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The Impact of Urbanization on Internal Freshwater Availability: Country-Level Analysis of Pakistan, India, and Bangladesh

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ABSTRACT
Rapid urbanization is becoming more problematic as it is threatening the internal freshwater resources of countries in various ways. This includes direct extractions of groundwater resources, reducing infiltration and groundwater recharge through rapid urban development and climate change, increased agricultural activities, and industrial water extraction, and polluting existing groundwater resources. This study aims to find out how the urban population has affected the renewable internal freshwater resources per capita of three countries of South Asia, namely Pakistan, India, and Bangladesh, which are the largest extractors of groundwater in South Asia. A mixed methods approach has been used, where quantitative findings are supported by qualitative evidence through existing literature and “Urban Environment Transition Theory” as the theoretical framework. For quantitative analysis, data on the urban population and renewable internal freshwater resources have been taken from The World Bank for thirty years, from 1990 to 2020. Simple linear regression analysis and correlation analysis are carried out to find the impact of urban population on renewable internal freshwater resources. A null hypothesis that there is no significant impact of urbanization on internal freshwater resources has been rejected in all three countries, and the research hypothesis is accepted. Results are substantial, and variables are highly, significantly, and negatively correlated. R-Square values also showed that the model is a good fit. The highest impact of urban population on renewable internal freshwater resources is seen in Bangladesh, the second highest impact is in Pakistan, and India shows the least impact in this study. Furthermore, forecasting has been done for the next ten years, starting from 2021 to 2030, which shows that if the current trend continues, Pakistan is the most vulnerable country and will become water-scarce in 2030. Bangladesh is the second most susceptible country after Pakistan, and the least vulnerable country is India in this regard.

Keywords: *Urbanization, Internal Freshwater Availability, Country-Level, Pakistan, India, Bangladesh.*

Introduction

Urbanization, known to be a global phenomenon, has brought in several transformative changes in all aspects of life, for instance, in social, economic, and environmental elements, as well as all the nations around the globe. As burgeoning populations gravitate towards urban centers, the demand for essential resources, particularly freshwater, experiences an unprecedented surge. This research is a mixture of both qualitative and quantitative methods in nature, whose aim is to delve into the paradigms of the impact of urbanization, mainly over the internal freshwater resources, and to further narrow it down over internal river flows and groundwater recharged from rainfall, at the country level, making this unit of analysis.

With the lens being fixated on the context of Pakistan, India, and Bangladesh, the objective of this study is to unravel the relationship, or the interplay of factors comprised of the urbanization trends and the availability of renewable internal freshwater resources per capita. Renewable internal freshwater resources, comprising internal river flows and groundwater sustained by endogenous precipitation, are indispensable for supporting various facets of human life, including agriculture, industry, and domestic consumption. The process of groundwater recharge through infiltration, where rainwater permeates the soil to replenish aquifers, is critical for maintaining the delicate balance of these resources. However, the accelerating pace of urbanization introduces multifaceted challenges that intertwine with the intricate hydrological cycles and ecological systems. With urbanization comes an escalating demand for freshwater to cater to the burgeoning urban populations. The surge in the urgent need of every citizen to have an adequate water supply, clean water for sanitation purposes, and the proper mechanisms of drainage results in exerting pressure on existing water resources.

Combined with this, there exist the ripple effects that extend beyond the direct extraction of groundwater, framing or revolving around the environmental degradation and contamination of water bodies through industrial, agricultural, and domestic waste. These anthropogenic activities not only diminish the quantity of usable water but also contribute to the degradation of land and the disturbance of ecosystems. Furthermore, the alterations in land use patterns induced by rapid urban development disrupt the natural processes of infiltration and groundwater recharge. Climate change, exacerbated by urbanization, brings about erratic hydrological patterns, manifesting as droughts and floods. These tremendous climatic changes further curtail the balance that needs to exist between groundwater and river flows, contributing to the challenges faced by urbanized regions.

Keeping this backdrop in focus, this research focuses on quantifying the impact of urbanization on internal freshwater availability per capita in Pakistan, India, and Bangladesh. By analyzing trends in land use, groundwater extraction, and climatic shifts, the study aims to provide valuable insights into the intricate relationship between urbanization and the sustainability of internal freshwater resources at the country level. In a nutshell, this attempt would help policymakers to make informed decisions along with resource management strategies for mitigating the adverse effects of urbanization on freshwater availability in the studied nations.

Literature Review

This literature review is an attempt to highlight specific trends, for instance, land use, groundwater extraction, and climatic shifts, through the existing data present mainly in terms of South Asia, to navigate the patterns of change in the usage of fresh water along with its availability, and delve into the insights residing.

Land Use

To commence with, the land use mainly due to urbanization has several underlying factors based on the availability of fresh water to per capita. The literature on land use reveals a rich tapestry of research exploring the intricate connections between human activities, urbanization, and the environment. Numerous studies underscore the profound impact of land use changes, particularly driven by urban expansion, on ecosystems, biodiversity, and natural resource availability.

The study conducted by Waqas Ahmad and colleagues (Ahmad et al. 2021) delves into finding the delicate relationship between land use/land cover changes, groundwater quality, and human health, specifically in District Peshawar, Pakistan. The research spans the years 2012 to 2019, analyzing 105 and 112 groundwater samples for various quality parameters, including pH, electrical conductivity, turbidity, chloride, calcium, magnesium, and nitrate. The findings reveal a concerning decline in groundwater quality in 2019 compared to 2012, particularly in densely populated areas. High nitrate concentrations, attributed to agricultural activities, are linked to a 14% increase in methemoglobinemia cases. Additionally, elevated calcium and magnesium levels are associated with urinary tract infections, peptic ulcers, and dental caries. The authors employ Landsat satellite imagery to assess land use/land cover changes, noting the impact of urbanization on groundwater quality. The study underscores the importance of addressing anthropogenic activities, such as urban expansion, wastewater discharge, and agricultural practices, as key drivers of groundwater quality degradation. The research further emphasizes the need for targeted policies and regulations to mitigate these issues, offering valuable insights for sustainable water resource management in the region.

Fischer and Heilig's (1997) study, whose primary focus lies on population momentum and its implications for land and water resources, attempts to critically examine the future world population growth by evaluating demographic factors and their relationship with land availability. The authors project a 65% increase in the global population by 2050, primarily in less developed countries. The research identifies regions, such as sub-Saharan Africa and South-Central Asia, facing substantial population growth, while developed areas witness minimal changes. Linking this study with the research on the impact of urbanization on internal freshwater availability in Pakistan, India, and Bangladesh reveals a significant research gap. Fischer and Heilig primarily address population growth and its demand on land and water resources on a global scale. However, the paper zooms in on the specific consequences of urbanization on internal freshwater resources at the country level. While Fischer and Heilig provide a macroscopic view, the study intends to offer a nuanced understanding of how urbanization patterns exacerbate the strain on internal freshwater resources, encompassing factors such as industrialization, agriculture, and environmental degradation, which would give this study a new outlook.

