	16.2	15.5	17.3	16.9	18.2	18.4	19.7
Odisha	11.4	13.5	14.3	15.3	15.8	15.4	16.2	16.7	18.7
Punjab	16.3	17.9	17.9	19.5	20.8	19.0	19.9	19.6	21.4
Rajasthan	14.6	15.9	15.3	15.2	15.5	17.5	18.3	18.8	20.5
Tamil Nadu	12.8	14.4	14.6	15.1	15.4	15.9	17.4	17.6	19.3
Uttar Pradesh	13.6	15.4	14.8	15.2	15.3	16.5	17.1	16.5	17.5
West Bengal	**	**	15.1	15.8	15.6	16.2	17.1	17.6	18.7
Range (H-L)	**4.9**	**4.7**	**4.5**	**5.9**	**6.1**	**4**	**4.4**	**3.7**	**5.1**

Source: Sample registration System, Census of India.

***Census was not conducted.*

Table 8: Life Expectancy at 70 years for Selected Indian States: 1970-2015

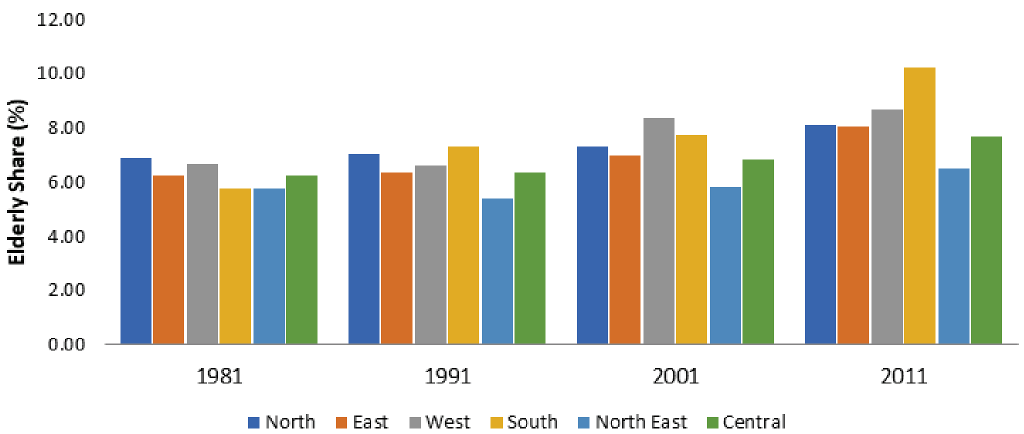
State	1970-75	1976-80	1981-85	1986-90	1991-95	1996-00	2001-05	2006-10	2011-15
Andhra Pradesh	8.0	9.8	9.9	9.1	9.1	10.1	11.6	10.9	12.9
Assam	7.6	9.4	9.1	9.0	9.6	9.8	10.4	10.5	11.0
Bihar	**	**	10.0	9.0	11.4	11.4	11.4	11.1	10.2
Gujarat	8.5	11.2	11.2	9.5	9.3	11.5	11.8	11.7	13.3
Haryana	9.9	9.3	11.6	11.5	11.7	12.0	12.8	12.3	14.0
Karnataka	10.9	10.8	11.3	11.0	10.8	11.5	11.6	11.6	11.4

State	1970-75	1976-80	1981-85	1986-90	1991-95	1996-00	2001-05	2006-10	2011-15
Kerala	9.8	10.9	11.4	10.4	13.0	11.5	12.2	12.3	14.3
Madhya Pradesh	9.2	10.0	9.4	9.8	9.5	9.9	10.5	10.4	11.1
Maharashtra	9.2	9.6	10.9	9.4	11.6	11.0	11.9	11.8	12.6
Odisha	6.9	9.0	9.5	10.1	10.6	9.9	10.4	10.6	12.4
Punjab	9.6	11.1	11.1	13.1	15.1	12.7	13.4	13.2	14.1
Rajasthan	10.0	11.3	10.4	9.5	9.0	11.6	11.9	12.2	13.5
Tamil Nadu	8.2	9.8	9.5	9.4	9.6	10.1	11.1	11.3	12.2
Uttar Pradesh	9.4	11.1	9.8	9.9	9.5	10.8	11.4	10.6	11.3
West Bengal	**	**	9.8	10.3	10.0	10.5	11.2	11.4	12.0
Range (H-L)	**4**	**2.3**	**2.5**	**4.1**	**6.1**	**2.9**	**3**	**2.8**	**10.8**

