Geospatial Application for Dairy Supply Chain Management

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Abstract: The broad availability of geospatial data has changed how we think about solving problems. There are numerous uses for GIS and remote sensing in a variety of fields. Such a field is supply chain management where GIS is used to map various stages like producers, consumers, processing facilities, suppliers, distribution centers, and transportation routes for better decision making and optimization of flow of goods. This study integrates geospatial technology to map raw material sources, processed product delivery routes, areas served by processing sectors, and ultimately to model the relationships between different elements of the dairy industry. Parameters taken involve import-export data of milk and milk products, roads network, service areas, and satellite derived vegetation index. Aanchal Dairy in Dehradun district of Uttarakhand is considered for this study. The primary data was collected through field visits and the raw data was structured for further analysis. Secondary data was obtained from various verified internet sources. Results indicate certain regions with high quantity of raw milk supply and areas where processed products are delivered. Optimised routes and the areas where Aanchal Dairy provides its services are also defined. Vegetation index shows that places with high raw milk supply have better fodder for dairy cows. Finally, the results are geospatially mapped and various relationships are presented in graphical form.

Keywords: Geospatial technology, supply chain management, dairy industry, network analysis

1. Introduction

The Indian dairy sector has evolved significantly with technological advancements playing a key role in this transformation. The establishment of National Dairy Development Board in 1965 and Operation Flood in 1969-70 was aimed at modernizing and developing the dairy sector using cooperatives. These developments enabled the considerable growth of milk output, from 21.2 million tonnes in 1968-1969 to 121 million in 2010-11, and then to 209.96 million tonnes in 2020-21 (Ministry of Finance, 2021). This makes dairy the most important agricultural commodity, contributing 5% to India's economy and supporting over eight crore farmers. With 23% of the global milk production, India now holds the top spot(Ministry of Finance, 2021).

The dairy sector is, however, susceptible to a variety of losses, including physical, economic, quality, and environmental losses. These losses can be caused by a number of factors, such as spills, breakage, contamination, oversupply, competition, and changes in consumer demand. Globally up to 8.2% of the milk is lost causing damages worth billions of dollars each year (March et al., 2019). As reported by FAO, just 37% of the milk produced in India is processed or packaged, with the remaining consumed as fresh or as unpasteurized milk through informal channels (Punjabi, 2009). This risks adulteration, harmful bacteria growth, and subsequent loss of milk without any further utilization for producing dairy products.

Here, supply chain management plays a critical role towards development of an integrated strategy to unite different entities in solving problems related to the movement of commodities and information. This improves the quality, shelf life, and consumer accessibility of dairy products.Supply chains comprise of upstream and downstream linkages, including commodities, services, and customers (Schmitz, 2011). A supply chain is described as a network of facilities with distribution options that fulfils the tasks of acquiring raw materials, transforming those materials into intermediate and final items, and delivering finished goods to customers. Thus, in order to reduce cost, increase sales and improve customer service, supply chain management organizes and controls the flow of goods, information, and finances among a network of producers, distributors, suppliers, and customers (Leistritz et al., 2009).To ensure that goods are produced and delivered at the appropriate times, in adequate quantities and at the proper locations while minimizing the cost factor and satisfying consumer expectations, supply chain management connects sources, manufacturers, distributors, and retailers (Kumar & Agrawal, 2011).Supply Chain Management has four major decision areas, viz. location, production, inventory and transportation.

The term "Supply Chain Management" first appeared in the early 1990s, though proper integration of GIS and Remote Sensing in Supply Chain Management started in recent years. GIS must be considered a geographic decision support system to improve the existing decision-making (Durga Prasad et al., 2009). These interactive computer-based solutions assist decision makers in data modeling and resolving unstructured issues (Subhas & Sambrani, 2009; Yusianto et al., 2020). Geographic Information Systems are a valuable tool for managing supply chain risks as GIS analysis allows graphical portray of the information. The analysis also lets the firm view the complete profile of the organization, including the location of raw material suppliers, processing units, manufacturers, office and warehouse locations, as well as the locations of distributors, retailers and consumers. Geospatial technologies are also used to map producers, consumers, processing facilities, suppliers, distribution centers, and

transportation routes, facilitating better supply chain management decision-making (Kumar & Agrawal, 2011; Bosona et al., 2013).Some specific examples of the use of GIS in supply chain management are (1) Retail companies (such as Walmart) use GIS to track the location of its products in real time. This information helps to ensure that products are always available in the right quantities at the right stores; (2) Companies dealing with shipping and logistics (such as UPS) use GIS to optimize its delivery routes. This helps to reduce fuel consumption and emissions, and to improve delivery times; and (3) Food industries (such as the Coca-Cola Company) use GIS to manage its global supply chain. GIS helps to track the movement of its products, to identify potential risks, and to plan for future growth.

Uttarakhand, unlike other prime milk-producing states having milk surpluses, produces enough only towards fulfilling its own needs. In addition, the dairy industry continues to face challenges such as low productivity, low quality, erratic supply, varying consumer requirements and natural causes, such as natural calamities disrupting timely supply. Aanchal Dairy is one of the top brands in Uttarakhand serving all 13 districts. It is an apex level State association, administered by Uttarakhand Co-operative Dairy Federation Limited (UCDF). UCDF under the brand name 'Aanchal Dairy' continues to increase milk production despite selling an average of 1 lakh 65 thousand liters of liquid milk per day. Since, such huge production requires an utmost supply chain management system for uninterrupted milk and dairy products supply, therefore through this study use of geospatial applications for a better supply chain is been presented.