Groundwater Extraction

Haque, Onodera, and Shimizu's (2012) study investigates the intricate relationship between urbanization and groundwater in South Asian megacities. Focusing on Delhi, Mumbai, Kolkata, Dhaka, Lahore, and Karachi, the research underscores the severe consequences of overextraction, sewage loads, and seawater proximity on groundwater quality and quantity. The study identifies chlorides and nitrates as primary pollutants, emphasizing their anthropogenic origins. The research urges policy recommendations to minimize urbanization's impact on

groundwater, acknowledging the critical need for sustainable practices. Analyzing this study in conjunction with our research on internal freshwater availability due to urbanization in Pakistan, India, and Bangladesh reveals a crucial research gap. Haque et al. concentrate on the quality and quantity of groundwater, but the study delves into the broader implications of urbanization, encompassing effects on internal freshwater resources. While Haque et al. spotlight specific pollutants and their sources, the research aims to provide a comprehensive understanding of how urbanization, beyond pollutant considerations, influences freshwater availability within particular regions. Bridging these perspectives can offer a more holistic view of the challenges and solutions concerning urbanization's impact on internal freshwater resources in South Asia.
Mukherjee et al. (2015) present a comprehensive overview of the groundwater systems in the Indian Sub-Continent (ISC), addressing challenges in quantity, quality, and management. As the ISC harbors approximately 23% of the global population within only 3% of the world's land area, it faces intense pressure on groundwater resources. The authors highlight the significance of aquifers in major river basins (e.g., Ganges, Brahmaputra, Indus), emphasizing their role in sustaining agriculture and domestic water needs. Moreover, these underscore the potential political sensitivity arising from the transboundary nature of these aquifers. Linking this review to this study on urbanization effects on South Asian megacities, a notable research gap emerges. While Mukherjee et al. address broad-scale issues, the focus on specific megacities allows for a finer analysis of urbanization's local impact on groundwater. The ISC's vulnerability to natural contaminants and climate change is acknowledged, but the urban nexus requires more nuanced exploration. A comparative analysis of urban and rural groundwater dynamics within the ISC can enhance understanding, aiding targeted policies for sustainable urban development. Additionally, Mukherjee et al. lay the foundation for examining groundwater economics and governance, opening avenues for future research aligning with the study's analytical approach.

Climatic Shift

Medani P. Bhandari's (2012) chapter investigates the environmental performance (EP) of South Asian countries, India, Nepal, Bangladesh, and Pakistan, in the context of climate change vulnerability. The research employs a comparative matrix, utilizing data from the Environmental Sustainability Index (ESI) and Environmental Performance Index (EPI) to evaluate the countries' responses to climate change-induced environmental challenges. Notably, the study reveals that economic growth is intricately linked to governance performance, emphasizing the importance of effective governance in addressing ecological concerns. The study evaluates governance using measures such as voice and accountability, political stability, government effectiveness, regulatory quality, rule of law, and control of corruption. Results indicate variations among the countries, with Nepal experiencing a drastic drop, attributed to factors like the Maoist insurgency. Nepal emerges as the best performer in environmental indices, followed by India, Pakistan, and Bangladesh. The study attributes Nepal's success to factors such as limited economic growth, lack of infrastructure, and global support for environmental initiatives. While Bhandari's work provides a comprehensive overview of EP and governance, a research gap exists concerning the specific urban dynamics and their impact on environmental performance. The main approach of this study revolves around urbanization effects in South Asian megacities, and it can extend Bhandari's findings by exploring how urban centers contribute to or mitigate environmental challenges. Analyzing governance at the city level and its role in shaping local environmental policies would enrich the understanding of the complex relationship between urbanization, governance, and ecological sustainability.

Srivastava, Singhal, and Jha's (2020) chapter illuminates the critical interplay between climate change and water resources in South Asian countries. The study emphasizes the pivotal role of water in sustaining economies, particularly in densely populated nations like India and Pakistan. The authors project a concerning future, predicting a decline in water availability, potentially triggering socio-economic problems and large-scale migration. The impact of global warming, illustrated in a flow diagram, presents a grim scenario, with rising sea levels and altered precipitation patterns threatening coastal populations and agricultural productivity. The chapter underscores the vulnerability of major economies like India and Pakistan to water scarcity, highlighting the potential economic downturn and migration crises resulting from water deficit conditions. The study emphasizes the significance of transboundary rivers like the Ganga, Brahmaputra, Meghna, Helmand, and Indus, underscoring their contribution to South Asian water resources and the potential consequences of mismanagement. While Srivastava et al.'s comprehensive chapter addresses the macro-level impacts of climate change on South Asian water resources, this study aims to delve deeper into the urban dimensions of this crisis. The literature highlights the transboundary nature of rivers, but a critical research gap exists in understanding how rapidly urbanizing areas contribute to and are affected by this broader water crisis. By focusing on specific urban centers, this paper aims to bridge the analytical gap, exploring the localized impacts of climate change on water resources and the subsequent challenges in sustainable urban development and water management.

Urbanization

The dissertation by Wakode (2016) focuses on the significant challenges posed by rapid urbanization in Hyderabad. The study employs remote sensing and GIS techniques to analyze urban growth trends, water supply, wastewater disposal, and the impact of urbanization on surface and groundwater resources. The findings reveal a substantial increase in the urban built-up area, causing adverse effects on land use categories, especially agriculture and open land. Surface water bodies have suffered losses and degradation due to encroachment practices during urbanization. Groundwater quality analysis indicates contamination with heavy metals and microbiological pollutants, rendering it unsafe for drinking. The study emphasizes the urgent need for sustainable planning to address the growing gap between water supply and demand. Linking this study to the research, a critical research gap emerges concerning the long-term effects of rapid urbanization on water resources and the inadequacy of existing urban planning to manage the environmental impact. The lack of comprehensive data, especially before 2000, and limited detailed land use information highlight the challenges in understanding the intricate interactions between urban growth and water resource dynamics. This study could build upon these insights, leveraging advanced satellite images and demographic data to provide a more nuanced and up-to-date analysis of urban expansion and its implications for water resources in a rapidly growing city. By addressing these gaps, it can contribute to a more holistic understanding of sustainable urban development, essential for guiding future policies and practices.

Singha et al.'s (2020) article delves into the complex interplay between urbanization and water insecurity in the Hindu Kush Himalaya (HKH) region, focusing on Bangladesh, India, Nepal, and Pakistan. The study underscores the inadequacies of current urban definitions, emphasizing the unique challenges faced by mountainous urban centers, which are often excluded due to standardized criteria. While Nepal recognizes the mountain-specificity, other nations lack such nuance, risking oversight of vital urban functions in smaller settlements. The article aligns with the research by exposing the pitfalls of uniform urban definitions, echoing concerns of a neglected urbanization in specific terrains. The significant findings reveal escalating water insecurity driven by governance issues, inadequate urban planning, tourism impacts, and climate change. Short-term coping strategies, including unsustainable groundwater extraction, exacerbate long-term water scarcity. The study identifies varied definitions of urban across nations and emphasizes the necessity for tailored mountain-specific criteria. The water crisis in HKH urban centers emerges from seasonal fluctuations, tourism-induced population influx, and overreliance on groundwater. Sustainable urban planning, ecological restoration, and acknowledging the unique fragilities of mountain ecosystems are proposed as crucial for water security. The research gap highlighted pertains to the need for comprehensive, mountain-specific urban planning strategies to address water scarcity, considering seasonal variations and tourist influx.

