Investigating Trends in World Migration from 1990 to 2020 by *Complex Network Analysis*

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Complex Systems and Networks

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DECLARATION

We, **Aditi Pandey, Mahiguhappriyaprakash, Neha and Sharon Seenu** certify that we agree with all the contents of the project.

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Abstract

Over the years, the international migration trend has changed very drastically due to numerous factors. People migrate from (or) to different countries in search of stable economic conditions, safety and familial responsibilities. A notable consequence is the drastic changes in the socio-economic status of countries, both in positive and negative ways. This project attempts to investigate the change of pattern in world migration from 1990 to 2020 using complex network analysis. Out of the four data-sets that we obtained from the UN database, one of them is used for generating a complex network using the 'networkx' module of python. Investigating the core structure of the network using k-core decomposition, we were able to find the regions that hugely contribute to world migration. Finding the centrality factors helps us find the most preferred and most influential region in the world. Clustering coefficients of such networks tells us about how well-connected different regions of the world are, in terms of migration. The other data-sets were used to determine the most and least preferred destinations for migration by different gender and age groups. Comparison of gender-based migration patterns gives us a clear picture of the socio-economic statuses of gender groups in different countries. Studying the migration pattern of different age groups allows us to infer various reasons for migration. For instance, student groups migrate mainly in search of quality education and stable job opportunities. The position of India in the world migration trend has also been investigated in detail.

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1 Introduction

The period of the 21st century has witnessed significant advances in technology, globalization, economic transformation, cultural exchange and other aspects of human life in which migration across nations or regions has emerged as a defining feature due to its dynamic influence on the structures of economies, civilizations, human lifestyle and cultures. Human mobility has a complex history, spanning from early human migrations motivated by survival instinct to the current migration of millions seeking economic prosperity or safety.

In light of this, the goal of this project is to investigate and explore the major global migration trends over the last 30 years i.e. 1990 to 2020, to shed light on the causes, trends, and effects of this worldwide phenomenon as well as how it has changed over time, in the hindsight studying its social and economic consequences.This study is not only interesting from an academic point of view, but also essential for policy makers, governments and organizations. We aim to offer an overall understanding of the forces shaping people's movements all over the world and study its impact, by analyzing data on migrant stock and case studies. First, it will take an in-depth analysis of major trends within the various regions and then

Figure 1: People migrating from Ukraine during the Russian invasion in 2022. Source: **TIME**

examine a historic context for migration around the world. Analysis of the network helps us to identify major migration centers around the world as well as study status of India in global migration. Considering international movements, we will investigate the economic, political, cultural and societal drivers of migration and the impact of such trends on host states, migrants and global relations is also to be discussed in the report.

2 Data and Methodology

The relevant data to study the international migration between 1990-2020 can be obtained from the UN website.Year in the dataset is the mid-year, estimated from 1 July. The following sets of data has been used for the analysis:

1. Sex and origin
2. Sex and destination
3. Origin and destination
4. Age, sex and destination

The statistical data is analyzed with the help of trendline and world map grouped according to continents, countries, development and income of the regions to study various aspects of migration such as the least and most preferred countries/regions, the time frames where different countries faced sudden increase in inflow/outflow of migrants, etc.

Datasets (1) and (2) consist of international male and female migrant stocks (in numbers) to/from different countries, continents and socio-economic regions of the world.

Dataset (3) has been used to generate directed networks of world migration between 1990 and 2020 using Networkx in Python. The countries or socio-economic regions serve as the nodes of the network and the number of migrants are the weighted links between nodes.The networks have been used to study various aspects of world migration as a complex network such as the clustering coefficient, degree distribution, structure and core of the network. K-core decomposition has been employed to study the core structure of the network. Centrality factors like degree and betweenness centralities have been found to determine the most popular and most influential nodes throughout the period 1990-2020.

Dataset (4) is used to study the reasons for migration of people from different age groups and determine the most preferred destination of different age groups and how it affects the socio-economic status of the countries they originate from or migrate to.

3 Analysis

3.1 Complex Network Analysis

3.1.1 Networks

Part 1 of the project simply involves the plotting of network graphs for individual years from 1990-2020 in an interval of 5 years.

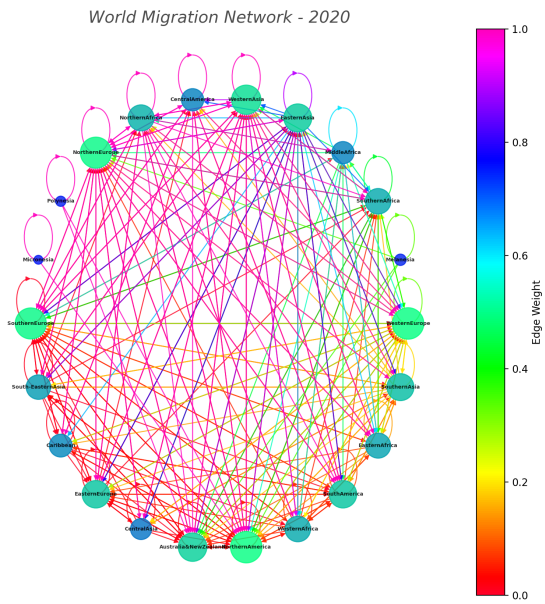


Figure 2: Network for 2020

This has been done for all the years which can be accessed through this link. In this, the threshold of no. of migrants is kept above 5000. The self links in the nodes shows the migration within the region, for example, if we find a self link for Western Europe, under which we have countries such as Austria, Belgium, France, Germany, Switzerland etc. that implies that there is migration among these countries. Here, the size and color of nodes varies according to the degree of each node whereas the color of directed edges vary according to the no. of migrants(i.e. weight of edges) from one region to another, represented by the colorbar in Figure 2.