This research focuses to integrate the spatial analytical capabilities of remote sensing into a suitable supply chain management system. The purpose is to model relationship between different parameters of a dairy industry and to incorporate geospatial technology towards optimal route finding, planning and scheduling for different regions of the study area.

2. Study Area, Datasets and Software

2.1 Study Area

Dehradun district has been taken as the study area, as shown in figure 1. Dehradun, the capital city of Uttarakhand lies at 30.3165° N and 78.0322° E, and is one of the largest cities in the Himalayas. It is also the most populous city of Uttarakhand, with a population of 16,96,694 (as of Census 2011), known for its scenic landscape, pleasant year-round weather and provides a gateway to the Himalayas.

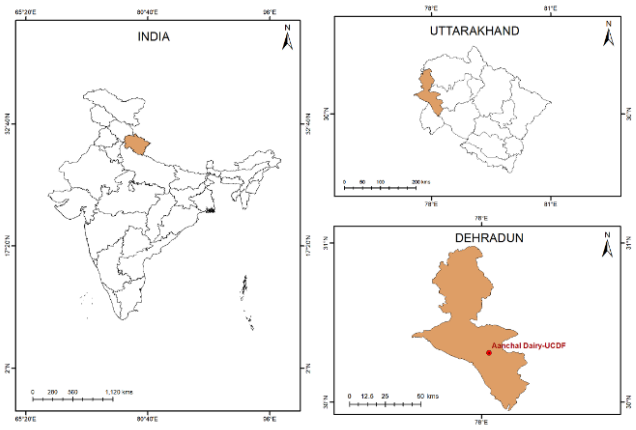

Figure 1. Study Area Map; The point marked with red shows the location of the regional head office of UCDF located in Dehradun district.

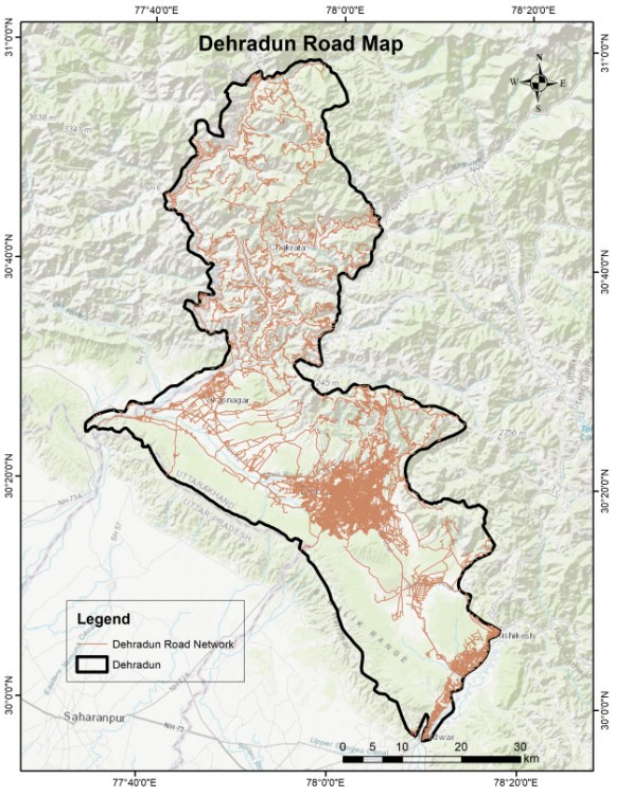

Figure 2. Dehradun Road Network

The primary source of the economy is tourism and the largest profession followed in the region is agriculture.

2.2 Datasets

2.2.1 Primary Dataset

The primary dataset (Table 1) includes names, pin-codes and coordinates of the import-export locations, details of the processing unit is included, along with daily and monthly import-export quantities of raw and processed milk respectively.

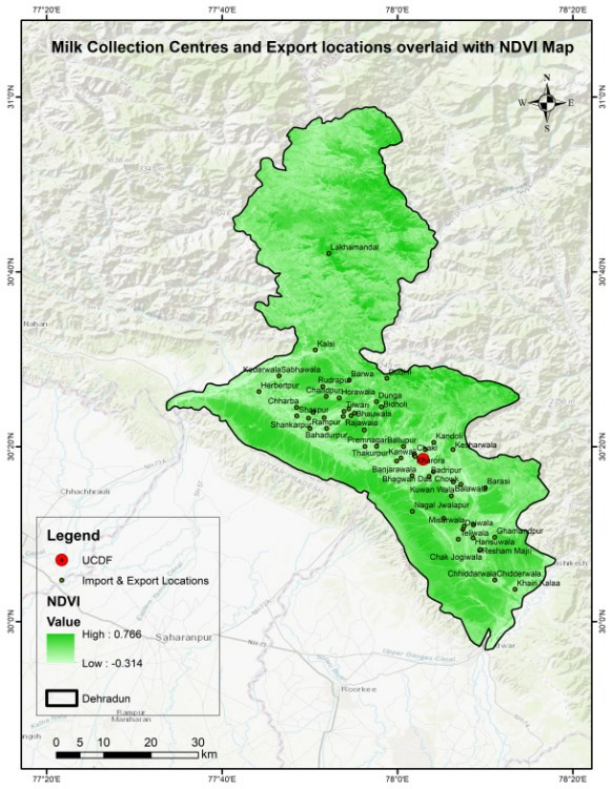

Figure 3. Milk collection centers and export locations overlaid with NDVI

2.2.2 Spatial Data

Various spatial data were used in the study. District boundary and road network for central India were collected from Open Street Map (OSM; https://www.geofabrik.de/) as shown in figure 2. It was then clipped in ArcGIS to acquire only the road network of Dehradun district. Total area of the district is 3088 km². Coordinates of 59 milk collection centers (also referred to as import locations) were collected through field visit conducted during June 2022 (Figure 3) and the satellite based Normalized Difference Vegetation Index (NDVI) of 10m spatial resolution is also acquired using Google Earth Engine figure 3. The NDVI is calculated from the median composite of Sentinel 2 images for the year 2021, using the standard normalized difference of visible and near-infrared bands (Weier &Herring, 2000). The NDVI value of the study area ranges from -0.31 to 0.76.