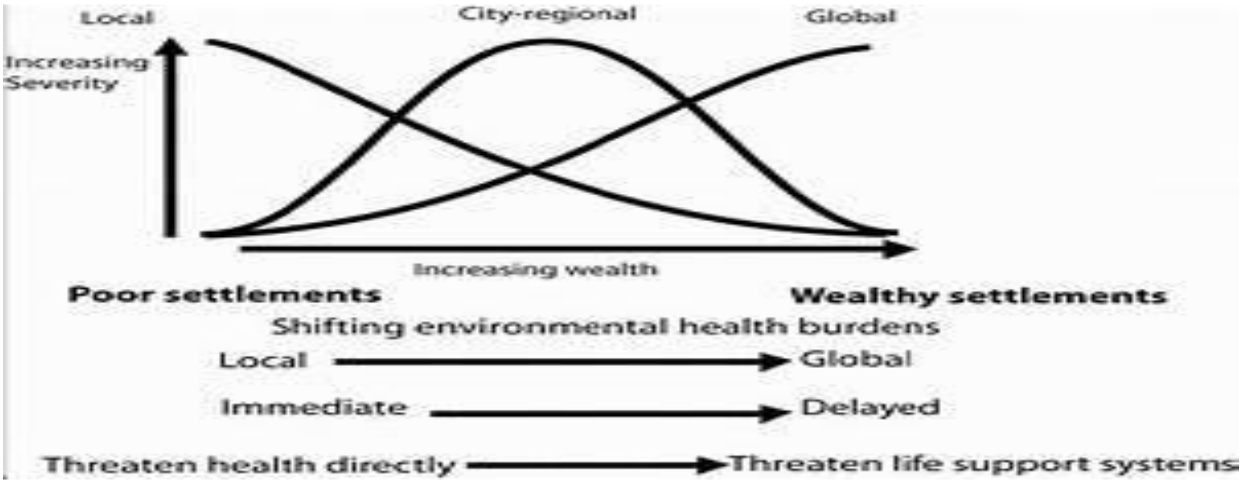
Theoretical Framework

McGranahan and his colleagues are credited with the development of “Urban Environmental Transition Theory” in the early 1990s. Rashid, Manzoor, & Mukhtar (2018) argue that the theory traces its roots to the studies on the increase in wealth and the environmental burden it creates in urban settings. This theory claims that ecological problems emerge from urban growth, as the environmental degradation traces a relationship with the extensive growth in urban population (Bekhet, Othman, &Yasmin, 2020). However, the primary concern in this discourse is the kind of development in cities and its overall impact that it creates in terms of the environmental burden (Rashid, Manzoor, & Mukhtar, 2018,70). Apparently, the towns that are poor and have lower revenues pose a significant threat to their environment, and in them lies a grave danger to the health of the people. In contrast, the environmental threat is widespread, inter-generational, and on a larger scale in cities that are more vibrant economically (Rashid, Manzoor, & Mukhtar, 2018). In fact, the toll on the environment created from the development of the cities is a consequence rather than something that is known beforehand (Rashid, Manzoor, & Mukhtar, 2018).

Consequently, Marcotullio & McGranahan (2012) argue that environmental challenges emerge from urbanization and economic growth; the challenges pertain to local environmental health issues on the one hand, causing significant deaths, and global climate change on the other hand, which poses a substantial threat to day-to-day life in the future. However, some of the noticeable issues associated with urbanization and economic growth include the contamination of urban waterways, smog, and degradation of peri-urban resources. These issues are associated to the location of economic production and populations in the urban centers, partly, in a way making the spatial argument for environmental impacts due to urbanization (Marcotullio & McGranahan, 2012).

Furthermore, Marcotulliol, Rothenberg, & Nakahara (2003) argue that the growing affluence of cities presents a change in the geographic scale based on the impact of environmental burdens. The shift from “brown” agenda items to “gray” agenda issues, those of quickly industrializing cities, to “green” agenda concerns characterizes the transition. Lack of clean water, poor waste management and pollution control, accidents related to traffic and crowding, habitation and

deterioration of sensitive areas, and the connections among these concerns are some of the "brown" agenda items (Marcotulliol, Rothenberg, & Nakahara, 200, 371). Usually, households and neighborhoods are affected as these costs are small-scale. Increases in air pollutants (SO2, total suspended particles, or TSP) and chemical water pollutants (measured, for instance, by chemical oxygen demand and phosphorus levels) that affect local air and watersheds are among the "gray" agenda items (Marcotulliol, Rothenberg, & Nakahara, 2003, 371).
In addition, "Green" agenda items that affect the area, if not the whole world, include persistent chemicals, non-point source pollution, and consumption-related burdens like CO2 emissions and waste creation (Marcotulliol, Rothenberg, & Nakahara, 2003). This means that environmental loads move from being localized, immediate, and health-threatening to being global, delayed, and ecosystem-threatening as cities get wealthier (Marcotulliol, Rothenberg, & Nakahara, 2003).



Putting this theory into the context of study, it can be seen that when a city develops or gets urbanized, it extracts groundwater at the expense of other surrounding areas, including semi-urban and rural areas. This implies that as the town becomes urbanized and gets wealthier, it may overcome its present time water needs, but it does so at the expense of other populations in semi-urban or rural areas. This phenomenon is happening in all cities and will deprive people of sufficient per capita water availability for every individual in the country. Taking this into the regional level, it can be seen that it is common that two countries may share a common aquifer. If one country extracts groundwater from that aquifer that it shares with a neighboring country, it can be said that the former country is extracting water to fulfill its needs at the expense of its neighboring country. Countries continue to do so until water availability is threatened at the regional level and ultimately at the global level. This water concentration in urban cities in the world ultimately threatens the global ecosystem.
Consequently, the researchers will employ the Urban Environment Transition theory for this research to study the nuances of urban growth in the three countries of the sub-continent and its impact, particularly on freshwater availability. Considering all three basic agendas of this theory, particularly the brown agenda, this study looks into the evolution of urban areas in relation to their environment. Not only in the aspects of how the environment is affected by urbanization, but also how the degradation of the environment is, in turn, harming human beings and affecting their urban life. While doing so, this research has taken a step further and examined

how such socio-economic dynamics play a significant role in formulating the water availability, usage, and disruption in such rapidly urbanizing areas.

Research Objectives

1. To find out the impact of urbanization/urban population increase on the availability of renewable internal freshwater resources.
2. To find out how urbanization degrades and exploits groundwater resources and to see if other South Asian countries follow any similar trend.

Research Question

1. What is the effect of urbanization or an increase in the urban population on renewable internal freshwater resources?
2. How does urbanization lead to the degradation and exploitation of groundwater resources?
3. How do major South Asian countries (Pakistan, India, and Bangladesh) follow similar trends in internal freshwater resource availability, given the phenomenon of urbanization, or do they differ in it?

Hypothesis

H0: There is no significant impact of urbanization on renewable internal freshwater resources.
H1: There is a significant impact of urbanization on renewable internal freshwater resources.

Research Methodology

This study is of mixed methods in nature, where both quantitative and qualitative methods have been used for country-level analysis. For qualitative analysis, the paper has an extensive review and analysis of existing literature, articles, and other reliable sources available. For quantitative analysis, it has a time series of data of three major countries in South Asia that include Pakistan, India, and Bangladesh from 1990 to 2020. These three countries are the largest extractors of groundwater in South Asia. The urban population will be our independent variable to gauge urbanization, and the renewable internal freshwater resources per capita serve as the dependent variable. Data is secondary in nature, taken from The World Bank. Simple linear regression and correlation analysis have been used to find out if there is a statistically significant impact of urbanization on renewable internal freshwater resources. Also, the reliability of the model has been tested in the results, and a conclusion has been drawn based on the results and stats that have been obtained.

Findings and Results

The paper is going to use simple linear regression to find out if urbanization has a significant effect on renewable internal freshwater resources. Along with this, it is going to provide a review and analysis of existing literature and articles to find out if existing literature supports our empirical analysis. To begin with, it starts with a simple linear regression model.

$$Y = a + b*X + e$$

Here, “**Y**” is the dependent variable, “**a**” is the constant or intercept, “**b**” is the slope and coefficient of regression that shows the change, and “**X**” is the independent variable. Here, “**e**” represents the errors or residuals that are always possible while making a regression analysis. The constant or intercept term shows the amount or quantity that the dependent variable (renewable internal freshwater resources) has even when the independent variable (urban population) stands at zero.

Incorporating the variables into this basic model;

Renewable Internal Freshwater Resources per capita = a + b*Urban Population + e

It has started with an analysis from South Asia and moved down to Pakistan, India, and Bangladesh. Further, it has used thirty years of data on the urban population and renewable internal freshwater resources.

South Asia

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.969[a]	.939	.936	52.919

a. Predictors: (Constant), Urban Population in South Asia

Figure 1

In the model summary given in Figure 1, the R value of 0.96 shows that both variables are strongly correlated. *R-squared shows that variations in the dependent variable are 93.9%* explained by the predictor or independent variable.