3.1.2 Other Parameters of Graph

[1] a) Degree Distribution:

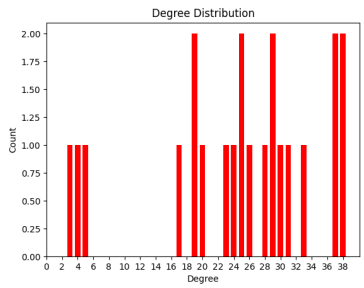


Figure 3: Degree Distribution for 2020

[1] b) In - Degree Distribution:

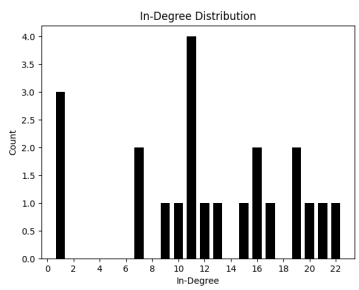


Figure 4: In-Degree Distribution for 2020

[1] c) Out - Degree Distribution:

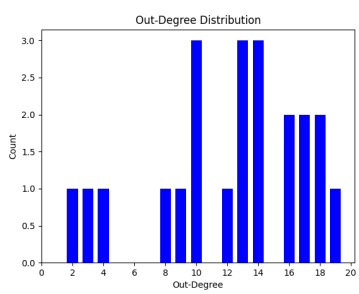


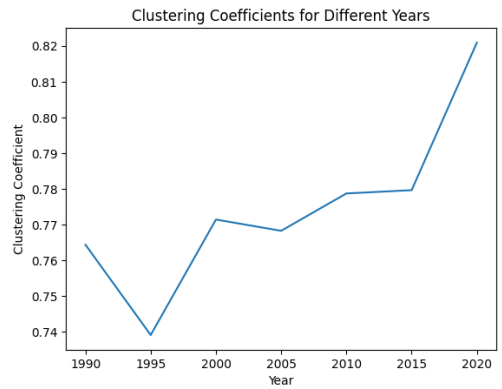
Figure 5: Out-Degree Distribution for 2020

This has been done for all the years.It can be accessed through the link.

[2] Clustering Coefficient: Here the clustering coefficient basically tells you how well the world is connected with each other. Here the average value of clustering coefficient for complete graph is implying that more than half of the population has neighbours which are also connected with each other very well. The following graph shows the evolution of the clustering coefficient of our network from 1990 to 2020.

1990	0.764375856756575
1995	0.7391178374684501
2000	0.7714180902700392
2005	0.7682685242803735
2010	0.7787182777084375
2015	0.7796397086747305
2020	0.8209242327470967

((a)) Clustering Coefficient



((b)) Trendline of clustering coefficient

Figure 6: Clustering coefficient for different years from 1990 to 2020 along with its trendline over the period

[3] Degree Centrality

Degree centrality and closeness centrality

Year	Most preferred destination	Control over the migration network
1990	Western Europe	Western Europe
1995	Northern America	Northern America
2000	Northern America	Northern America
2005	Western Europe	Northern America
2010	Western Europe	Northern America
2015	Western Europe	Northern America
2020	Western Europe	Northern America

Figure 7: Degree Centrality

[4] K-core: Figure 8 shows the core of the world migration network in 1990. The k-cores that have been generated are fully-connected since the core number of each node is the same that consists of all the main continents of the world. We observed that core number remained 17 from 1990 to 2005 which changed 18 in 2010, 19 in 2015 and 20 in 2020. This increase in the core number of the k-core network suggests that the nodes existing in the core are forming stronger connections with each other, leading to a more cohesive core structure. It also indicates that the core of the network is more stable and it facilitates better information flow. Southern Africa left the network in 1995 and re-emerged in 2010 while South-eastern Asia left the network by 2015. In the case of Southern Africa, conflicts and civil wars in the region began to subside, which reduced the number of people seeking refuge in neighboring countries. Significant economic growth in Southeast Asian countries might have resulted in the decrease in the outflow of migrants from these regions, eventually leading to the elimination of the region from the core of the network.

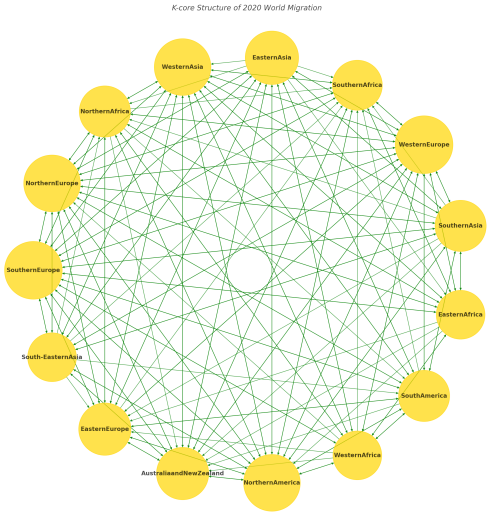


Figure 8: K-Core of 2020 with core number 20 for every node

This is done for all the years. It can be accessed through the link.

[5] Network Density: It is described by the ratio of the number of connections existing in a network to the total number of connections that could possibly exist in the network. As observed from the graph, there is a dip in network density in 2000 which may be due to economic slowdown and strong immigration policies in some regions.

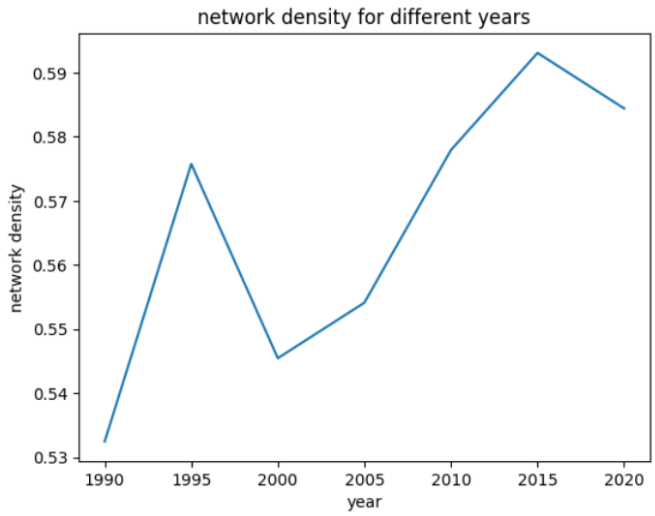


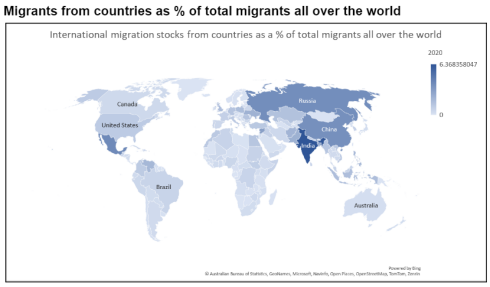
Figure 9: Trendline of network density

3.2 Sex and Origin:Countries

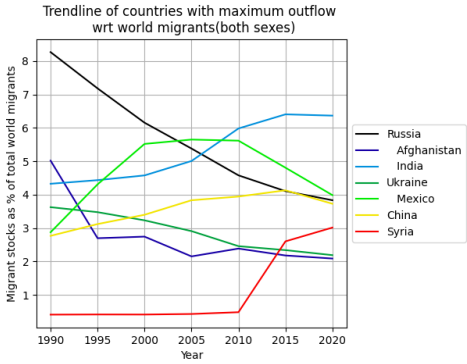
Various methods have been employed to study the outflow of migrant stocks from different countries, continents, development and income groups. Let us first discuss about the countries with maximum outflow (migration stock as a % of total world migrants all over the world):

Figure 10 shows the countries which contributes the most to outflow of migrants as well as the changes in the trends over the period of 30 years is also inspected. The drivers for migration are multi-dimensional varying from the need to secure a good lifestyle to taking refuge in a country for safe environment and from striving to have a better job opportunities to climate change being one of the causes.