Table 1 includes data such as geographical coordinates and pin codes of the locations that supply raw milk. Import quantities of raw milk and export quantities of processed milk and dairy products are also recorded in the table. These data are in daily and monthly basis measured in liters. Data of only 14 locations out of 59 milk collection centers are shown in the table due to space constraint. The first seven rows show top 7 raw milk import locations and the last seven rows indicates places with least raw milk supply to UCDF.

2.2.3 Software Used

Different tasks were performed using the software given below to complete the study.

1. Google Earth Engine: It is a cloud-based geospatial analysis platform used to carry out large-scale geospatial processing, visualization and analysis of different satellite images. In this study NDVI cloud free median composite is acquired using Earth engine.

2. Tableau Public: It is a web tool for exploring, generating and distributing data visualizations. In this study, it is used to analyze the data, creating geospatial data view through Tableau Maps.

3. ArcGIS (v10.3) enables users to interact with maps and geographic data. It is used to handle numerous applications, compile and evaluate the mapped data, and creating maps of the research area.

4. Google Earth Pro: It is powerful mapping software providing a 3D interactive globe that aids planning, analysis and decision making. It was used for acquiring online geo-referenced address.

3. Methodology

This study primarily focuses on the integration of geospatial capabilities and relating various parameters with ground truth data. Quantitative data is generalized to model the relationship between different factors and illustrate the results of location and route analysis. Figure 4 gives a brief outline of the overall methodology used in the study.

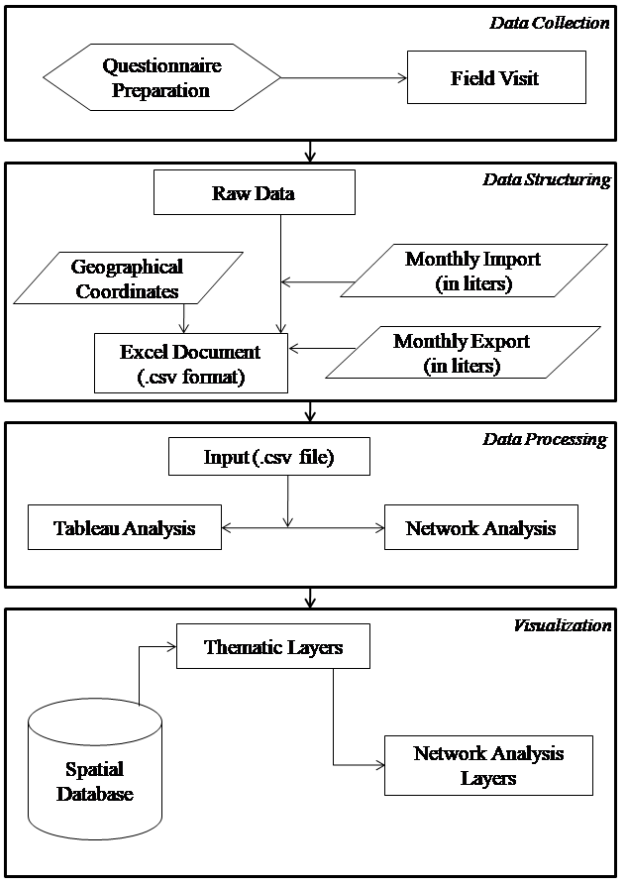

Figure 4. Proposed Methodology

3.1. Data Collection

The process includes a field survey conducted at UCDF, Dehradun, to collect ground truth data. A structured questionnaire was designed, which consisted of 3 phases. Phase 1 emphasized the sources, i.e., places supplying the raw milk. Phase 2 involved the processing details, and Phase 3 had questions related to the export of the processed materials. The survey included a total of 5 queries.

1. Details of the sources from where the raw milk is imported, along with the location coordinates.
2. Quantities of raw milk imported daily and monthly from each source.
3. Total processed items, i.e., processed milk and other milk products.
4. Quantities exported daily and monthly from the processing center.
5. Export Locations of the processed items.

3.2. Data Cleaning

Before analyzing, the gathered data was structured and checked for any anomalies and outliers. The data was structured into .csv format, which is also the desired format for further analysis in the study. The data involved coordinates of the import, processing unit and export locations. Daily and monthly dairy data was also an input in the excel sheet. Collection and distribution of milk and dairy products are measured in kilograms (kg) since the weights of transport vehicles were considered. The unit was converted to liters to ease the understandings of further analysis. Conversion involved the formula:

1 kg of milk = 0.9708 liters milk (for density of milk = 1033 kg/m3).

Once the primary data was structured, secondary data were collected from different sources involving verified websites.

