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SUSTAINABILITY OF ROADS IN COASTAL ZONES EFFECTS CARGO TRANSPORTATION

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ABSTRACT:
The sustainability of road infrastructure in coastal zones, particularly in the Godavari region of Andhra Pradesh, is critical for supporting economic activities and efficient cargo transportation. However, these coastal areas face unique challenges including high salinity, waterlogging, soil erosion, weak subgrade conditions, and frequent exposure to cyclones and tidal surges. These environmental and geotechnical constraints significantly deteriorate road conditions, leading to reduced lifespan, frequent maintenance needs, and disruptions in logistics. Consequently, cargo transportation suffers from increased delays, higher fuel and vehicle maintenance costs, and loss of perishable goods, thereby impacting regional trade and economic stability. This paper explores the relationship between coastal road sustainability and cargo movement efficiency, highlighting key threats and proposing adaptive strategies such as the use of geosynthetics, soil stabilization, climate-resilient materials, and improved drainage systems. Enhancing the resilience of coastal road networks is essential for ensuring uninterrupted cargo flow, economic resilience, and long-term infrastructural sustainability in vulnerable coastal regions.

I. INTRODUCTION

The Godavari basin extends over states of Maharashtra, Andhra Pradesh, Chhattisgarh and Odisha in addition to smaller parts in Madhya Pradesh, Karnataka and Union territory of Puducherry having a total area of 3,12,812 Sq.km with a maximum length and width of about 995 km and 583 km. It lies between 73°24' to 83°4' east longitudes and 16°19' to 22°34' north latitudes and accounts for nearly 9.5% of the total geographical area of the country. The basin is bounded by Satmala hills, the Ajanta range and the Mahadeo hills on the north, by the Eastern Ghats on the south and the east and by the Western Ghats on the west. The Godavari River rises from Trimbakeshwar in the Nashik district of Maharashtra about 80 km from the Arabian Sea at an elevation of 1,067 m. The total length of Godavari from its origin to outfall into the Bay of Bengal is 1,465 km. About 64 km. from the origin, the Godavari is joined by Dharna, on its right bank and a short distance down stream the Kadana joins it from the left. The combined waters of the Pravara and Mula which rise in the hills of Akola join the river from left about 217 km. from the origin. About 338 km. from the origin, the river receives the combined waters from the Purna and Dudhna rivers and after a further 138 km. at the border of Maharashtra and Andhra Pradesh, the waters of the Manjira river joins it from the South. At this point, Godavari flows at an elevation of about 329 m. The river Pranhita, conveying the combined waters of Penganga, the Wardha and Wainganga, which drain Nagpur and southern slopes of the Satpura ranges, falls into Godavari about 306 km. below its confluence with the Manjira. The waters of the Indravathi join the river Godavari 48 Km downstream. The last major tributary is the Sabari, which joins the Godavari, 100 km. up-stream of Rajahmundry. The largest tributary of the Godavari is the Pranhita with about 34.87% coverage of drainage area. The Pravara, Manjira and Maner are right bank tributaries covering about 16.14%, the Purna, Pranhita, Indravathi and Sabari are important left bank tributaries, covering nearly 59.7% of the total catchment area of the basin. The Godavari in the upper, middle, and lower reaches make up for the balance 24.16%. The major part of basin is covered with agricultural land accounting to 59.57% of the total area and 3.6% of the basin is covered by water bodies. The basin spreads over 51 parliamentary constituencies (2009) comprising 21 of Maharashtra, 18 of Andhra Pradesh, 4 of Madhya Pradesh, 3 each of Chhattisgarh and Odisha and 1 each of Karnataka and Puducherry.

Polluted loads in Godavari:

This is about two states, Andhra Pradesh and Telangana (the latter being 29th Indian state formed in 2013 after a protracted struggle). Since the discussion is on the state of rivers, it may be noted that these are two states whose historical trajectory is intrinsically linked to the history of, mainly, two major rivers—Krishna and Godavari, although the two states have many other rivers. Furthermore, the new state (and old region and what was once the Hyderabad state), Telangana, was created after many years of struggle and out of one basic river-water discourse: over the utilisation of Godavari river and unequal development of the Godavari delta region vis-à-vis Telangana on account of the numerous irrigation projects and hydro-power projects commissioned and implemented in the coastal Andhra region (now in AP state), besides several later projects commissioned for the Rayalaseema region, to which the former Chief Minister of AP, Dr. Y.S. Rajasekhara Reddy belonged.