Source: Sample Registration System, Census of India

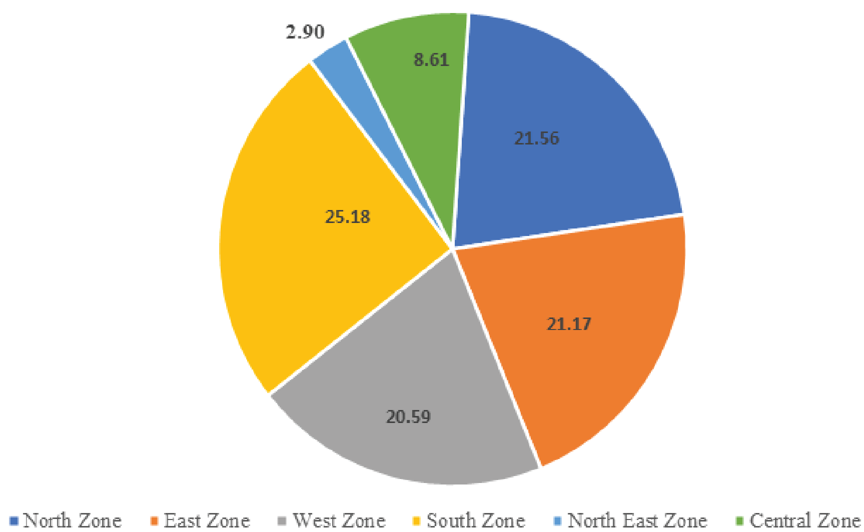
***Census was not conducted.*

Figure 1: Percentage Share of Elderly (60+ years) by Regional Zones, India, 1981-2011



Source: Census of India

Figure 2: Share of Regions in India's Total Elderly (60+ years) Population: 2011



Source: Census of India

Figure 3: Box Plot for Percentage share of Child Population (0-14 years) across states, India, 1981-2011

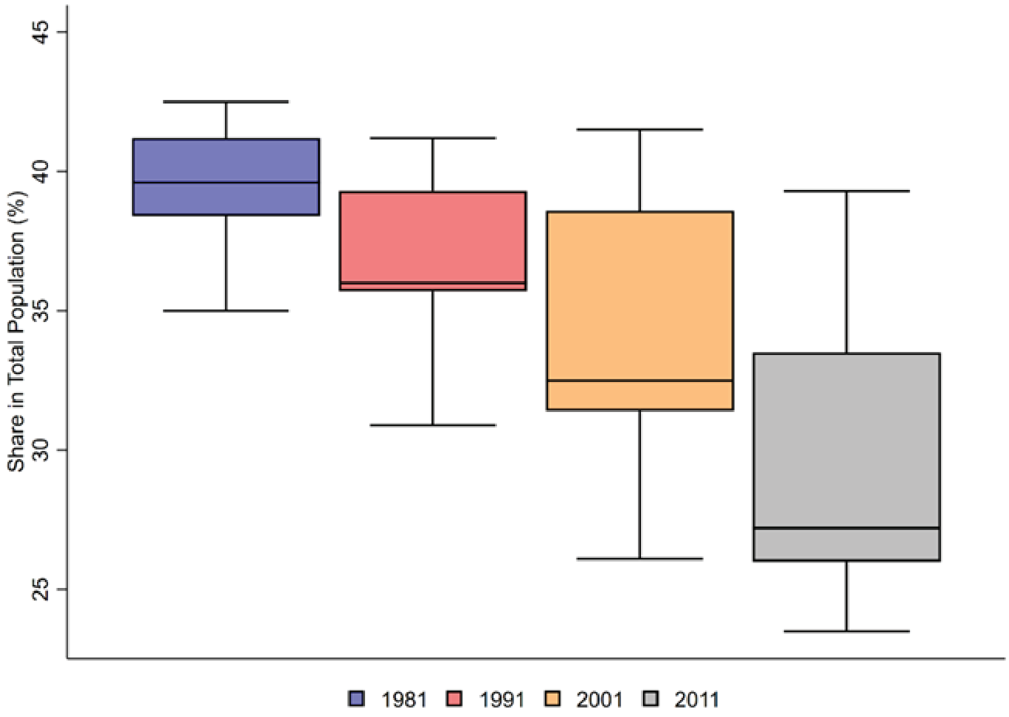


Figure 4: Box Plot for Percentage share of Adult Population (15-59 years) across states, India, 1981-2011