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	2149.668	40.128		53.570	.000
	Urban Population in South Asia	-1.802	.086	-.969	-21.042	.000

a. Dependent Variable: Renewable Internal Freshwater Resources Per Capita in South Asia

Fig 2

Significance level of .000 in Figure 2, when compared with the *alpha value* of *0.05*, shows that it is less than *0.05*, and the model is highly significant. The *b coefficient* is *-1.802*, which can be interpreted as showing that with a one-unit increase in Urban Population in South Asia, the renewable internal freshwater resources decreased by 1.802 units, showing a negative relationship between the two. More specifically, it can be said that for every one million increases in urban population, internal freshwater resources go down by 1.802 cubic meters per capita. The regression line would be;

*Renewable Internal Freshwater Resources Per Capita = 2149.66 - 1.802*Urban Population + e*

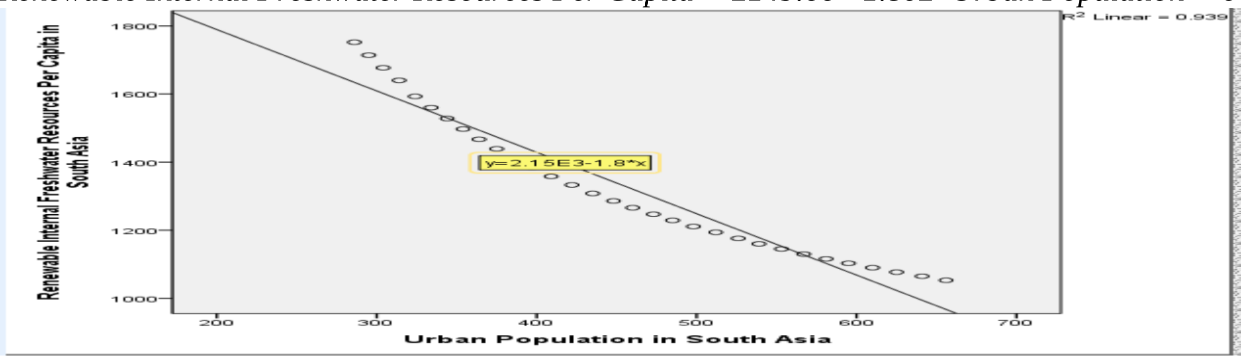


Figure 3

A graphical representation in Figure 3 has been depicted, which represents a clear negative relation between the two variables. The regression line can be seen with the equation and R-squared at the top right. Plotting the data points on this graph shows a negative downward trend, which implies that as the urban population increases, the internal freshwater resources would move down along the axis.

Correlations

		Urban Population in South Asia	Renewable Internal Freshwater Resources Per Capita in South Asia
Urban Population in South Asia	Pearson Correlation	1	-.969**
	Sig. (2-tailed)		.000
	N	31	31
Renewable Internal Freshwater Resources Per Capita in South Asia	Pearson Correlation	-.969**	1
	Sig. (2-tailed)	.000	
	N	31	31

**. Correlation is significant at the 0.01 level (2-tailed).

Figure 4

Computing the correlation, a significant negative correlation between the two variables can be found, which implies that if one variable (Urban Population) increases, the other variable (Renewable Internal Freshwater Resources) decreases. This correlation is strong, as it stands at 96.9% negative, and the results are significant, which can be seen by looking at the significance level of *0.000*.

Pakistan

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.977[a]	.954	.952	15.578

a. Predictors: (Constant), Urban Population in Pakistan

Figure 5

In the case of Pakistan, the R value of 97.7% which means there exists a strong correlation between the two variables. *R-squared of 95.4% shows that the independent variable highly explains the variations in the* dependent variable.

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	602.666	11.457		52.600	.000
	Urban Population in Pakistan	-4.602	.189	-.977	-24.410	.000

a. Dependent Variable: Renewable Internal Freshwater Resources Per Capita in Pakistan

Figure 6

The significance level of *.000* in Figure 6 shows that the model is highly significant. The coefficient of *b* concludes that with one unit or one million increases in urban population in Pakistan, renewable internal freshwater resources would decrease by *4.602* units or cubic meters per capita. The graphical depiction of the linear regression line can further confirm this.

*Renewable Internal Freshwater Resources Per Capita (Pakistan) = 602.66 - 4.602*Urban Population (Pakistan) + e*

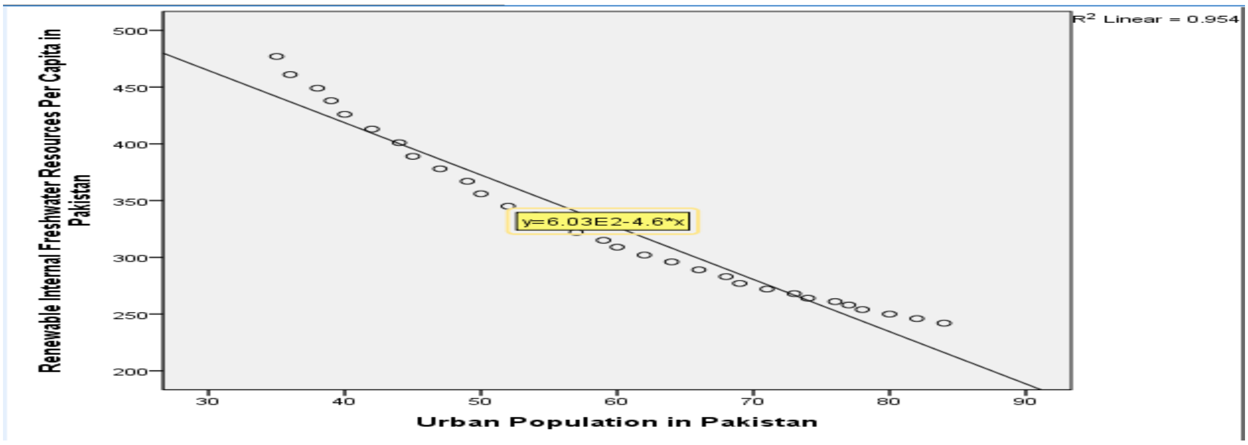


Figure 7

The graph shows scattered plots of data sets, which are again more or less perfectly downward sloping, implying that an increase in urban population causes a decrease in internal freshwater resources in Pakistan.

Correlations

		Urban Population in Pakistan	Renewable Internal Freshwater Resources Per Capita in Pakistan
Urban Population in Pakistan	Pearson Correlation	1	-.977**
	Sig. (2-tailed)		.000
	N	31	31
Renewable Internal Freshwater Resources Per Capita in Pakistan	Pearson Correlation	-.977**	1
	Sig. (2-tailed)	.000	
	N	31	31

**. Correlation is significant at the 0.01 level (2-tailed).

Figure 8

Correlation analysis in Figure 8 depicts a significant and strong negative correlation between the two variables. This stands at negative *97.7%* showing that variables are *97.7%* correlated in an inverse relation. Results are significant when looking at *the significance value of 0.000, establishing that if the* independent variable (urban population) increases, it causes the dependent variable (renewable internal freshwater resources) to decrease.

India

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.972[a]	.945	.943	45.011

a. Predictors: (Constant), Urban Population in India

Figure 9

India has a *correlation coefficient* of *97.2 %* which again shows a strong correlation between variables. *R-squared value of 94.5 % further confirms a good-fit model where urban population explains 94.5% of the variations in the* dependent variable and ultimately the significance of the model.

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	2067.431	35.781		57.781	.000
	Urban Population in India	-2.274	.102	-.972	-22.373	.000

a. Dependent Variable: Renewable Internal Freshwater Resources Per Capita in India

Figure 10

In the coefficient table of Figure 10, the *significance level* is *.000*, which is less than the alpha value of 0.05 and represents the significance of the model. The b coefficient is negative 2.274, which implies that with every one unit increase in urban population, India's renewable internal freshwater resources per capita decrease by *2.274* units. This claim is further confirmed by a downward-sloping graph with a regression line in the center.