Itinerary of Godavari River:

The river is an important stream in central India, rising in the Western Ghats Mountain Range. The name of the origin is Trimbakeshwar and it is situated in the Nashik District or Subdivision in the state of Maharashtra and runs towards the east over the Deccan terrain through the Maharashtra state. The river is also named as Southern Ganges or Dakshin Ganga. The river moves into Andhra Pradesh at Kandhakurthi in Nizamabad district of Andhra Pradesh, moves past the Deccan terrain and subsequently bends to run according to a southeasterly course till it pours into the Bay of Bengal via two mouths. An important place of attraction on the riverbanks is Basara in Adilabad District. It houses a popular place of worship for Goddess Saraswati. It is also the second oldest temple for the deity in India.

Drainage basin of Godavari River:

The catchment basin of the river is 342,812 $km^2$and it comprises more than one state, which is almost 1/10th of India and is bigger than the territories of Ireland and England combined. The Indravati, Pravara, Wardha, Wainganga, Kanhan, Pench, and Penuganga rivers flow a huge quantity of water into the Godavari River System. Major tributaries of the river are as follows

- Manjira River
- Indravati
- Sabari River
- Bindusara River

Religious importance:

The Godavari River is regarded as holy by Hindus and there are various religious spots on the riverbanks. The river has been revered as a particular site of pilgrimage for a considerable period of time. A number of eminent individuals, including Baladeva (5000 years back) and lately Chaitanya Mahaprabhu (500 years back) have dipped in her waters to offer prayers. Godavari is also regarded as Dhakshin Kashi (Rajahmundry) or Dakshin or Southern Ganges. The Pushkaram Fair is organized on the riverbanks. Countless people have a sacred bath in the holy waters of the river to wash themselves off of any misdeeds.It has been mentioned in the myth that the famous mentor Gautama stayed on the Brahmagiri Hills, located at Trayambakeshwar with his wife Ahalya. The sage kept the store of rice in a granary. At one time, a cow came into the granary and consumed the rice. Once the sage attempted to drive the cow out with Durbha grass, it died. The sage wished to save himself of the wrongdoing of "Gohatya". He offered prayers to Lord Shiva and urged him to fetch the Ganges to cleanse his abode. Lord Shiva was satisfied with the sage and emerged as Triambaka and fetched the Ganges River. As the Ganges River was taken down by Sage Gautama to Triambakeshwar, the river is named here as Gautami. The river is also called as Godavari since the river assisted Sage Gautama to wash away his misdeeds

Environmental importance:

The delta of the Godavari River is home to the Coringa mangrove forests and they are the second biggest mangrove development in India. A portion of this has been acknowledged as the Coringa Wildlife Sanctuary, which is famous for its reptiles. The sanctuary is also home to a broad range of crustaceans and fishes. These jungles also function as impediments for windstorms, cyclones, and surges and waves hence safeguarding the villages close by The Krishna Godavari catchment area are one of the principal nesting locations of the imperiled Olive Ridley Turtle. The Godavari ranks as the second biggest river in India following the Ganges

Climate & Rainfall:

Rainfall along the coastal tracts of Peninsular India is of monsoon type, normally spread over two seasons in a year. The southwest monsoon, from June to September, contributes bulk of the annual rainfall along the east and west coasts except for coastal areas of Tamil Nadu and Southern coast of Andhra Pradesh, where the maximum rainfall is from northeast monsoon during the months of October, November and December. The southwest monsoon hits the Kerala coast by the end of May or beginning of June and advances towards northern parts of the country. Orographic influence is dominant in the distribution of rainfall in this season, as the prevailing winds blow almost at right angles against the Western Ghats. It brings copious rainfall along the west coast. But, the region of high rainfall along the west coast is limited to a narrow belt having steep slopes between the Western Ghats ridge and the coastal plain. Rainfall increases from the ridge of the Western Ghats towards the western steep slopes and rapidly deceases on the eastern lee side. Along the east coast, the rainfall distribution is almost reversed, with higher rainfall of 600 to 1000 mm in the northern parts and relatively less in the southern parts within the range of 200 to 600 mm. The monsoon starts withdrawing gradually by early September and leaves the country by middle of October.