3.3. Data Processing

The primary data were analyzed using the Tableau Public software, wherein comparisons and relations were analyzed and represented in map form including import and export localities. Integrated primary and secondary data were used for Network Analysis in ArcGIS software. Evaluation of the road layers helped in determining the shortest path from processing unit to the export locations. Also, service areas of the processing unit were demarcated. Single delivery stages were identified wherein the raw material collection and processed material distribution follows different approaches. Graphical representation showing the import-export variations was also carried out.

3.4 Experimental Setup

This section briefly explains about NDVI, network analysis, analysis using Tableau and finally visualization of the acquired results.

3.4.1 NDVI

NDVI shows the density of greenery in an area. It is computed using the reflected energy in near-infrared and visible electromagnetic spectrum.
The formula is:

$$NDVI = \frac{NIR-Red}{NIR+Red} \quad (1)$$

Since the most important food source for dairy cows involves green fodder, thus NDVI helps in identifying the places with better fodder density. Subsequently, validation using ground truth was done. The NDVI satellite imagery product of Sentinel 2 used in the study was collected using Google Earth Engine and had 10m spatial resolution. Point based sampling on import locations was done for the analysis.

3.4.2 Network Analysis

Various network issues include determining the best path through the study area, locating the nearest processing facility, determining the service area, and solving vehicle routing problems were analyzed using the ArcGIS Network Analyst extension (Patel et al., 2019).

3.4.3 Tableau Analysis

This analysis helped in locating the prime milk import locations. Fleets from UCDF collects milk from these locations which serve as a center point for a locality. Private dairy farms and farmers bring the milk to these locations set by Aanchal Dairy. Thus, milk is collected from a particular point wherein milk from the nearby localities is stocked. Import localities of raw milk and export localities for processed milk and processed dairy products were analyzed and geospatially viewed using Tableau.

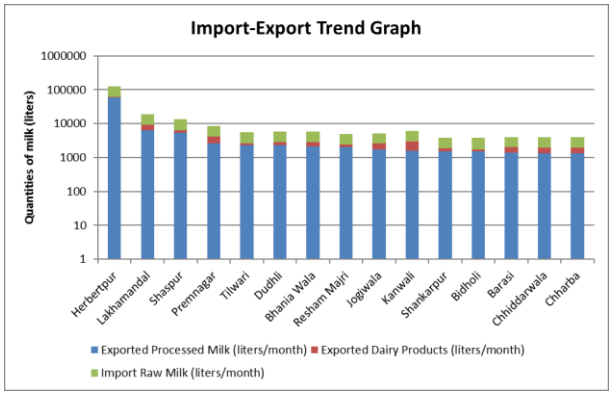

Figure 5. Import vs Export Trend Graph of 15 top locations receiving processed milk from UCDF; Export centers with monthly consumption/ sale of more than 1000 liters have been shown here; Y axis is in log-scale.

Table 1. Sample of field data collected; Coordinates of milk collection centers and monthly quantities of import-export of milk and milk products; The data sample has been sorted based on the 'Import Raw Milk (monthly)' column showing likely location of low and high production/ collection patterns. All quantities are in liters, unless mentioned otherwise.

Place	Pin code	Latitude (°N)	Longitude (°E)	Import Raw Milk (daily)	Import Raw Milk (monthly)	Export Processed Milk (daily)	Exported Processed Milk (monthly)	Exported Dairy Products (daily)	Exported Dairy Products (monthly)
Herbertpur	248142	30.4383	77.7366	2194.95	65848.5	1963.1	58893.3	87.4	2621.1
Lakhamandal	248124	30.7016	77.8695	319.90	9597.0	213.9	6407.7	93.2	2796.0
Shaspur	209743	30.3919	77.8087	236.61	7098.3	174.8	5245.5	38.8	1164.9
Premnagar	248001	30.3340	77.9602	149.41	4482.3	87.4	2621.4	49.5	1485.3
Kanwali	248001	30.3118	78.0067	101.26	3037.8	52.4	1572.6	46.6	1398.0
Tilwari	248197	30.4010	77.8982	98.45	2953.5	77.7	2329.8	10.7	320.1
Bhania Wala	248161	30.1842	78.1443	98.45	2953.5	69.9	2097.0	24.3	728.1
…….	……..	………	……	……	……	……	……	……	……
Sabhawala	248197	30.4683	77.7749	11.46	343.8	16.5	495.0	4.9	145.8
Khairi Kalaa	249204	30.0614	78.2234	11.35	340.5	5.8	174.6	6.8	203.7
Bhauwala	248007	30.3972	77.9182	10.97	329.1	6.7	201.0	2.9	87.0
Bhagwan Das Chowk	248001	30.2616	78.1204	10.79	323.7	8.7	261.0	4.9	145.5
Namkeen Bhandar	248001	30.3060	77.9984	9.82	294.6	11.7	349.5	6.8	203.7
Chaki	248001	30.3191	78.0325	5.30	159.0	12.6	378.6	6.8	203.7
Kharora	248001	30.3164	78.0321	3.50	102.0	17.3	519.9	7.3	219.0

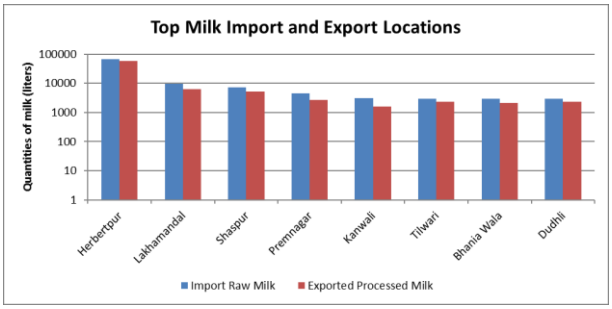

Figure 6. Top raw milk import and pasteurized milk export locations; Y axis is in log-scale

3.5 Data Visualization

Spatial data involving district map and road map was used to create thematic layers of road network and location of source-destination. NDVI overlay upon the import locations was visualized to determine the areas with suitable fodder for dairy cows. Finally, various network analysis layers were developed and evaluated to acquire the results.