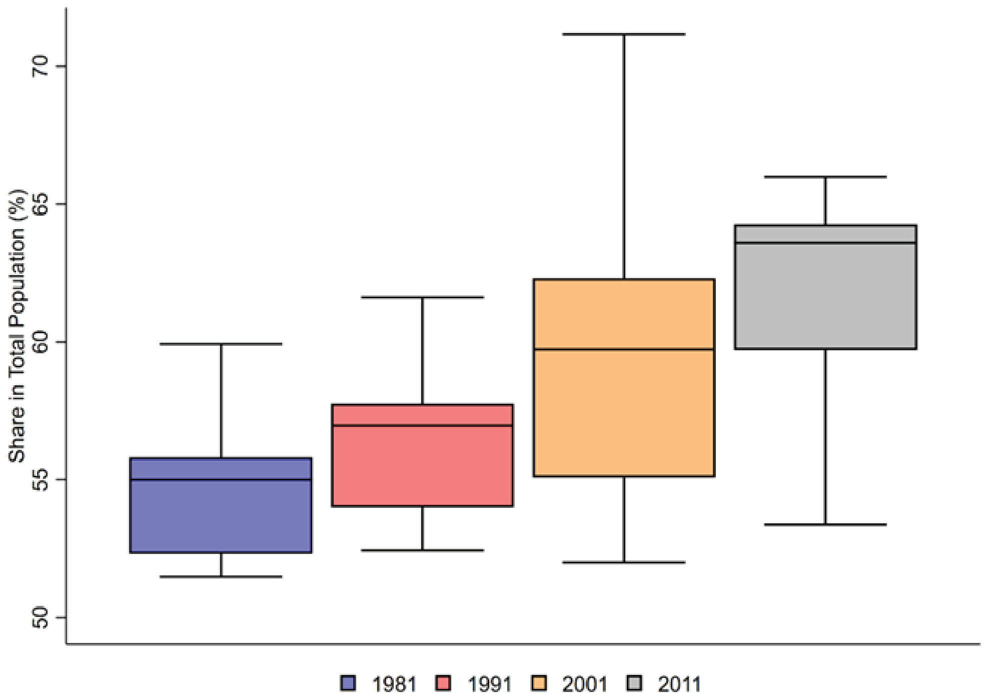


Figure 5: Box Plot for Percentage share of Elderly Population (60+ years) across states, India, 1981-2011