Drainage Characteristics:

Coastal streams, especially in the west, are short and episodic. The coastal areas of India show wide variations in drainage characteristics from place to place. In Gujarat, there are two distinct sets of rivers. The rivers Rupen, Saraswati and Banas in the NW part flows into the Rann of Kachchh, while the major rivers draining the central and southern coast of Gujarat, viz., Narmada, Tapi, Sabarmati and Mahi fall into the Gulf of Khambat. In Saurashtra, there are many intermittent rivers like Bhadar, Ojat, Madhyvanti, Noli, Megal, Hiran, Saraswati, Singwada, Singwadi, Rupen and Machundri carrying rain water to the sea. Out of these, river Bhadar is the longest. These rivers rise in the central plateau region of Saurashtra and meander in a radial pattern through the plains to meet the Arabian Sea.

Proposed Link Canals Between Godavari and Krishna:

The NWDA had taken up and completed scientific hydrological analysis of various river basins to assess the water balance position in the basins at the ultimate stage of development (by the year 2025 AD). As per the water balance studies of NWDA, there are sizeable surplus waters in the Mahanadi and Godavari basins. On the other hand, the Krishna, Pennar and Cauvery basins were found to be deficit. Based on these studies, it has been estimated that, considering the ultimate development scenario in these basins, the Mahanadi basin will have a net surplus of 11176 Mm3 at 75% dependability at Manibhadra and the Godavari basin will have a surplus of 15020 Mm3 at 75% dependability at Polavaram. The deficit in Krishna basin at Prakasam barrage will be of the order of 3235 Mm3 . Considering these water balance assessments, it has been proposed to divert 11176 Mm3 of water from the Mahanadi river to the south through the Mahanadi - Godavari link. The transferred water will be partly used for irrigation en route in the States of Andhra Pradesh and Orissa and the remaining quantity of 6500 Mm3 will be received in the Godavari. About 21520 Mm3 of water including 6500 Mm3 received from Mahanadi will be transferred to further south to meet the enroute irrigation and domestic water requirement in the Krishna, Pennar, Cauvery and Vaigai basins.

Topography:

The Godavari basin falls in Deccan plateau. The basin is bounded on the north by the Mahadeo Hills, the Satmala Hills comprising a series of table lands varying from 600-1200 m in elevation. The western edge of the basin is bounded by an almost unbroken line of the North Sahyadri range of the Western Ghats, from 600-2100 m height. The eastern area of the basin is majorly covered by the Dandakaranya Range with the Eastern Ghats rising from the plains of East Godavari and Vishakhapatnam to the level of the table lands of Jeypore. The basin's southern boundary of the basin follows the Harishchandra Range in west, Balaghat Range in the center and the Telangana Plateau in east. In the interior part of the basin lies the Maharashtra Plateau. Maharashtra Plateau gently slopes from Sahyadri eastward though apparently one is resolved into broad extensive interfluves and the valleys. The Ajanta hills, the Godavari valley, the AhmadnagarBalaghat plateau and part of Mahadeo Upland falls under Maharshtra plateau part in the basin. The longest of the rivers of the Deccan, the Godavari virtually bisects the plateau of Maharasthra.

Table: Elevation zones

Elevation (m)	Area (Sq. km)	% of Total Area
< 5	810.25	0.26
5-10	1374.58	0.44
50-100	2778.22	0.89
100-200	4711.13	1.51
200-300	27105.94	8.67
300-400	55928.81	17.88
400-500	54140.26	17.31

The western part of Vidarbha plain, drained by the Wardha and Penganga rivers and their tributaries, is the Wardha-Penganga plain. It is mostly underlain by basalt presenting the familiar trappean landscape of the plateau. The wardha plain is denuded so that its general elevation does not exceed 300 m asl, though the plateau and the hilly areas on the north-west, culminating into the upland of