Mexico ([17],[6],[9]) has seen a huge increase in the outflow of migrants during the 1990s due to the increase in job opportunities in the southeastern cities because of the potential



((a)) World map



((b)) Trendline of top countries

Figure 10: World map and trendline of migration stock from different countries around the world as a percentage of total world migrants.

impact on the prospects in labor markets of comparatively less-skilled African Americans. The analysis of emigration from Russia ([3],[25]) has identified five stages of modern Russian emigration caused by social, political and economic changes in Russia and by legislation changes in host countries. On the other hand as we look through the history of the People's Republic of China ([18],[23]), migration has been managed for selective developmental aims and often in service of broader geopolitical goals. As a result, Chinese authorities have taken a practical approach to international migration: accommodating the migration flows they considered desirable without much long-term planning or more fundamental reforms.

A significant increase in migration is observed in Syria [19] from 2010 as a result of Syrian Civil War, Russian military action and the international coalition led by the US in 2015 to fight ISIS. Numerous Syrians have been forced to flee in search of safety as a result of the conflict's extensive violence, destruction of infrastructure, deaths and grave violations of human rights. A similar civil unrest, conflict, political turmoil and economic devastation was found to be the cause of migration in Afghanistan [26] forcing people to take refuge in neighboring nations.

At the same time, another aspect of migration depicts a picture about the outflow of migrants with respect to population of country and hence top 5 countries are being analysed to study the factors for migration.

The first Gulf war in 1990-1991 together with the recent expulsion of Palestinians [27]

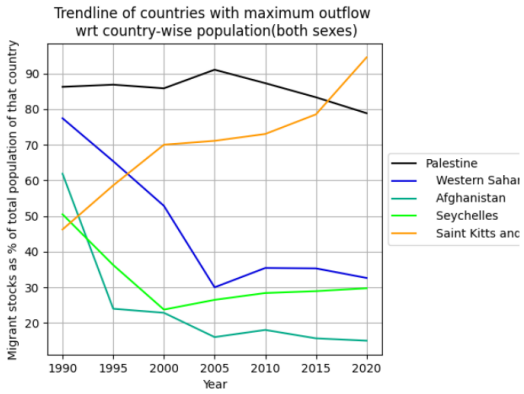


Figure 11: Migration from continents as a percentage of total population of that country

from Iraq in 2006 caused additional waves of Palestinian refugees around the world. In the period of 2000s, the number of returnees declined sharply as a result of the refusal of Israel to accept their return and the dangerous living conditions in Palestine. A sharp decline is observed for Afganistan as the large number of Afghan refugees during the Soviet-Afghan War (1979-1989) significantly reduced after the withdrawal of Soviet forces in 1989. During the Taliban era, Afghanistan faced international isolation due to the regime's policies and its association with terrorist groups which limited opportunities for legal migration or asylum-seeking in other countries.

Seychelles [20], country with a tropical and humid climate, emigrants represented 37.4% of its total population in 2020. Climate change due to rising sea levels cause the uncertainty for securing their lives forces people to migrate from the republic. Saint Kitts and Nevis [13], an island country has population of around 45,000, experienced migration to seek better economic prospects,better living condition and in order to avoid natural disasters. Our analysis of Western Sahara's migration [12], from 1990 to 2005, reveals a decline in migration rates, followed by a subsequent increase peaking at around 5% . The region has been marred by persistent disputes between Morocco and the Polisario Front, contributing to internal displacement with individuals taking refuge in neighboring countries like Algeria, leading to the creation of refugee camps.

3.3 Sex and Origin:Continents

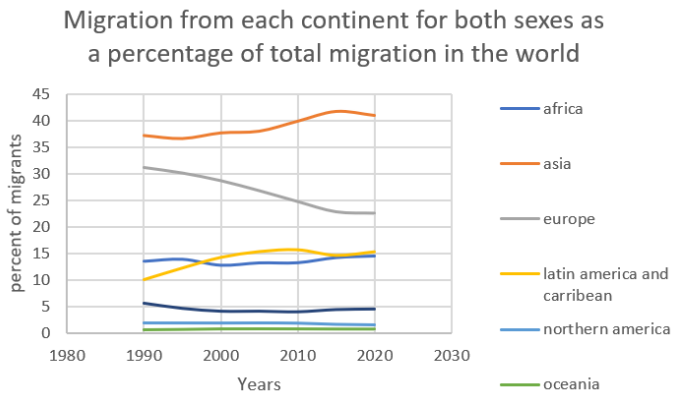


Figure 12: Migration from continents as a percentage of total world migrants

According to a survey conducted by the IPL researchers, migration from Africa [4] is mainly due to economic factors (searching for jobs or seasonal work). Other reasons include family related factors (following family or friends) and a small fraction of people migrate because they fear for their safety.It was also found from the survey that men are more likely to migrate than women whereas fraction of women migrate due to family reasons.

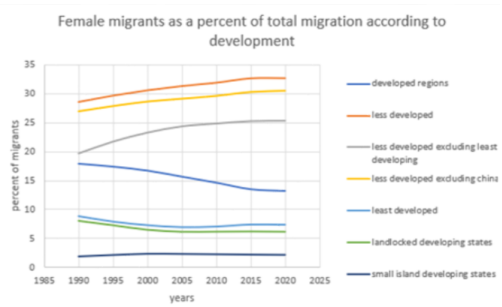
Migration in Northern America [5] is dominated by migration into the region, primarily to the United States. Nearly 59 million migrants were residing in Northern America from a variety of regions in 2020. Hence, due to its increased opportunities and advanced lifestyle, people tend to stick around the place, resulting in very less migration from the place.