*Renewable Internal Freshwater Resources Per Capita (India) = 2067.43 - 2.274*Urban Population (India) + e*

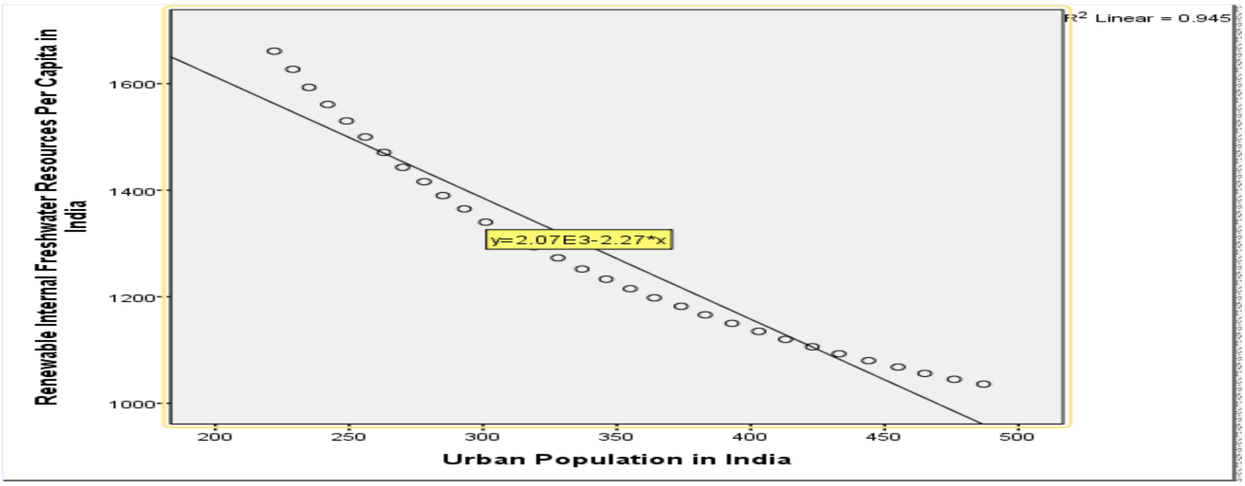


Figure 11

Scattered plots in Figure 11 are downward sloping along the regression line, which also confirms the negative relationship between the two variables.

Correlations

		Urban Population in India	Renewable Internal Freshwater Resources Per Capita in India
Urban Population in India	Pearson Correlation	1	-.972**
	Sig. (2-tailed)		.000
	N	31	31
Renewable Internal Freshwater Resources Per Capita in India	Pearson Correlation	-.972**	1
	Sig. (2-tailed)	.000	
	N	31	31

**. Correlation is significant at the 0.01 level (2-tailed).

Figure 12

Correlation analysis is again significant at *a 0.000 significance level with a negative 97.2 % which shows a strong inverse relationship between urbanization* and internal freshwater resources in India.

Bangladesh

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.939[a]	.882	.878	36.964

a. Predictors: (Constant), Urban Population in Bangladesh

Figure 13

In the case of Bangladesh, a correlation of 93.9% which means that the variables are highly correlated. R-squared is comparatively less than other countries, but still shows a high value with 88.2 % variations in dependent variables being explained by the independent variable, implying that this model is also a good-fit model.

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	1056.144	20.477		51.576	.000
	Urban Population in Bangladesh	-7.397	.503	-.939	-14.707	.000

a. Dependent Variable: Renewable Internal Freshwater Resources Per Capita in Bangladesh

Figure 14

The model is again significant at *a .000 significance level with a b coefficient of -7.397,* which means that for every one unit increase in urban population, renewable internal freshwater resources decrease by *7.39* units. Precisely, every one million increases in urban population would decrease internal freshwater resources by *7.397* cubic meters per capita. Graphical representation further confirms the regression line and the antagonistic relation between the two.

*Renewable Internal Freshwater Resources Per Capita (Bangladesh) = 1056.144 - 7.397*Urban Population (Bangladesh) + e*

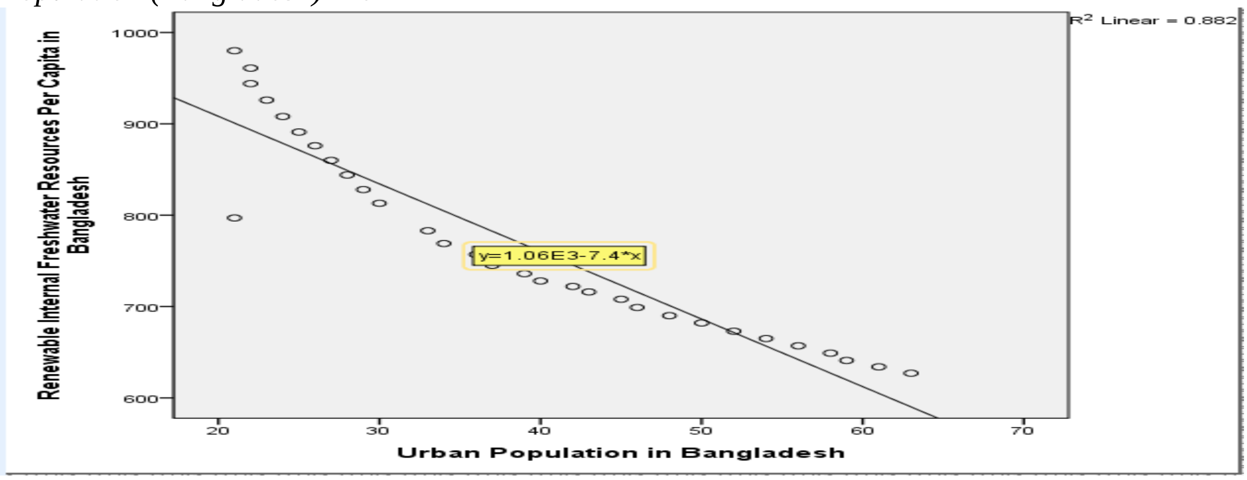


Figure 15

Again, in this case, scattered plots are perfectly downward sloping, which shows the inverse relationship between urban population and internal freshwater resources in the case of Bangladesh.

Correlations

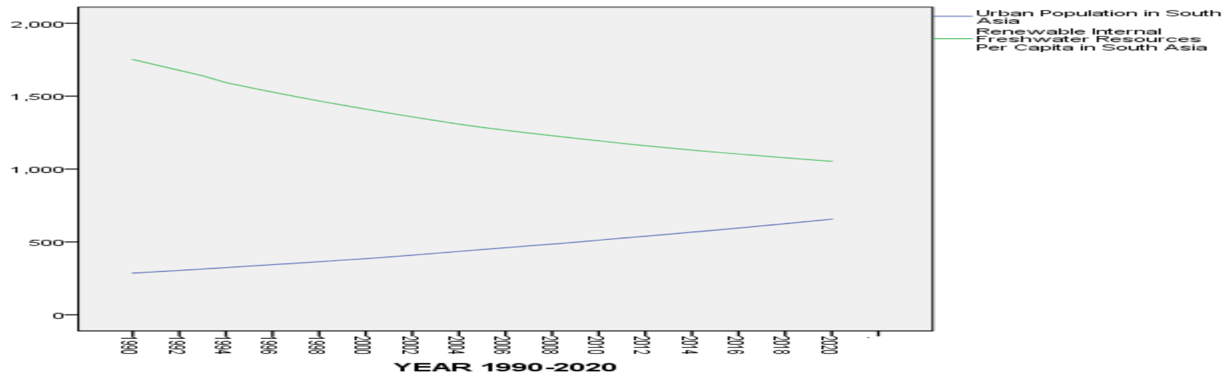
		Urban Population in Bangladesh	Renewable Internal Freshwater Resources Per Capita in Bangladesh
Urban Population in Bangladesh	Pearson Correlation	1	-.939**
	Sig. (2-tailed)		.000
	N	31	31
Renewable Internal Freshwater Resources Per Capita in Bangladesh	Pearson Correlation	-.939**	1
	Sig. (2-tailed)	.000	
	N	31	31