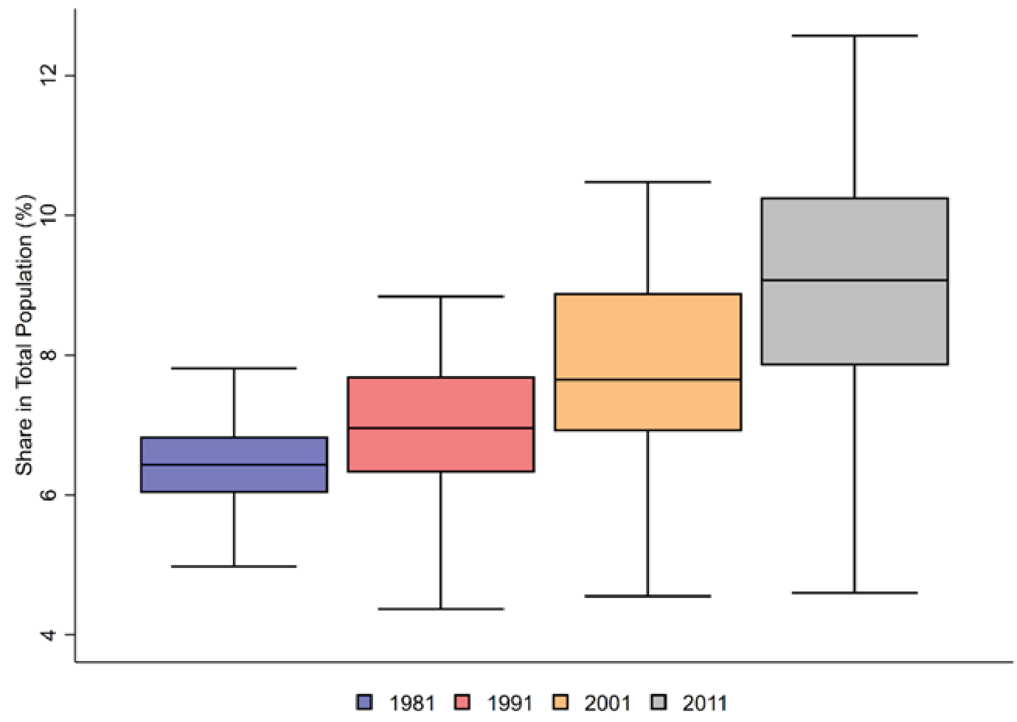


Figure 6: Old Age Dependency Ratio (%) in India, 1950-2015

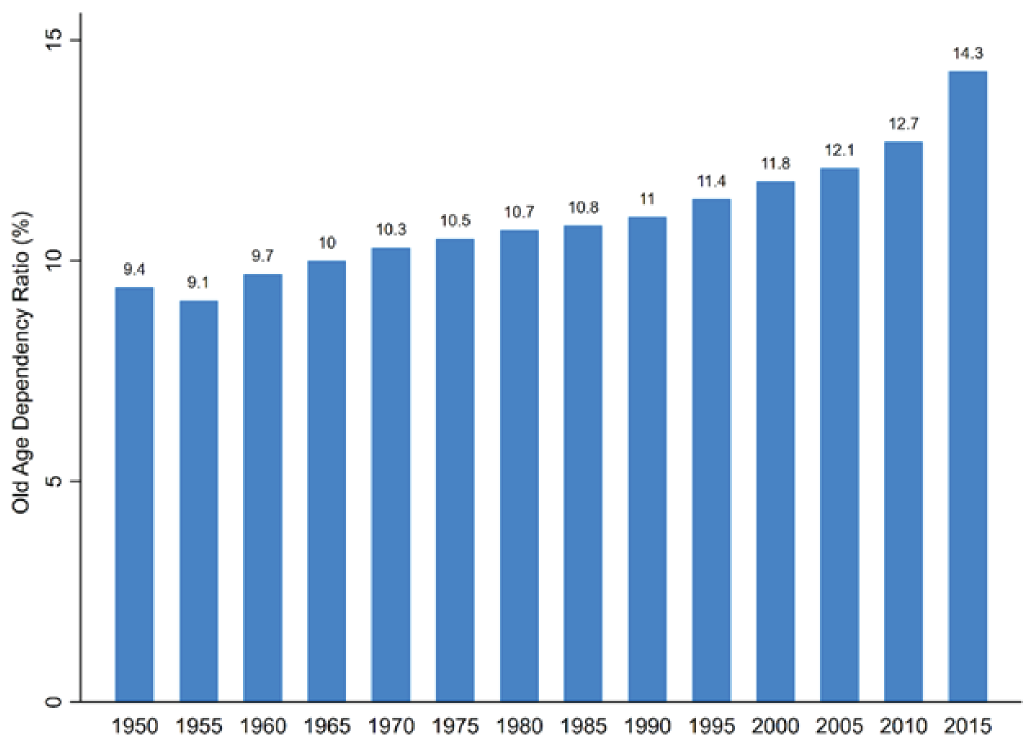


Figure 7: Box Plot for Percentage Life Expectancy at Birth across Indian States: 1975-2015