Asia is the most populous continent, with a diverse range of countries and demographic structures. The sheer size of the population means that even modest migration rates can result in significant numbers of people moving within the region or to other parts of the world. Economic disparities within Asia, along with the pursuit of better economic opportunities, improved living standards, educational opportunities in Asia fostered cultural exchange and economic interactions. The policies of certain Asian countries [7] promoting overseas employment or skilled migration can influence migration patterns.

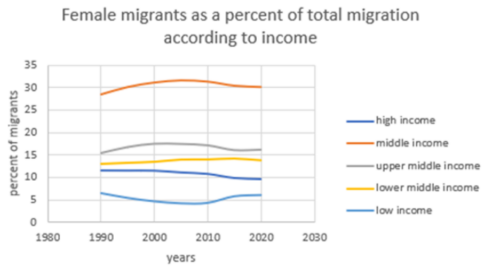
The early 2000s saw economic growth and political stability in some European countries, which might have reduced the push factors for emigration. Conversely, the global finan-

cial crisis of 2008 and subsequent economic challenges in certain European countries may have impacted migration patterns. The United Kingdom's decision to leave the European Union has influenced migration patterns, with changes in immigration policies and potential impacts on the movement of people between the UK and the EU.

3.4 Sex and Origin:Development and Income Regions

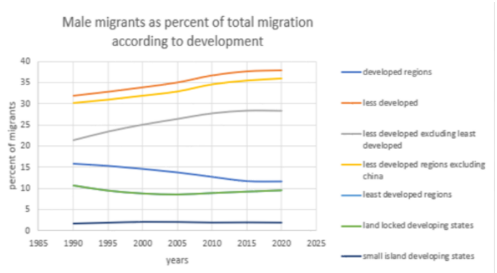


((a)) According to development

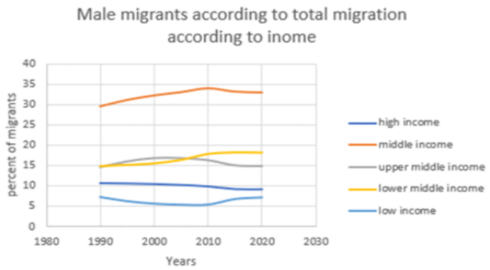


((b)) According to income

Figure 13: Female migration from regions according to development and income as a percentage of total world migrants.



((a)) According to development



((b)) According to income

Figure 14: Male migration from regions according to development and income as a percentage of total world migrants.

Evidence shows that female migrants from less developed country [8] account for a majority and/or a growing share of labor migrants for some developing countries (SriLanka, Indonesia, Philippines, Bangladesh, Thailand etc.). The growing demand for low-skilled services in developed and aging economies, the persistent poverty and high unemployment in

developing countries explain the recent increasing share of women among the international migrants who move from developing to OECD countries in search of work. The reason for male migrants is more or less the same , however job opportunities for men are more than for women. The social stigma surrounding when a female migrates is quite large, therefore it explains the reason why male migrants are more than female migrants in most of the less developed regions. Comparing the trendline of male and female migrants as a percentage of total migrants for Bangladesh[1], we see a significant disparity in the socio-economic status of men and women.

According to the Asia and Pacific Migration Journal, people of the small-island countries [34] migrate due to complex reasons such as to improve their economic situation and lifestyle, for example Puerto Rico[30], to be close to friends or family, for political or safety reasons or to protect themselves from environmental or other threats. The ongoing climate change like sea-level rise, rising temperature and extreme weather events, adversely affects these regions, both economically and physically. The Philippines[2], a developing economy, highly prone to storms, floods and earthquakes, while in the southern region of Mindanao, conflict and instability drive displacement.

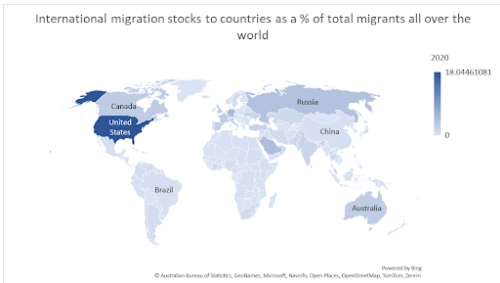
As we see from Figure 13 and 17, the fraction of people migrating from the low income countries [14] is the least. High cost of emigration, geographical and linguistic barriers account for a small fraction of the population of low income countries migrating. One plausible explanation for the dip in 2005 from above graph could be the measurable decline of the global economy in 2005, partly due to growing surpluses in the Asian, European and oil-exporting economies and the rising external deficit of the US. While the above trend has only been significant in male migrants, the percentage of female migrants originating from low income countries has remained relatively constant [10]. The socio-economic status of women in these countries such as poor education, gender pay gap and lower employment-to-population ratio could account for this pattern. For example, we found, Ukraine has experienced a series of economic crises, social upheavals and wars over the past 30 years due to several reasons, including the dissolution of the USSR [22].

Migration from middle income country like Brazil, Turkey, South Africa etc. [32] is basically to improve the living standards and seek better opportunity of jobs and educa-

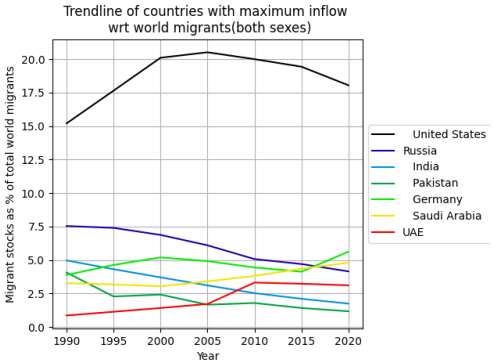
tion. Some middle-income countries have experienced economic growth and improved living standards over the years, there may be less incentive for individuals to migrate for better opportunities elsewhere. Economic shifts, global market changes, and the emergence of new economic hubs can influence migration patterns.

High-income countries provide stable economic environments with good job opportunities and high standard of living, so citizens are less inclined to migrate. They also have better social services and welfare programs that provide support to their residents. This safety net can reduce the need for individuals to migrate for economic reasons or social assistance. The further analysis was also done using graphs available in the **link.**

3.5 Sex and Destination:Countries



((a)) World map



((b)) Trendline of top countries

Figure 15: World map and trendline of migration stock to different countries around the world as a percentage of total world migrants.