Arvi, stand out from the plains. The black or medium black soil occupying the valley is most fertile, but morand, the grey soil, forms the most extensive cover that is suitable for cotton, jowar and rice. The Wainganga sub-basin is a structural syncline it occupies a crystalline base, having more than 1500 mm of rainfall. Rapid fluvial erosion has reduced the land considerably leaving a number of isolated hills. Rocky surfaces, often devoid of thick soil cover, are usually covererd with forests. The valley comprising the Nagpur, Chandra and Bhandara districts of Maharshtra accounts for more than half of the forest area of the state. Tropical Decidous forests of Wainganga valley are the main sources of timber and bamboo and support the paper industry at Ballarpur. On the west it is highly dissected by the tributaries of the Godavari including Indravati. The Kanker region, a southward extension of the Chhattisgarh plain, crosses a few higher ridges of quartzites. The Bidar plateau part of Karnataka state falls in the basin. The Central Godavari valley which is distinct for its faulted structure, thick forest cover and abundant rainfall falls in Andhra Pradesh. The elevation variation in the basin is depicted in Map 3. Major area falls under the 500-750 m elevation zone Basin is very rugged in the north-eastern part and flat towards downstream side (Map 3). Slopes in the floodplains are very flat (0 to 3%) that is causing inundation in the floodplains.

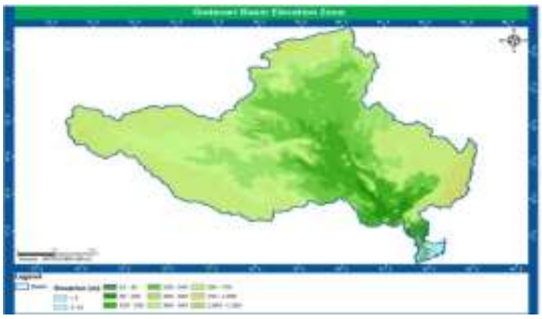


Figure: Elevation zones

Climate:

The basin being fairly large, climatic contrasts particularly the variations in the amount of rainfall are obvious. With a limited latitudinal extent and not so very pronounced vertical range of altitude, the temperature conditions do not change significantly. Climate has assumed an important role in landscape evolution. The Godavari basin has a tropical climate and the evaporation losses vary from 1800 to 2440 mm over different parts of the basin (Source: Reassessment of Water Resources Potential of India, CWC 1999). The weather in the basin is cold from mid-October to mid-February and the wetsren and the north-eastern part being colder than the rest of the basin. The weather is comparatively hotter in the westernmost parts of the basin in comparison to the Central, northern and eastern region. The Dankaranya region in the basin lies within tropics is characterized by hot and humid climate. Away from western ghats, particularly the crestline eastwards in the Maharashtra state a sudden drop in the amount of rainfall has fostered aridity and the development of a general inselberg type of landscape.

Rainfall:

South-west monsoon sets in by July and ends by September receiving maximum part of its annual rainfall during it. The monsoon entering through the west and south-west coast of the basin meets the Sahyadri Range sweeps across the interior of the peninsula. The crest zone of Sahyadri about 25 km wide is the belt of heaviest rainfall in the Maharashtra region. Regions falling in the rain shadow area of the Sahyadri receive scanty rainfall. Further east, there is a progressive increase in the amount of rainfall that changes the landscape and the cropping pattern in the eastern Maharashtra, the Wardha-Wainganga sub-basins. The rainfall in the Dankaranya region of the basin characteristically occurs between June and September. The rainfall, fairly heavy though irregular and unevenly distributed, is mostly caused by the south-west monsoon. Based on daily rainfall data (0.5 X 0.5) of the last 34 years (1971-2005) collected from IMD the average annual variations in the basin is shown in Map 4.