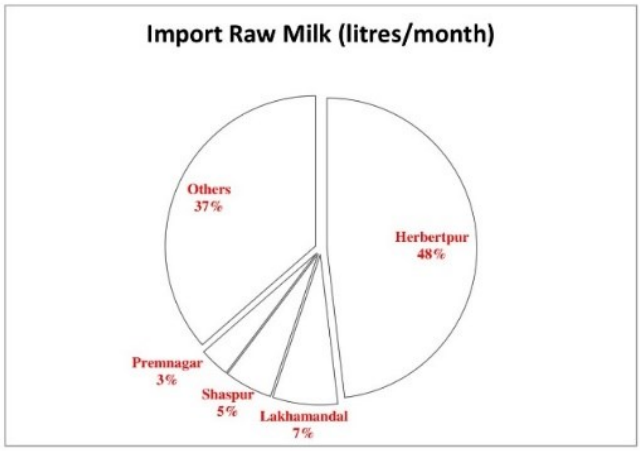

Figure 7. Percentage of raw milk import

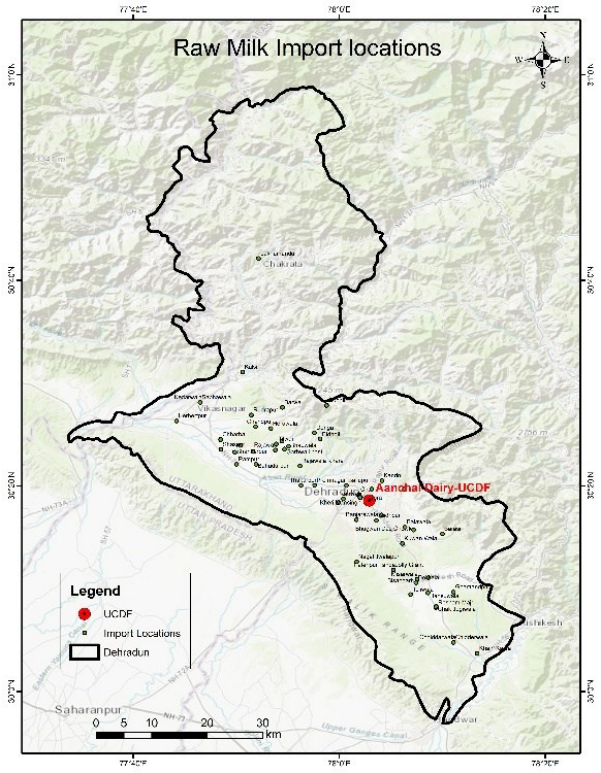

Figure 8. Import Locations of raw milk

4. Results and Discussion

4.1 Data Analysis in Graphical Form

Figure 5 shows import versus export trend of the different locations across Dehradun. This graph shows centers receiving processed milk greater than 1000 liters per month (i.e., 15 centers). The complete data (not shown) contains information from 59 milk collection centers. It can be clearly noticed that places such as Herbertpur, Lakhamandal, Shaspur, Premnagar, etc. receive highest quantity of processed milk and dairy products. In all the 15 centers shown, there is a net surplus of imported milk i.e., the quantity of imported raw milk is greater than the sum of the quantities of exported processed milk and exported dairy products. The data for 59 milk collection centers shows that 34 centers are in surplus, and 25 centers are in deficit. However, the quantity of milk in surplus 34 centers (~8100 liters) far exceed the deficit (~2600 liters) in the remaining 25 centers.

Figure 6 shows eight locations that supplies bulk quantities milk. Bhaniawala and Kanwali supplies around 100 liters milk per day which totals around 3000 liters a month from each source. Premnagar supplies around 4500 liters milk per month. Shaspur and Lakhamandal supply a total of 16000 liters per month whereas Herbertpur supplies highest raw milk with 2194 liters milk per day and a total of 66000 liters milk per month. The graphs in figure 5 and figure 6 are plotted using logarithmic scale in MS Excel by talking a base of 10 for a better visualization.

From figure 7 it is observed that 50% of raw milk is supplied by Lakhamandal and Herbertpur, whereas the other half is imported from the remaining sources. In the pie-chart others (40%) constitutes of 30 collection centers which contributes less than 1% each.

4.2 Interpretation of the Map Layouts

The maps given below shows the analysis of import locations, shortest path to export locations, service areas and NDVI generation for fodder required to the cattle.

4.2.1 Import Locations of Raw Milk to UCDF

Figure 8 shows 59 import locations of raw milk to UCDF. The initial process of the supply chain management in this paper shows the import of raw milk from various locations across the study area. The processing plant is marked in red whereas the black dots refer various raw milk collection centers.

4.2.2 Shortest Path to Export Locations

Once the raw milk is processed it is then packed and the milk products are exported to various locations across Dehradun. This is done by the transport facilities of UCDF which takes various routes to the export locations. The routes involve different road networks and through this study an analysis was done to determine the shortest path from the processing center to those export locations. Figure 9 shows the road network expansion across Dehradun while the highlighted line in the figure shows the shortest path. This is the optimized path from UCDF to various export locations receiving end products of Aanchal Dairy across Dehradun region.