From graph 15, we can infer that the most preferred destination by the world migrants is the USA[29]. Though it is commonly perceived that there should be a continuous increase in the immigrant level, we observe kinks in the graph from 1990 to 2000 and a downward trend following it. According to the Pew Research Center, the sharp rise of immigrants during the 1990s is due to the rapid economic and job expansion. As the economy went into a downturn after 2001, the number of migrants going to the United States declined. If we were to compare the migration trends *from Mexico [17]* (10) and *to the USA* (15), we

observe a similar trend. The report from the Pew Research Center states that this is due to the change in Mexican labor force (the largest single source of U.S. immigrants).

The sharp decline in the percentage of migrants to Germany [36] from 2005-2010 is accounted by global economic crisis of 2008, leading to Euro crisis and other economic and institutional shocks. The Blue Card initiative in 2012, which was designed to attract highly skilled workers from abroad and address labour and skills shortages, helped increasing the percentage of migrants into Germany since 2015.

The Gulf countries such as Saudi Arabia [15] and UAE [33] have experienced rapid economic growth, driven primarily by their vast oil and natural gas reserves which led to an expansion of various industries, creating job opportunities in sectors such as construction, finance, healthcare, and hospitality, also the tax-free income in KSA [11] is an attractive incentive for migrants. These countries are known for their political stability, relatively low crime rates and diverse population provides a secure living environment and appeals to migrants as it offers exposure to different cultures and experiences. However, women migration is quite small in these countries [16] owing to patriarchal strict rules and lesser job opportunities.

Russia [3] has a diverse and growing economy, providing employment opportunities in various sectors such as energy, technology, and construction. The geographical proximity of Russia, high quality education and it being rich in natural resources makes it the second preferred destination for the migrants.

3.6 Sex and Destination:Continents

The trend for Asia [2] has increased after 2005 which can be accounted by the economic growth in some Asian countries. Rise of Asia as a global technology hub and increasing globalization of businesses led to more companies expanding their operations into Asia. The promotion of regional economic integration, such as the ASEAN Economic Community, facilitated the movement of labor within the region. On the other hand, the growth of the tourism sector in countries like Thailand, Malaysia, and Vietnam led to an increase in expatriates working in hospitality, entertainment, and related industries.

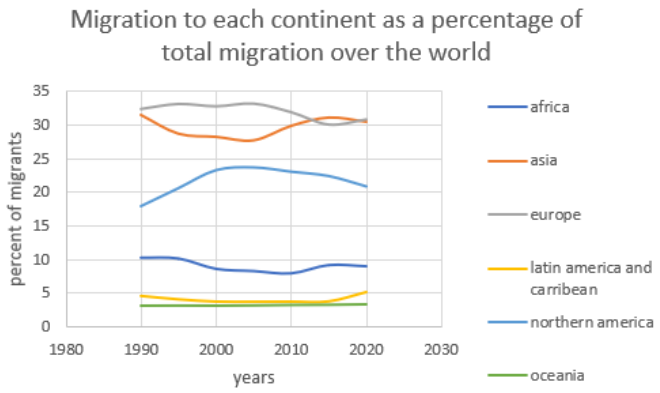


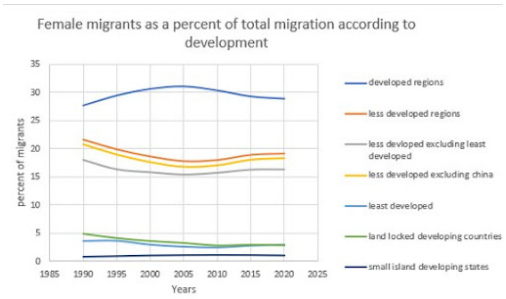
Figure 16: Migration to continents as a percentage of total world migrants

There has been a significant inflow of migrants from Eastern to Western Europe [21] from 1990 after the fall of the Iron Curtain and the dissolution of the Soviet Union because people sought better economic opportunities, political asylum or refugee status. There are several reasons for Europe attracting a large part of the world's migrants, some of them being the expansion of the European Union, refugee crisis due to wars in the Balkans, Iraq, Syria, Afghanistan and other parts of the Middle East and North Africa. After the late 2010s, immigration policies have been tightened to tackle the increased migration flows and political pressure.

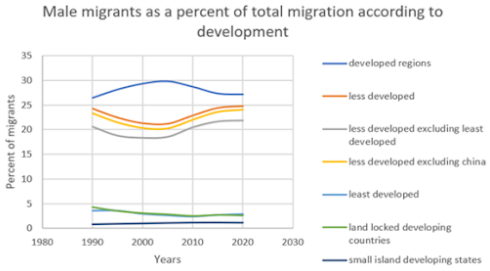
Although Northern America [21] is expected to be most preferred, the graph says otherwise. This could possibly be due to geographical proximity of Europe with Asia and Africa, which goes easy on the migrants in terms of travel costs, access and familiarity. Other reasons might be the colonial ties that the other countries have with Europe, strict immigration policies of the countries of Northern America.

3.7 Sex and Destination:Development and Income Regions

Developed regions typically offer better educational and career advancement opportunities. Women may choose to migrate to access quality education, professional development programs, and career paths that align with their goals as these regions have more established frameworks for gender equality and women's rights. The presence of effective law



((a)) Female migration



((b)) Male migration

Figure 17: Gender-wise migration to regions according to development as a percentage of total world migrants.

enforcement, lower crime rates, and overall stability can make a destination more appealing. Developed regions may be more culturally diverse and inclusive, providing an environment where people from various backgrounds can feel accepted and integrated. The reasons are more or less the same for countries having high income.

Political instability and conflicts due to war has pushed many refugees to seek refuge in neighboring less developed nations because they find it more accessible than other regions. Unprecedented environmental factors have also displaced populations from various regions of the world to these country as they are located in geographically safer sites. Less developed countries with policies that could attract foreign investment have been observed to have high influx of migrants.

Over the period from 1990 to 2020, there has been a significant decrease in the influx of migrants to middle income countries. This is possibly due to the economic growth creating better employment opportunities, strict immigration policies that limit the inflow or the advancement in technology might have allowed people of middle income countries to work remotely. It could also be that the decrease in the population growth and birth rates have less pressure for people to migrate for better prospects.