Annual rainfall of the basin varies from 755 mm to 1531 mm. The average annual rainfall in the basin is 1096.92 mm. It is found that the rainfall varies temporally and spatially across the basin. In Godavari the high rainfall zone in the Western Ghats the annual rainfall varies from 1000 to 3000 mm in this reach. January and February are the driest months in the basin with the annual rainfall ranging from less than 0.5 mm to 55 mm. During the next three months, upto end of May, it varies from less than 1 mm to 50 mm. The maximum rainfall recorded was 1531 mm in 1990 and minimum was 755 mm in 1952

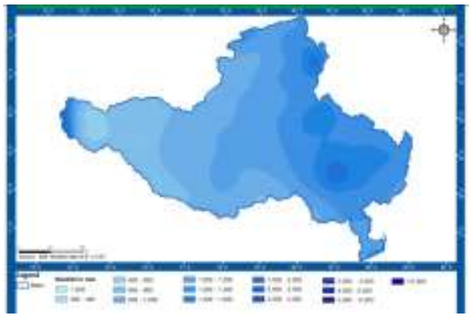


Figure: Annual average rainfall

II. LITERATURE REVIEW

Sharma, Y., and Singh, A. P. **(2013)** the Godavari is the Pranahita with about 34.9% coverage of drainage area. The Pravara, Manjira and Maner are right bank tributaries covering about 16.1%, the Purna, Pranahita, Indravati and Sabari are important left bank tributaries, covering nearly 59.7% of the total catchment area of the basin. The Godavari basin as whole receives 84% of the annual rainfall on an average, during the southwest monsoon, between mid-June and late August. The Godavari basin has rich forest and mineral wealth. The principal minerals found are Bauxite, Manganese, Iron ore and Coal. Other minerals like lead, zinc, corundum, refractory minerals and kaolin are also found in small quantities in different parts of the basin. Two major (and historically, as well as politically significant) projects on river Godavari are located at mile 852 of the river (Cotton Barrage / Dowlaiswaram Barrage) and at mile 829, the Polavaram project; the former is a colonial period legacy and the latter, a present-day predicament

Bhakar, P. and Singh, A.P**. (2018).** this river gave its name to an entire districts that covered the delta region in its entirety and part of the reason was the Godavari ani cut, or the Dowlaiswaram barrage or the Sir Arthur Cotton barrage, which besides being the first major colonial reservoir built in this region, also happened to have brought with it, an entire administrative mechanism around Godavari river and its ‘utilisation’ for purposes of irrigation and navigation (latter, to a limited extent, since Arthur Cotton’s grandiose plan of building a country-wide navigation project connecting different rivers did not take off, but which has come back to haunt us in the form of the river interlinking project of the Indian state, irrespective of the political party holding the reins at the centre). Godavari river holds a very deep link to the history of Andhra Pradesh and Telangana.

P., Kanuganti, S., Sarkar, (2017) the Krishna river was said to be inadequate to meet the demand of irrigation of Krishna delta farmlands, the Godavari river has been linked to Krishna through the Polavaram Right Bank Canal with the help of Pattiseema Lift scheme. The project was commissioned in 2015 and recently the Chief Minister of AP, Chandrababu Naidu had a symbolic inauguration of the interlinking of these two rivers. The diversion is expected to augment water availability in Prakasam Barrage in AP, the canals of which are part of the National Waterway 4. Like other rivers, this river is also held as sacred and a bath in this river is believed to cleanse people of their sins. Here, too, the Krishna Pushkaralu are held once in 12 years at different ghats, and this year, the event was celebrated in Andhra Pradesh and Telangana, starting on 12 August and ending on 23 August. The period, in the traditional calendar, is observed for 12 days, from the time Jupiter enters Virgo (kanya rasi). This is the period of the ritual cleansing of both the river and the people.

Jain and Kothyari (2000) proposed and demonstrated a Geographical Information System (GIS) based method for the identification of sediment source areas and the prediction of storm sediment yield from catchments. Data from the Nagwa and Karso catchments in Bihar (India) have been used. The Integrated Land and Water Information System (ILWIS) GIS package has been used for carrying out geographic analyses. An Earth Resources Data Analysis System (ERDAS) image processor has been used for the digital analysis of satellite data for deriving the land cover and soil characteristics of the catchments. The catchments were discretized into hydrologically homogeneous grid cells to capture the catchment heterogeneity. The cells thus formed were then differentiated into cells of overland flow regions and cells of channel flow regions based on the magnitude of their flow accumulation areas. The gross soil erosion in each cell was calculated using the Universal Soil Loss Equation (USLE) by carefully determining its various parameters. The concept of sediment delivery ratio (SDR) was used for determination of the total sediment yield of each catchment during isolated storm events.