4.2.3 Service Areas of Exported Products

Figure 10 shows the regions where the processed products (processed milk and dairy products) are delivered by UCDF. The service area of UCDF and its distributors were determined by field observations. Figure 10 shows three buffer zones around UCDF and the export locations. The 500m buffer zone is the one where UCDF vehicles deliver the products. In the 1000m buffer zone, UCDF distributors are located. These distributors deliver the products to retail shops within 2000m buffer zone under the brand name 'Aanchal Dairy'. It should be noted that the distances were calculated based on straight line distance, and not distance by road.

4.3 Fodder Map

The fodder map or NDVI Map shows the NDVI of Dehradun (Figure 11). The range of NDVI varies from -0.31 to 0.76 in the entire study area. There is strong evidence to suggest NDVI and livestock productivity are linked (Manning et al., 2017; Pearson et al., 2021).The NDVI at collection center points range from 0.2 to 0.4. This indicates the nearby localities of these regions have high density of shrubs and grasslands (Weier & Herring, 2000), which is also the best fodder for dairy cows. In return the raw milk production is also high in these regions supplying more than 80 liters per day as indicated by the field data.

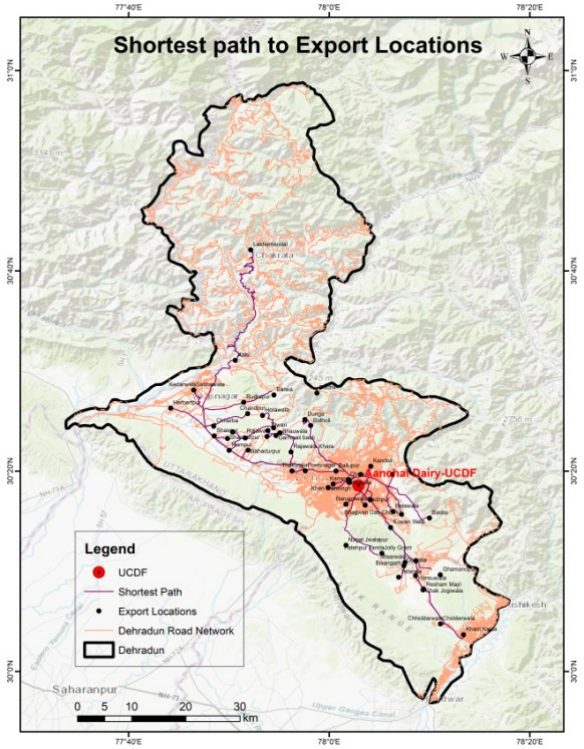

Figure 9. Shortest Path Map from UCDF to export locations

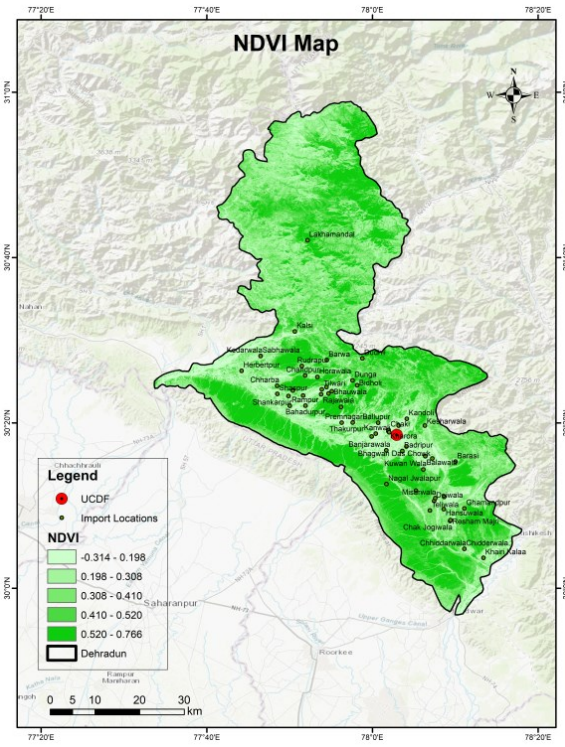

Figure 11. NDVI Map

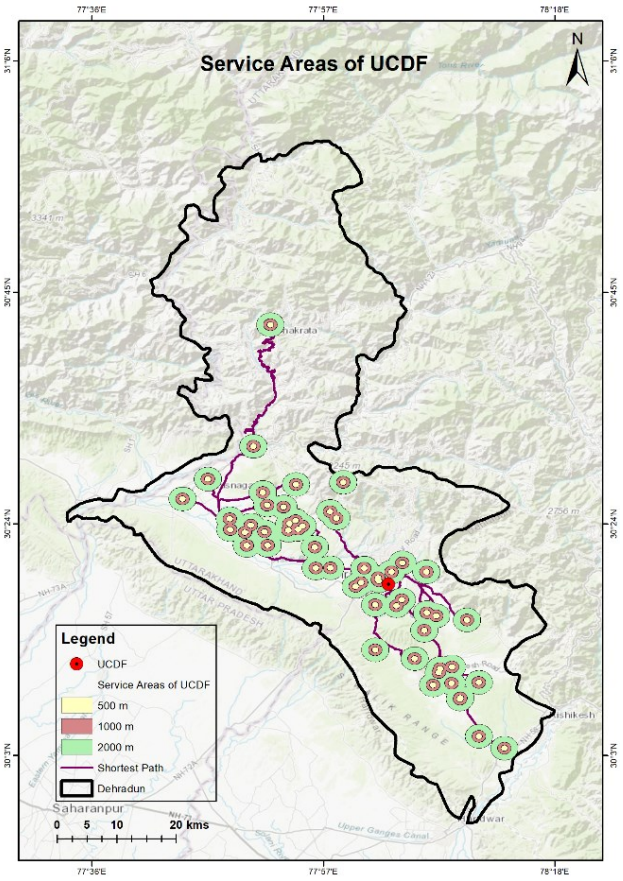

Figure 10. Service area map of Aanchal dairy

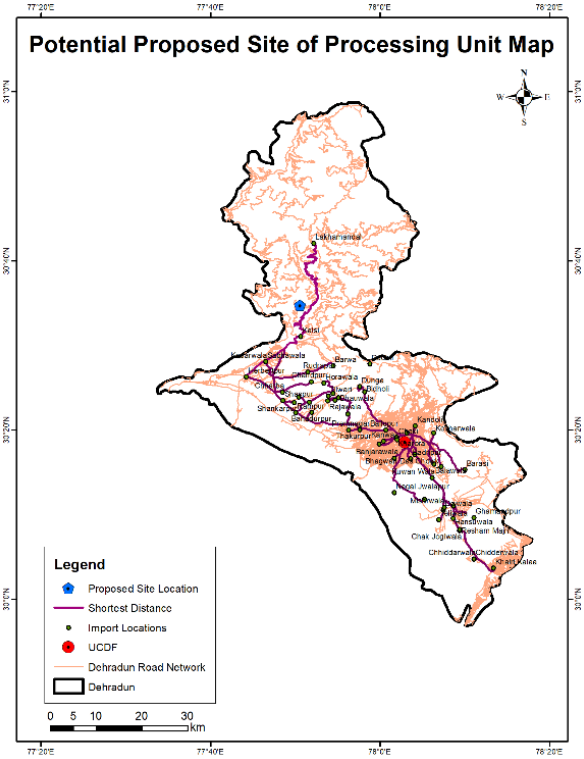

Figure 12. Potential proposed site for a new milk processing plant map

4.4 Proposed New Sites