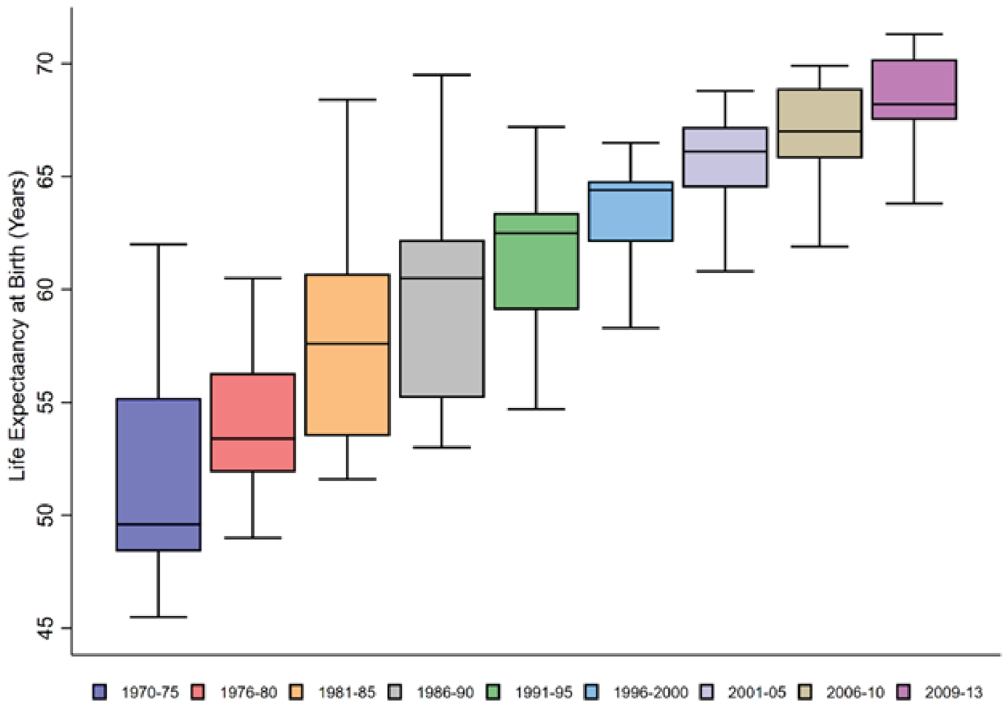


Figure 8: Box Plot for Life Expectancy at 60 across states, India, 1975-2015

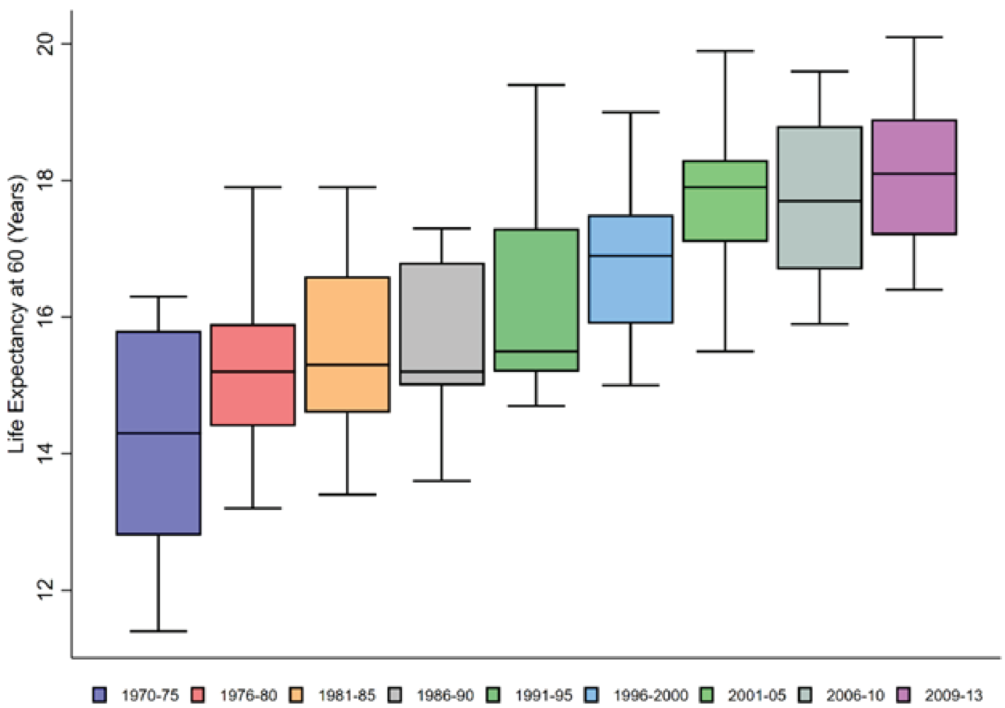


Figure 9: Box Plot for Life Expectancy at 70 across states, India, 1975-2015