The further analysis was also done using graphs available in the **link.**

3.8 Age Factor

It has been observed from the graph that male migrants under the age group of 20 to 50 see more migration as compare to other age group.

Young Adults (20-35) : This age group often migrates for educational purposes, pursuing higher education or specialized training in a foreign country,like UK, Germany and USA. The seekers in this age group often move to regions with strong job markets, especially in sectors like technology, finance, and healthcare.

Middle-Aged Adults (35-50) : Middle-aged individuals may migrate for career advancement, pursuing job opportunities that align with their skills and experience. Migration for family reasons, such as reuniting with family members or providing a better environment for children, is common in this age group. Some middle-aged adults migrate for entrepreneurial opportunities, seeking to establish businesses in foreign markets which can be accounted for the rise in number of immigrants to UAE and Saudi Arabia [24].

Children and adolescents may migrate with their families for family reunification or due to their parents' migration for work or educational reasons.Older adults often migrate for retirement, seeking a more favorable climate, better healthcare, and a more relaxed lifestyle.

The further analysis was also done using graphs available in the **link.**

3.9 Socio-Economic consequences

Social consequences: One of the foremost advantage of migration is that it promotes cultural diversity and cross-cultural understanding but at the same time cultural differences and language barriers can result in social isolation. It also contribute to population growth in receiving communities, potentially offsetting declining birth rates whereas labor market faces job competition, wage suppression, and exploitation of migrant labor. It also involve changes in family dynamics that impacts relationships and well being. Migration can contribute to "brain drain" in origin countries, where highly skilled individuals leave for better opportunities abroad. For example, we observed that Nepal [31] is popular destination for women migrants as it contributes to social causes, cultural experiences, adventures, spiritual practices and includes study in fields related to Himalayan studies, culture, development

studies and cultural anthropology.

Economic consequences: Migration comes with its own share of economic out-turn which impacts the GDP of both origin and destination countries. For instance, skilled migrants contributes to increased productivity, innovation, and economic growth in receiving countries, positively influencing GDP. Canada has a pro-immigration policy that has contributed to population growth which led to increased consumer spending, benefiting various sectors of the economy. Germany, for example, has experienced labor shortages in various sectors, and the influx of immigrants has helped fill these gaps and support economic productivity. Fluctuations in remittance flows or disruptions can impact GDP, for example, countries like Nepal and Bangladesh, heavily depend on remittances and cities with significant immigrant populations, such as London and New York, have faced challenges in providing affordable housing, impacting both immigrants and the local population.

3.10 India : To and Fro

As Origin: The UN Migrant Stock Database shows that the population of Indians living abroad has grown to reach 1.80 Crores by 2020. On an average, there's a rise in the immigrant population in between 1990 to 2020 by 3.4 percent but there have been periods when the departure was faster. Many individuals migrate from India [28] to other countries in search of better job prospects and higher salaries, especially in fields like IT, healthcare, engineering,business and finance. India is a source of international students seeking higher education in countries renowned for their educational institutions contributing to brain drain concerns. Individuals migrate to countries with a higher standard of living, better healthcare facilities, more secure environment, improved quality of life and professional development.

As Destination: World Bank data [35] from 1975 to 2020 shows that international remittance inflow to India peaked in 2019, a year before COVID struck. India has several reputed educational institutions, attracting students from neighbouring countries for higher education in fields such as engineering, medicine, business, and the arts. India's growing economy and emerging job markets, make it an attractive destination for skilled professionals and entrepreneurs. It's rich cultural heritage, diverse traditions and historical significance draw

individuals interested in exploring and experiencing a unique cultural environment acting as a tourist destination. Compared to some western countries, the cost of living in India can be more affordable, making it an attractive destination for those seeking a relatively lower-cost lifestyle. English is widely spoken in India, making it easier for migrants, especially from English-speaking countries, to communicate and integrate into the society. India's connectivity with the rest of the world, both physically and digitally, makes it easier for individuals to migrate and stay connected with their home countries. The initiative aims to attract both domestic and foreign investment in various sectors, with the goal of making India a global manufacturing hub.

3.11 Gravity Model of Migration

A gravity model assumes that the flow between two regions in the world are directly proportional to their size, be it population or GDP, and are inversely proportional to the physical distance between them. This is analogous to the Newton's law of gravitation, which deals with the gravitational force between two objects in space. This is very useful, in case of bilateral migration data, in understanding the various factors affecting migration due to the impacts caused by public policies existing in different countries. While analysing the networks qualitatively, we were able to find a few factors that suggests that our network follows gravity model of migration:

(i) We observe a similar pattern in the migration from one region to another. The main factors of migration being better employment opportunities and a stressful environment in countries, due to war and global economic crisis. This suggests that the migration flow is dependent on how stressed the political, social and economical conditions of a region is. This qualitatively follows the gravity model of migration.

(ii) We also observe while investigating several reasons for migration that the majority of the migration flow from origin is seen in neighboring countries. This goes along with the gravity model of migration, in the sense that the less the distance, the more is the migration.

(iii) It is further evident from our network analysis that the larger the area (in terms of GDP) of the destination, the larger is the migration.

4 Summary and Discussion

In the pursuit of a deeper understanding of migration patterns, our research focuses on unraveling the complex web of push and pull factors influencing diverse populations, examining the far-reaching consequences on economic landscapes, family structures, and beyond.

Our analysis revealed that economic challenges, population growth, war, conflicts, environmental pressures, political instability, limited access to education and social facilities have been identified as major push factors behind migration. We also explored various pull factors that facilitates migration, such as improved quality of life, good economic opportunities, protection of human and civil rights and favourable climate. The data assisted us in identifying the major centres of global migration, which turned out to be the nations with the highest emigration rates and the most popular destinations that were Afghanistan, India, US, Saudi Arabia, Russia, UK and Germany. Our inspection led us to the conclusion that Northern America controlled the network throughout this period whereas Western Europe turned out to be the most preferred destination. The inter-connectedness of the network has increased over the years due to globalization, awareness and in pursuit to have a good quality of life. Our study of origin and destination on the basis of gender reveals the socio-economic disparity between males and female,for instance in less developed and low income country, women are typically stereotyped to be the homemakers and males as the primary bread-winner are obliged to migrate.

In our focus on India, it has emerged as a viable destination and origin during the past 30 years. The surge in migration from India in recent years can be attributed to improved resources and increased awareness of educational and career opportunities. However, it has also been noted that it has functioned as an excellent destination because of human resources, spiritual upliftment, hospitality and cultural diversity.