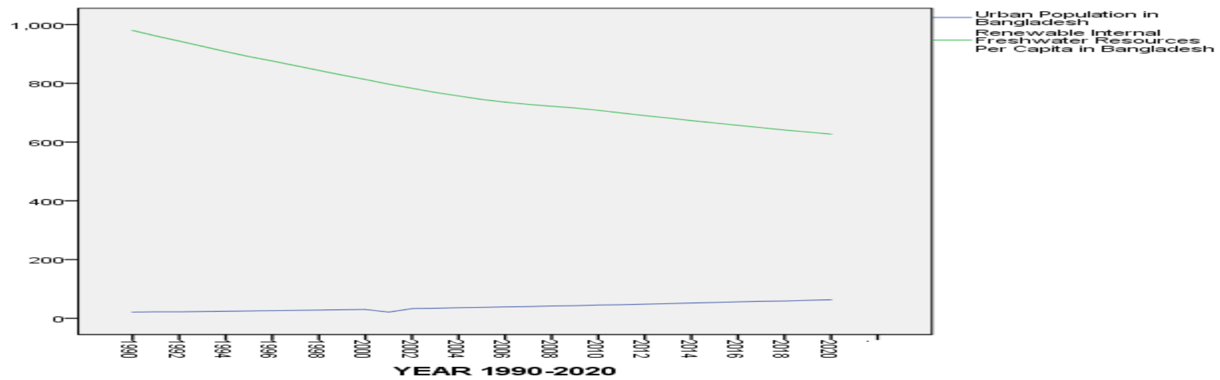
**. Correlation is significant at the 0.01 level (2-tailed).

Figure 16

Correlation analysis in Figure 16 shows a strong *significance level* of *0.000*, and a negative relation between the variables stands at *–93.9%* implying that both variables are 93.9% correlated but in an inverse relation.

Time Series Analysis





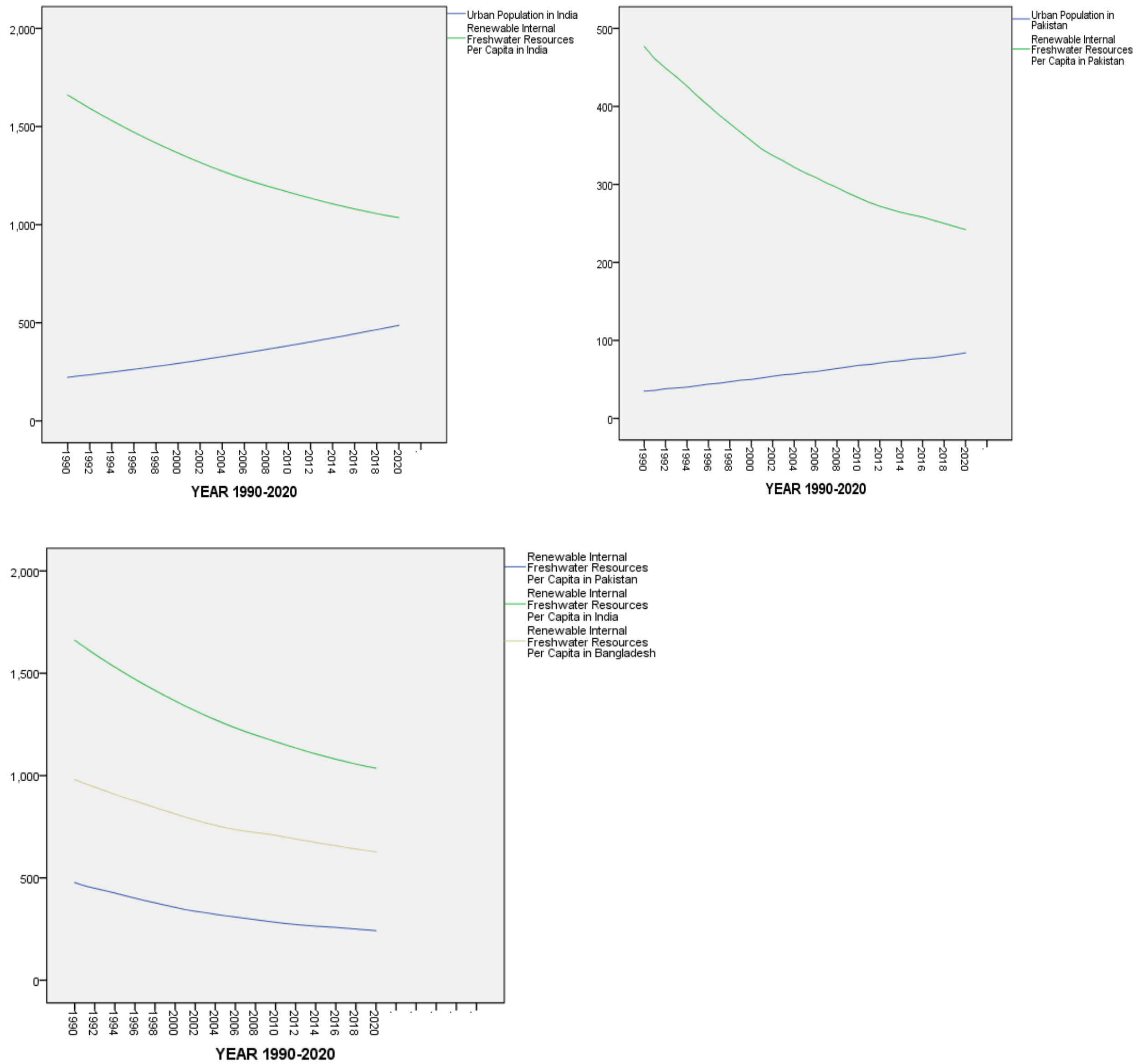


Figure 17

Trends of both variables are shown in the above-mentioned graphs for all cases discussed above. All countries have an upward trend in urban population, while a downward trend could be observed in renewable internal freshwater resources. Here, the urban population in Bangladesh is less compared to other countries. This suggests that any drastic increase in urban population in Bangladesh would have a greater impact on its internal freshwater resources. The study already observed this phenomenon in the regression line, where the highest impact of urban population on freshwater resources is in the case of Bangladesh. Placing all three countries on the same graph, it can be seen that Pakistan has the least internal freshwater resources compared to the other two. Bangladesh lies in the middle, while India has the highest internal freshwater resources.

Forecasting

Forecast

Model		2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Renewable Internal Freshwater Resources Per Capita in South Asia-Model_1	Forecast	1042	1031	1020	1010	1001	992	983	975	967	960
	UCL	1046	1040	1037	1034	1033	1033	1034	1036	1039	1043
	LCL	1037	1021	1004	987	969	952	934	917	899	882
Renewable Internal Freshwater Resources Per Capita in Pakistan-Model_2	Forecast	238	234	230	226	222	218	214	210	206	202
	UCL	240	239	239	239	240	241	243	245	247	249
	LCL	236	229	221	213	204	195	185	175	165	155
Renewable Internal Freshwater Resources Per Capita in India-Model_3	Forecast	1027	1020	1013	1007	1002	998	994	992	990	989
	UCL	1029	1022	1017	1012	1009	1007	1005	1005	1006	1008
	LCL	1026	1017	1009	1002	995	989	983	979	975	971
Renewable Internal Freshwater Resources Per Capita in Bangladesh-Model_4	Forecast	620	614	608	603	598	594	590	586	583	580
	UCL	623	620	618	616	616	617	618	620	623	627
	LCL	618	609	599	590	580	571	561	551	542	532

Figure 18

Given the historical data, the researchers ran a forecasting analysis using SPSS to predict the future values of the dependent variable. Given the trends in the data, the dependent variable shall continue to decrease in its predicted values up to the year 2030. For example, in the case of Pakistan, renewable internal freshwater resources would decrease from 238 cubic meters per capita in 2021 to 202 cubic meters per capita in 2030. A similar situation can be observed in the case of India, where internal freshwater resources would remain only 989 cubic meters per capita in the year 2030 if the trend continues. For Bangladesh, it would fall to only 580 cubic meters per capita from 620 cubic meters per capita in the year 2030. Pakistan will be observing the highest percentage decrease, ranging between 1.94% and 1.68%. Bangladesh will face a percentage decrease from 0.96% to 0.51%. India seems to be comparatively less vulnerable, as it shows a reduction between 0.10% and 0.68%. These calculations are made purely based on past values and historical trends in the data sets.