The primary dataset in the study shows that some places supply raw milk to a larger extent compared to other places. The places are Lakhamandal and Herbertpur which account for more than 50% raw milk supply to the present processing unit. Figure 12 proposes a new processing plant near places supplying high quantity of raw milk so that the efficiency of the federation and supply of end products is

not hampered. The site was decided based on factors such as connectivity, terrain and distance from high yield collection centers. The proposed site does not include socio-economic factors and only focuses upon accessibility from the above-mentioned locations.

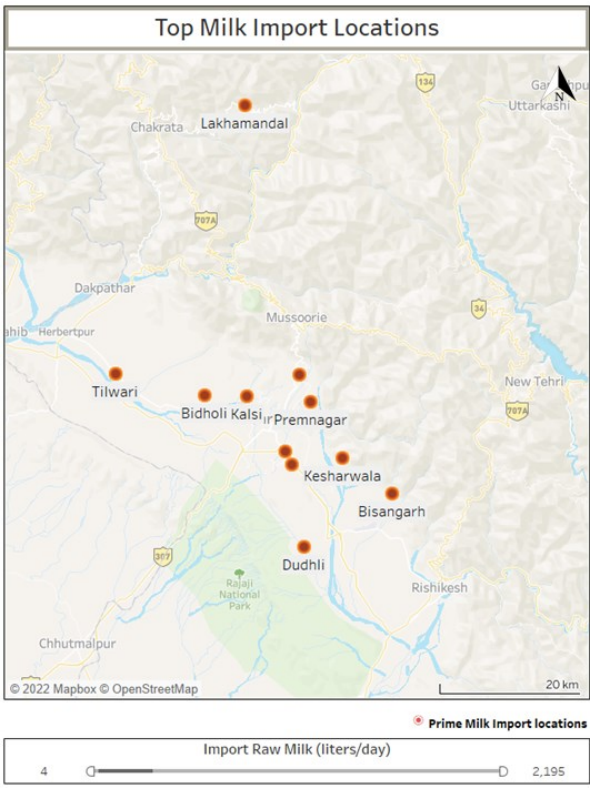

Figure 13. Prime milk import locations

4.5 Import-Export Relationship

Figure 13 shows the different locations which supply better quantities of milk than other locations in the region. 11 milk collection centers provide better quantities of milk than the rest. The milk is collected in these centers and then it is transported to the processing unit. The locations are Lakhamandal, Herbertpur, Premnagar, Tilwari, Kanwali, Bidholi, Bhaniawala and Shaspur. Analysis on Tableau helps in locating areas supplying raw milk (Figure 14). In the map dark brown indicates more quantity of raw milk supply and lighter the color lesser the quantity of milk supplied to UCDF. Raw milk is collected from the localities and collected in a location set by UCDF.

Figure 15 shows the areas receiving processed milk from UCDF. The analysis shows Herbertpur as the top export location. Various dairy products such butter, cheese, ghee etc. are also supplied to these areas under the brand name 'Aanchal dairy'.