Through this comprehensive exploration of migration dynamics and their far-reaching impacts on GDP, family structures, and societal dynamics, our research contributes valuable insights essential for informed policy making and a nuanced understanding of the intricate relationship between human mobility and its multifaceted consequences.

5 Future Directions

We were able to analyse various factors that contribute to the emigration and immigration in different regions of the world, according to the data that we acquired from the UN database. However, since world migration is a vast topic of research interest, a part of the analysis is yet to be done.

- The push and pull factors for migration in a few countries that topped the list are yet to be analysed.
- A quantitative analysis of the net migrant flow, annually, can be done with the provided data set.
- An in-depth analysis of migration in different age groups can be done.
- The dynamics of the network was well-studied to an extent by observing the appearance and disappearance of certain nodes. Quantities like edge activity and inactivity can also be studied.

6 Authors' Contributions

The primary code for network was written by Aditi Pandey for 2020. This was modified for different years accordingly:

i) 1990, 1995 - Sharon Seenu

ii) 2000, 2005 - Neha with Sharon Seenu

iii) 2010, 2015 - Mahiguhappriyaprakash

The different parameters of the network was found accordingly:

i) Degree Distributions - Sharon Seenu

ii) Clustering Coefficient - Sharon Seenu

iii) K-core - Mahiguhappriyaprakash

iv) Centrality - Mahiguhappriyaprakash

v) Network Density - Neha

Everyone read the relevant research papers and gave their inputs of what the they could make of it.

i) Trendlines for evolution - Sharon Seenu

ii) Analysis using world maps - Mahiguhappriyaprakash

iii) Historical aspects - Neha

iv) Analsyis of Data - Aditi

Report writing was a collective effort of all the members together. Sharon, had sufficient knowledge of writing in latex, everyone wrote their parts and gave it to her to be added to the report file. Aditi and Mahi edited the report.

Acknowledgement

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We express our sincere gratitude to Mr. Sarthak from the Takshashila Organisation for lending support and guidance to us whenever required.

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7 Appendix

```
# -*- coding: utf-8 -*-
"""Network.ipynb

Automatically generated by Colaboratory.

Original file is located at
    https://colab.research.google.com/drive/1YrV1qLtHu8Na4zCrp6XwwAf9AsMRYdfC

# Code to Generate Network
The following code snippet has been worked out by Ms. Aditi Pandey. The code generates the complex network of the given world migration data for the years 1990-2020, in a presentable format.
"""

pip install xlrd pandas networkx matplotlib   #installing the required libraries

import pandas as pd
import matplotlib.pyplot as plt
import networkx as nx
import numpy as np
# Loading the Excel data into a Pandas Dataframe
df = pd.read_excel("/content/2005 FINAL.xlsx")

# To extract edge data
edges = df[['SOURCE', 'TARGET', 'WEIGHT']].values
# To create a directed graph using NetworkX
G = nx.DiGraph()
# To add directed edges
for source, target, weight in edges:
    G.add_edge(source, target)

#defining an array to store the degree of each node
degs=[]
#defining an array to store the size of each node
nodesize=[]
for i,deg in nx.degree(G):
  degs.append(deg)
  nodesize.append(25*deg)

#defining a colormap for nodes
colormap = plt.get_cmap('winter')
```

```python

degrees = dict(G.degree())
#to give different colours to node based on their degree
node_colors = [colormap(degree / max(degrees.values())) for degree in degrees.values()]

for index, row in df.iterrows():
   G.add_edge(row['SOURCE'], row['TARGET'], weight=row['WEIGHT'])
# Extract edge weights
edge_weights = [row['WEIGHT'] for index, row in df.iterrows()]

# Define a colormap for edges
cmap = plt.cm.gist_rainbow
edge_colors = [cmap((weight)*0.000001) for weight in edge_weights]

# Draw the graph with edge colors
pos = nx.shell_layout(G)
# Creating a plot
fig=plt.figure(figsize=(8,8),dpi=200)
plt.grid(True, linestyle='--', alpha=0.7)
nx.draw(G, pos, with_labels=True, node_size=nodesize, node_color=node_colors, node_shape='o'
    , font_size=5, font_color='black',font_weight='bold', arrows=True, alpha=0.8, arrowsize
    =9, edge_color=edge_colors, edge_cmap=cmap)
plt.title("World Migration Network - 2020", fontsize=16, color='0.3', style='italic')
# To display colorbar for weighted edges
sm = plt.cm.ScalarMappable(cmap=cmap)
sm.set_array([])
plt.colorbar(sm, label='Edge Weight')
plt.savefig("1.png")
plt.show()
```

Listing 1: Code snippet worked out by Ms. Aditi Pandey to generate the complex network of world migration from 1990-2020 in a presentable format

```python
# -*- coding: utf-8 -*-
"""K-core&centrality.ipynb

Automatically generated by Colaboratory.

Original file is located at
    https://colab.research.google.com/drive/1zRnLgYCng9s6awGE4CWqlkU8dQW1mPee

# Code to Find the Core and Centrality of Network
The following code snippet has been worked out by Ms. Mahiguhappriyaprakash. The code
    generates the core of the network using k-core decomposition with the best k-value.
```

```
    Additionally, the code also computes the degree- and betweenness-centrality of the
    network.
"""

pip install xlrd pandas networkx matplotlib   #installing the required libraries

import pandas as pd
import matplotlib.pyplot as plt
import networkx as nx
import numpy as np
# Load the Excel data into a Pandas DataFrame
df = pd.read_excel("/content/2005 FINAL.xlsx")

# Extract edge data
edges = df[['SOURCE', 'TARGET', 'WEIGHT']].values
# Create a directed graph (DiGraph) using NetworkX
G = nx.DiGraph()
# Add weighted directed edges
for source, target, weight in edges:
    G.add_edge(source, target)

#node with maximum score
def largest_node(centrality):
    """gets the node with the best (largest score)

    Returns:
     int: name of the node with the best score
    """
    return list(reversed(sorted((value, node)
                                for (node, value) in centrality.items())))[0][1]

#To find the degree centrality and hence the popular nodes
degree_centrality=nx.degree_centrality(G)
max=largest_node(degree_centrality)
print("The most preferred destination is ",max)
bet=largest_node(nx.betweenness_centrality(G))
print("The region which has more control over the migration network is",bet)

#To find the core structure of the network using k-core decomposition
G.remove_edges_from(nx.selfloop_edges(G))
core_num=nx.core_number(G)
G1=nx.k_core(G)
G1.degree()
```

```

#visualizing the core
degs=[]
nodesize=[]
for i,deg in nx.degree(G1):
  degs.append(deg)
  nodesize.append(25*deg)
cmap = plt.get_cmap('winter')
degrees = dict(G1.degree())

# K-core graph
pos = nx.shell_layout(G1)
fig=plt.figure(figsize=(19,19),dpi=200)
plt.grid(True, linestyle='--', alpha=0.7)
nx.draw(G1, pos, with_labels=True, node_size=nodesize, node_color='gold', font_color='black'
    ,font_weight='bold', arrows=True, alpha=0.7, arrowsize=9, edge_color='green')
plt.title("K-core Structure of 2005 World Migration", fontsize=15, color='0.3', style='
    italic')
plt.savefig("2005_kcore.png")
plt.show()
```