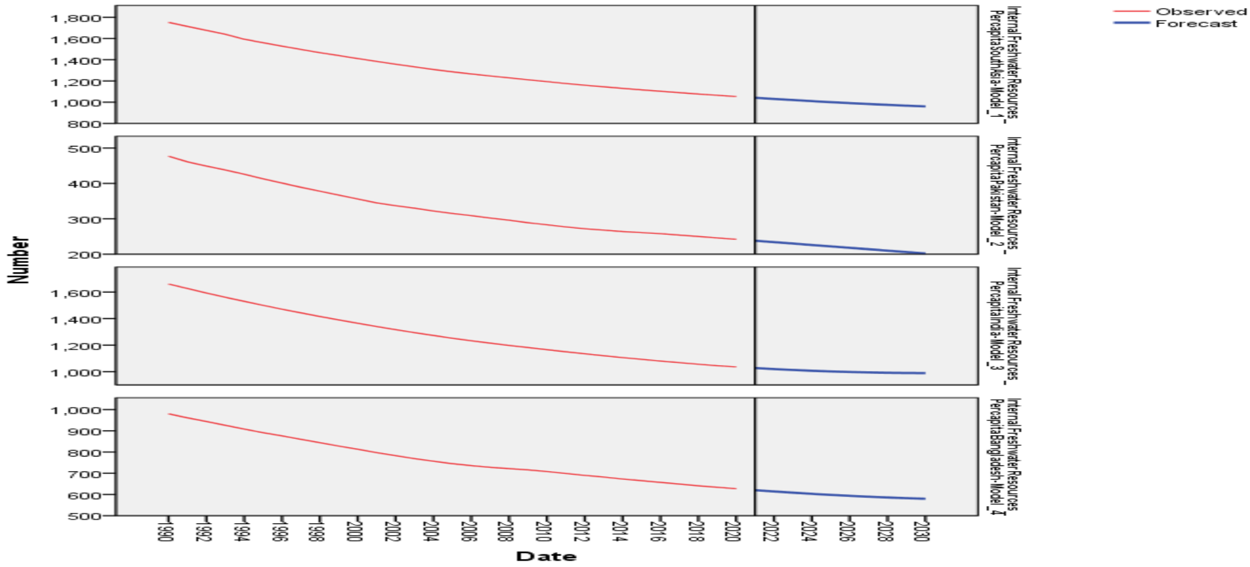


Figure 19

This is the graphical representation of the forecasted values, where all countries would have continued to trend downwards in their internal freshwater resources with more or less the same rates. Pakistan, already having less internal freshwater resources as compared to the other two countries in the sample, seems to be in a more vulnerable position where internal freshwater resources might hit the baseline by the year 2030.

Discussion

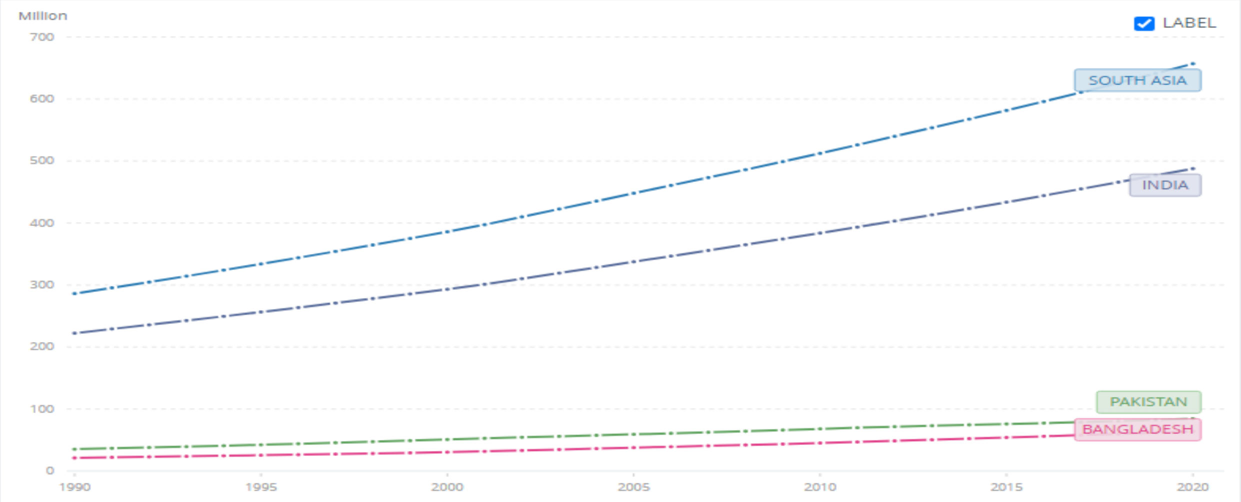


Figure 20: Graphical Representation of Urban Population Country-Wise (Source: The World Bank)

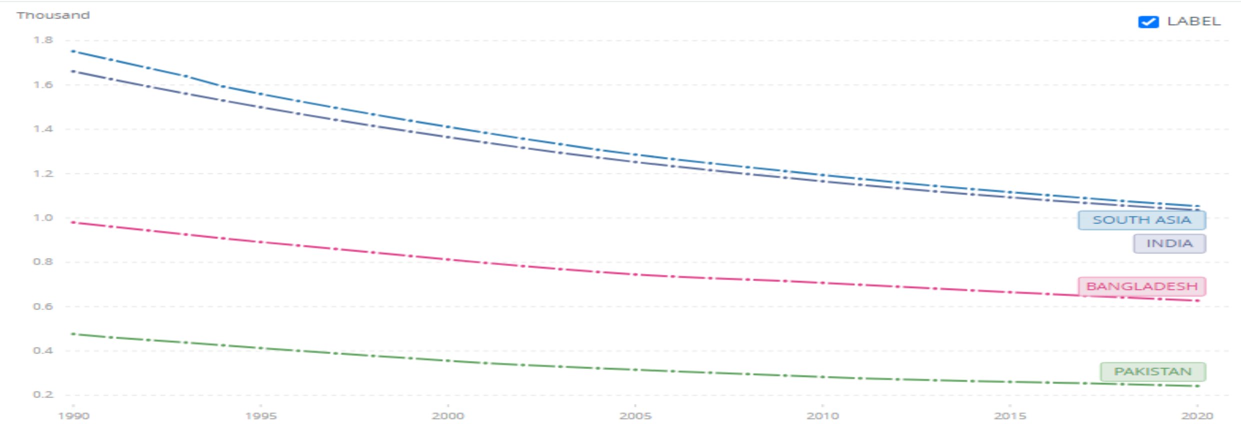


Figure 21: Graphical Representation of Renewable Internal Freshwater Resources Per Capita Country-Wise (Source: The World Bank)

Observing the trends in graphs, all three countries depict an upward trend in urban population and a downward trend in internal freshwater resources. India has the highest urban population, followed by Pakistan and then Bangladesh. The Indian urban population grew by 2.29% from 476 million in 2019 to 487 million in 2020. The urban population in Pakistan grew by 2.46% from 82 million in 2019 to 84 million in 2020. For Bangladesh, the percentage increase was 3.24% from 61 million in 2019 to 63 million in 2020.