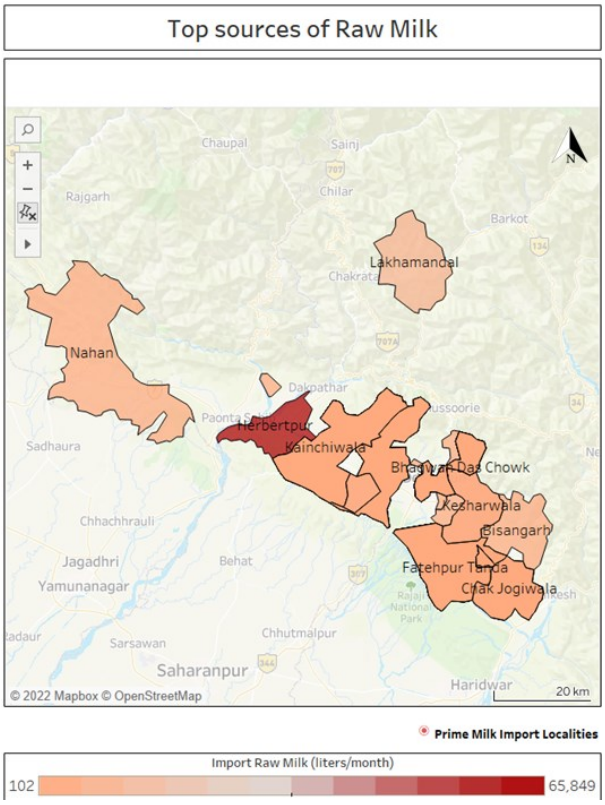

Figure 14. Raw milk import localities

4.6 Validation of the results

After validation it was observed that the fleet delivering the processed products take different routes to different locations. Also, there are various localities where deliveries with a single vehicle are possible as the locations fall in the same route. Taking the shortest path and managing the fleet accordingly can save a considerable amount of time and money while satisfying consumer needs. Also ground truth validation of NDVI shows that the area where NDVI ranges from 0.2 - 0.4 supply more quantity of milk than the other locations. These locations have a high density of grasslands and shrubs, which is an important fodder for dairy cows as well. Therefore, better the fodder for lactating cows more is the raw milk procurement.

5. Conclusion

The objective of this study was to integrate various spatial analytical capabilities of remote sensing into a suitable supply chain management. Graphical analysis of the import-export data shows areas providing milk to Aanchal Dairy (UCDF). Qualitatively, it was found that, milk collection centres having higher milk imports also had NDVI values ranging from 0.2 - 0.4. This implies that the regions also had a better fodder density for dairy cows. Once the milk is procured, it is then processed into packed milk and other dairy products.

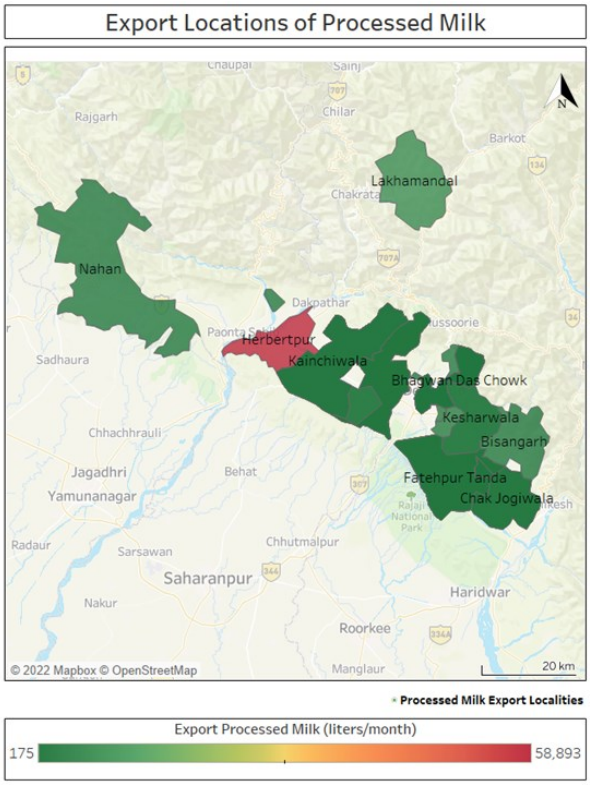

Figure 15. Processed milk and dairy products export localities

The processed products are then supplied to different places and through this study route analysis was conducted towards finding an optimized route for an efficient supply chain. The areas where Aanchal Dairy provides their services were also analyzed. Some regions supply more raw milk than they acquire the processed products. This was due to unbalanced import-export of raw milk and processed products.

The study finally helped in answering the research questions which involved various parameters of a dairy industry, their inter-relationship and the use of geospatial technologies for a practical and improved Supply Chain Management.

6. Recommendation

This study can include other secondary variables such as location of distributors, time frame and fleet size. Time frame can include total time required for the delivery of products from the processing unit to export locations. Loading-unloading parameter can also be included. Fleet size can answer the vehicle capacity related queries. It was difficult to incorporate the fleet in this research as the firm consisted vehicles with different dimensions and carrying capacity. Pollution parameter can also be included which will led to queries related to reduction in emissions and environmental benefits (Elasseri et al., 2020). Additional data on factors affecting milk production such as cattle breed, age, milking frequency, health, dry period, diet and accommodation could enhance predictability of supply.

Considering the rural-urban demarcations, analysis can be done to understand the impacts of a better supply chain management on rural development. Demand-Supply data can also be incorporated which can give a better insight to the trends of high and low season productivity and availability. Since, the main focus of this study was on the integration of spatial capabilities of GIS and Remote Sensing, further research can be done considering various socio-economic factors, especially for identification of new sites, and by applying these techniques to another study area.

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