Listing 2: Code snippet worked out by Ms. Mahiguhappriyaprakash to find the core of the network using k-core decomposition with the best possible k-value. Additionally, the code also computes the degree centrality and betweenness centrality.

```
# -*- coding: utf-8 -*-
"""Degree_distribution.ipynb

Automatically generated by Colaboratory.

Original file is located at
    https://colab.research.google.com/drive/1uk5OCzs5NBwO9IPmZku7N_oKa39ujZsa

# Code for Degree Distribution and Clustering Coefficient
The following code snippet has been worked out by Ms. Sharon Seenu. The code generates the
    degree distribution for every network that has been generated and calculates the
    corresponding clustering coefficient. Additionally, the in-degree and out-degree
    distribution have also been calculated.
"""

pip install xlrd pandas networkx matplotlib   #installing the required libraries

import pandas as pd
```

```
import matplotlib.pyplot as plt
import networkx as nx
import numpy as np
# Load the Excel data into a Pandas DataFrame
df = pd.read_excel("/content/2005 FINAL.xlsx")

# Extract edge data
edges = df[['SOURCE', 'TARGET', 'WEIGHT']].values
# Create a directed graph (DiGraph) using NetworkX
G = nx.DiGraph()
# Add weighted directed edges
for source, target, weight in edges:
    G.add_edge(source, target)

# computing degree distribution
import collections
degree_sequence=sorted([d for n,d in G.degree()],reverse=True)#degree
degreeCount= collections.Counter(degree_sequence)
deg,cnt= zip(*degreeCount.items())
fig,ax=plt.subplots()
plt.bar(deg,cnt,width=0.70,color="r")
plt.title("Degree Distribution-2005")
plt.ylabel("Count")
plt.xlabel("Degree")
ax.set_xticks([d for d in deg])
plt.savefig("Degree_2005.png")
plt.show()

nx.average_clustering(G) #clustering coefficient

# Compute in-degree and out-degree for each node
in_degrees = dict(G.in_degree())
out_degrees = dict(G.out_degree())

out_degrees

in_degrees

# computing in-degree distribution
import collections
degree_sequence=sorted([d for n,d in G.in_degree()],reverse=True)#degree
degreeCount= collections.Counter(degree_sequence)
deg,cnt= zip(*degreeCount.items())
```

```
fig,ax=plt.subplots()
plt.bar(deg,cnt,width=0.70,color="k")
plt.title("In-Degree Distribution")
plt.ylabel("Count")
plt.xlabel("In-Degree")
plt.xticks(np.arange(0, 24, 2))
plt.savefig("3.png")

# computing out-degree distribution
import collections
degree_sequence=sorted([d for n,d in G.out_degree()],reverse=True)#degree
degreeCount= collections.Counter(degree_sequence)
deg,cnt= zip(*degreeCount.items())
fig,ax=plt.subplots()
plt.bar(deg,cnt,width=0.70,color="b")
plt.title("Out-Degree Distribution")
plt.ylabel("Count")
plt.xlabel("Out-Degree")
plt.xticks(np.arange(0, 24, 2))
plt.savefig("4.png")
```

Listing 3: Code snippet worked out by Ms. Sharon Seenu to generate the degree distribution and hence the corresponding clustering coefficient of the world migration network from 1990-2020. Additionally the code also works out the in-degree and out-degree distributions of the network.

```
# -*- coding: utf-8 -*-
"""Clustering_Coefficient.ipynb

Automatically generated by Colaboratory.

Original file is located at
    https://colab.research.google.com/drive/1JfNFSsnV8tLFSBPo58k7s0w3MxglTEXy

# Code to Generate Trendline for Clustering Coefficient and Evaluating Network Density
The following code snippet has been worked out by Ms. Neha. The code generates the trendline
     for the clustering coefficient that has been generated from Ms. Sharon Seenu's code.
    Additionally, Neha worked on finding the network density for the given dataset and
    analysed the trend from 1990-2020
"""

#Clustering Trend
import matplotlib.pyplot as plt #import library to plot graph

```

```
year=[1990,1995,2000,2005,2010,2015,2020]

clustering_coefficient=[0.764375856756575,0.7391178374684501,0.7714180902700392,
    0.7682685242803735,0.7787182777084375,0.7796367086747305,0.773604171957107]

plt.plot (year,clustering_coefficient)
plt.title("Clustering Coefficients for Different Years")
plt.xlabel("Year")
plt.ylabel("Clustering Coefficient")
plt.show()
plt.savefig("cluster_trend.png")

#Network Density
import pandas as pd
# Assuming 'df' is your DataFrame
rows, columns = df.shape
print(f"Number of rows: {rows}")
print(f"Number of columns: {columns}")
n=G.number_of_nodes()
print(n)
E=G.number_of_edges()
print(E)
D=E/(n*(n-1))
print(D)

year=[1990,1995,2000,2005,2010,2015,2020]

network_density
    =[0.5324675324675324,0.5757575757575758,0.5454545454545454,0.5541125541125541,
                  0.577922077922078,0.5930735930735931,0.5844155844155844]

plt.plot (year,network_density)
plt.title("network density for different years")
plt.xlabel("year")
plt.ylabel("network density")
plt.show()
plt.savefig("network_density.png")
```

Listing 4: Code snippet worked out by Ms. Neha to generate the trendline of clustering coefficients obtained from Ms. Sharon Seenu's code snippet and to work out the network density and its trend.