Pakistan has the lowest internal freshwater resources, while India has the highest. But all three countries show a continuous decrease in these resources. Pakistan's internal freshwater resources decreased by 1.63% in 2020 from 246 cubic meters per capita to 242 cubic meters per capita. India faced a decrease of 0.86% from 1045 cubic meters to 1036 cubic meters per capita in the same year. Bangladesh observed a decline of 1.1% from 634 cubic meters in 2019 to 627 cubic meters per capita in 2020. Here, it can also be observed that India has the highest number of urban populations, along with the highest numbers for renewable freshwater resources. Pakistan has the second-highest population in the sample, but has the lowest internal freshwater resources. Bangladesh has the lowest population in the sample but the second-highest internal freshwater resources.

Using the data sets from the World Bank, the research can look at the overall South Asian region for broad analysis by conducting a regression analysis between urban population and renewable internal freshwater resources. Then it narrowed down to country-level analysis with Pakistan, India, and Bangladesh as the most prominent countries in the region being the largest extractors of groundwater in South Asia, and in terms of economy, population, GDP, and other factors that make these countries necessary in geopolitical and geoeconomic aspects. By using 30 years of data on the variables and running a regression analysis, the paper rejects the null hypothesis and accepts the research or alternative hypothesis. Significance levels were tested in all cases. It establishes that there is a statistically significant impact of urbanization on renewable internal freshwater resources. The model best fits in the case of Pakistan with the highest R-squared value, followed by India and then Bangladesh. As per the data set, it can compare the value of regression coefficients, which shows that Bangladesh's urban population increase would have the highest impact on its renewable internal freshwater resources, resulting in a decrease in internal freshwater resources by 7.397 units or cubic meters per capita for every one unit or one million increases in urban population. After Bangladesh comes Pakistan with the second highest impact on internal freshwater resources, with a decrease of 4.602 units for every one unit increase in urban population. India shows the lowest impact of urban population on its freshwater resources, with a decrease of only 2.274 cubic meters per capita for every one million increase in urban population. Given the forecasting analysis, Pakistan seems to be in a vulnerable position as its internal freshwater resources are already low compared to those of other countries taken into this study. Pakistan could easily be seen to hit the baseline in forecasting graphs in the coming ten years and might change its status from a water-stressed to a water-scarce nation if adequate measures are not taken. India could also be seen closer to baseline when compared with Bangladesh.

India, Pakistan, and Bangladesh are the largest extractors of groundwater resources in South Asia, with an estimated annual extraction of 320 billion cubic meters, with India having 230 billion cubic meters, Pakistan 60 billion cubic meters, and Bangladesh 30 billion cubic meters. In order to produce more food for an increasing population, these countries have to expand the irrigated area, along with the intensification of groundwater usage.

Pakistan currently withdraws 83% of its renewable groundwater. It is the 3rd largest user of groundwater. According to Khan, Hina, and Ali (2019), the water sector in urban areas of Pakistan includes contamination of surface and ground water resources through industrial, agricultural, and domestic discharge of waste and wastewater, increasing floods, loss of wetlands and aquatic biodiversity, sea water intrusion, physical reduction in water resources quality and quantity, and operational and managerial incapacities. All of these highlight how urbanization has proved devastating for internal freshwater resources in both direct and indirect ways. This rapid urbanization in Pakistan is posing a massive challenge to the water management of the country. Municipal sewage is one of the primary sources of surface and groundwater pollution in Pakistan. The government needs to expand its storage capacity by 22 billion cubic meters by 2025 to meet the annual demand of 165 billion cubic meters.

According to WWF, thirty Indian cities would face a grave water risk. The problems include poor management of water resources, contaminated supplies, leaky distribution networks, and a vast volume of untreated wastewater poured into Indian rivers. These problems arise due to the continuous growth of the city and high urban population growth. Water demand is increasing in urban areas in India as it is facing rapid urbanization. Indian urban population growth in water-scarce regions is projected to be much higher than in other countries, increasing from 222 million to 550 million people in 2050 (He et al, Nature). This puts extra pressure on the existing water resources of the country. Many urban areas in India face water scarcity due to over-extraction of groundwater (Mihir Shah, 2014). Unsustainable water management and climate change are also contributing factors. A study conducted by the Centre for Science and Environment found 48% of India's urban water supply comes from groundwater. In seven of India's ten populous cities, groundwater levels have dropped significantly over the last two decades.

Bangladesh also faces serious water issues, given the rapid industrial boom, rapid urbanization, and extensive agrochemical use. Untreated wastewater is being dumped into rivers and distributaries. Bangladesh gets 92% of its water from rivers originating in India and China. This water is also under intense pressure, given the population growth in upper riparian states, where they want to acquire as much water as they can to support their growing population.

In all three countries, urbanization is affecting freshwater resources through two principal pathways. The first is a direct impact, whereby the expansion of urban populations increases groundwater extraction to meet growing demands for water supply, sanitation, and drainage. The second is an indirect impact, in which rapid urbanization contributes to climatic shifts and altered hydrological patterns, thereby affecting the ecosystem on a broader scale. Deforestation, large-scale infrastructure development, and the conversion of agricultural land for commercial and residential purposes have significantly reduced groundwater recharge. For instance, in Multan, known as Pakistan's "Mango City", thousands of acres of mango orchards were reportedly cleared in 2021 to make way for private housing societies, resulting in substantial farmland loss and public outcry. Such land-use changes diminish natural infiltration rates, reduce aquifer replenishment, and increase surface runoff, which in turn exacerbates flooding risks. Collectively, these processes alter precipitation regimes, accelerate groundwater over-exploitation, and disrupt ecological balance, thereby highlighting the multifaceted ways in which urbanization degrades freshwater resources.

Policy Recommendations

Urbanization in South Asia has significant implications for water resources, particularly in terms of land use, groundwater extraction, and climate shifts as depicted in the above research. However, to address these identified challenges, the following are some policy recommendations:

- A practical framework for land use needs to be introduced based on the land features to minimize adverse impacts on groundwater.
- Strict regulations for the extraction of water through sustainable practices should be introduced to avoid degradation of land as well as groundwater aquifers.
- Modern techniques need to be employed to regulate the use of water both for domestic use and commercial use, which will include monitoring, leak detection, and metering.
- The boundaries of cities and limits on the population density have to be defined to avoid overpopulation; this will help in navigating the use of internal fresh water, avoiding overexploitation.

- Environmental-friendly infrastructure needs to be promoted to meet the needs of the people as well as safeguard the ecosystem so that the internal freshwater resources replenish continuously.

Conclusion

Conclusively, this research paper has taken into consideration the impact of the growing urbanization in this 21st century world on the internal freshwater resources. This research encompasses the region of South Asia, particularly its three major countries: Pakistan, India, and Bangladesh. This study used a mixed-method approach, combining the review of existing literature with quantitative analysis, to depict how the increasing urban population has put a strain on the water resources of these regions. The evidence is then strengthened with the application of Urban Environmental Transition Theory. This study, through its quantitative regression and correlation, and the literature review, reveals how the increasing direct extraction of the water resources has significantly impacted the per capita water availability in these three countries. As per the results of these analyses, a rejection of the null hypothesis was observed, which underscores the fact that urbanization has adverse effects on per capita water resources. This negative correlation between internal freshwater resources and urban population portrays a concerning trend. Apart from this, qualitative analysis reveals how the anthropogenic activities being carried out in urban settings not only put a strain on freshwater resources but also on the environment and ecology. The results of this research marked Bangladesh as the most vulnerable country out of the three countries in the region of South Asia. In addition to this, the forecasting of the next decade is also a part of this research, which indicates severe water scarcity in Pakistan in the upcoming years if the current trends persist. Since this study clearly shows how disastrous such circumstances could be, better policy recommendations have also been a part of this study to prevent the worsening of such conditions and ensure the well-being of current and future generations.

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