Kothyari and Jain (1997) has developed a method for determination of the sediment yield from a catchment using a GIS. The method involves spatial disaggregation of the catchment into cells having uniform soil erosion characteristics. The surface erosion from each of the discretized cells is routed to the catchment outlet using the concept of sediment delivery ratio, which is defined as a function of the area of a cell covered by forest. The sediment yield of the catchment is defined as the sum of the sediments delivered by each of the cells. The spatial discretization of the catchment and the derivation of the physical parameters related to erosion in the cells are performed through a GIS technique using the Integrated Land and Water Information Systems (ILWIS) package

III. METHODOLOGY

This study adopts a mixed-method approach to analyze the sustainability challenges of road infrastructure in coastal zones and their impact on cargo transportation, with a focus on the Godavari coastal region. The methodology consists of the following key components.

The Godavari coastal zone, located in the state of Andhra Pradesh, India, is a highly productive and strategically important region. Encompassing parts of East and West Godavari districts, this area is renowned for its agricultural richness, aquaculture potential, and proximity to major ports such as Kakinada and Visakhapatnam. Efficient road infrastructure in this region plays a critical role in the transportation of cargo—especially perishable and export-oriented goods like rice, fish, prawns, and oil products. However, the sustainability of roads in this low-lying, flood-prone coastal zone remains a persistent challenge.

Coastal roads in the Godavari region are frequently exposed to environmental hazards such as salinity, high groundwater levels, monsoonal flooding, and cyclonic activity. These conditions accelerate pavement deterioration, reduce structural integrity, and increase the frequency of maintenance interventions. In many areas, inadequate drainage systems, poor-quality construction materials, and suboptimal design exacerbate the degradation process. As a result, road networks often become impassable or unsafe, directly affecting cargo movement, increasing transportation costs, and disrupting regional supply chains.

This study aims to explore the challenges faced by road infrastructure in the Godavari coastal zone, assess their direct and indirect impacts on cargo transportation, and recommend engineering, planning, and policy-based strategies to enhance long-term road sustainability and logistics performance in coastal environments.

Rainfall pattern in the Basin:

The Godavari basin receives its maximum rainfall during the Southwest monsoon. The monsoon currents strike the West Coast of the peninsula from West and South-West, meet the Western Ghats or Sahyadri Range which present almost an uninterrupted barrier ranging from 600 m. to 2100 m. in height. Before surmounting this barrier the currents deposit most of their moisture on its windward side, and then sweep across the interior of the peninsula on the Easterly course. Rainfall is governed largely by the orography of the area, which leads to variation in the amount of precipitation. In crossing the Ghats, the monsoon wind loses a large part of its moisture. The monsoon currents follow the Eastward slope of the country from the crest of the Ghats, which form the watershed. Conditions in the interior are, therefore, somewhat unfavorable for heavy precipitation except in association with the depression from the Bay of Bengal The north-east part of the Godavari basin also receives some rain in association with monsoon depressions, which move west-north-west across the Orissa coast.

Figure: River Overview Map

Prograded coast:

The prograded east coast exhibits number of deltas, sand bars, extensive deposits of marine sediments, etc. The coastline is very smooth with well developed long beaches. A classic example of prograded coast is the Khejuri and Hijli areas of East Medinipur district, West Bengal. These two areas were non-existent about 400 years ago and got fully developed only about 250 years ago. Khejuri holds 30 to 40 m thick top fresh ground water. The prograding nature of the coastline has also left behind huge water bodies in the form of lakes and lagoons. The beach ridges levees, palaeo channels, etc. formed in the prograded coastal plain support fresh ground water aquifers

East Coast:

The coastal plain stretches in almost N-S direction from Kanya kumari to Krishna river mouth with an average width of 120 km. It takes a turn and extends in NE direction. Towards north of river Godavari, the coastal plain narrows down over a small stretch due to rocky coast and again widens towards north of Chilka lake in Mahanadi delta and Balasore coastal plain where they merge into the vast plains of Ganga- Brahmaputra delta system. The coastal plain in Tamil Nadu stretches from Coastal Features of Kerala Average height above msl Status Kanya kumari with a width of about a km and attains its maximum of about 150 km near Cauvery River and again narrows down towards Pudu cherry. The other important coastal plain is formed in Nellore district near the mouths of The coastal plain of Andhra Pradesh is bordered by Archaean group of rocks on the west. The plain was formed under fluvial, fluvio- aeolian and fluvio-marine depositional environments. It was fluvial in the upper deltaic plain and along the river courses. In the lower deltaic plain, towards coast and other parts of the coast line, the fluvio-marine and fluvio-aeolian environments were dominant. In addition, the transgressed and regressive nature of the sea, especially in the middle part of the coastal tract of the state, has resulted in deposition of a complex sequence of formations, ranging from coarser to finer clastics often with rapid facies variation.

Figure: East coast zones of India

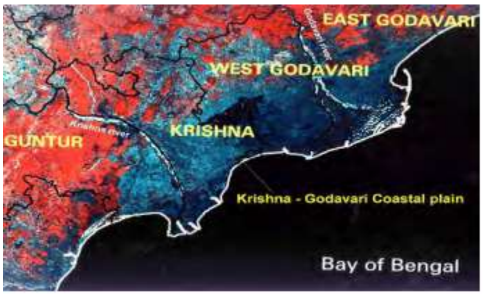


Figure: View of Krishna-Godavari coastal plain, Andhra Pradesh

Dams, Barrages/Weirs/Anicuts:

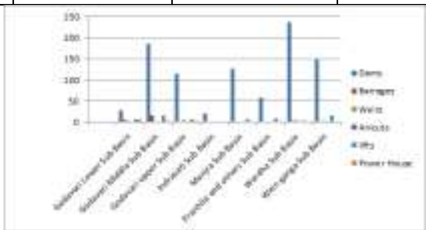
Water resources structures are manmade structures to store the water for hydropower, irrigation, drinking water supply, etc. The number of dams constructed in Godavari basin is the highest among all the river basins in India. Sub-basin wise the distribution of these structures is mentioned in Table There are 921 Dams in Godavari basin basin among which maximum numbers of dams are in Wardha Sub Basin. Major dams in the basin are Sriramsagar (SRSP)/Pochampad dam, Gosikhurd dam, and Jayakwadi dam. The longest dam in the basin is Sriramsagar (SRSP)/Pochampad dam in Nizamabad district of Andhra Pradesh after the confluence of Manjra river with Godavari with a total length of 15.6 kms and 2555 MCM live storage capacity. Bandardhara Dam, the highest in the basin is located in Ahmadnagar district of Maharashtra on river Pravara with a height of 82.35 meters

Godavari has been dammed by Gangapur Dam right after its origin in Tryambakeshwar (Image Source: The Indian Express)

Table: Sub-basin wise number and type of water resources structures

Sub Basin	**Dams**	**Barrages**	**Weirs**	**Anicuts**	**lifts**	**Power House**
Godavari Lower Sub Basin	28	5	3	1	7	7
Godavari Middle Sub Basin	186	16	0	0	15	3
Godavari upper Sub	114	0	5	0	7	3

Basin						
Indravati Sub Basin	21	0	0	0	0	0
Manjra Sub Basin	128	1	1	0	6	2
Pranhita and others Sub Basin	59	1	2	0	8	0
Wardha Sub Basin	236	3	4	0	4	0
Wein ganga Sub Basin	149	2	3	0	15	1



Graph: Sub-basin wise number and type of water resources structures

Figure: Godavari upper sub-basin and water resources assets

Ground water resources:

Ground water level data is temporal and dynamic in nature. It is mainly controlled by rainfall pattern in relation to the aquifer material. A large part of agricultural irrigation depends on ground water availability. The Central Ground Water Board has explored aquifers in various States/UTs under its scientific exploratory drilling programmers by utilizing latest studies and technologies which includes remote sensing and geophysical techniques. The Board is monitoring the ground water levels in the country, four times a year (Jan/May/Aug/Nov) through a network of Ground Water Observation Wells. In the basin observation wells are there to assess the ground water potential in different hydrogeological set up. Priority was accorded to drought affected and tribal areas, hard rock areas, pollution affected areas, etc. Godavari Upper Sub Basin comprises of the least number of observation wells (93), with the maximum (346) in Wardha Sub Basin The distribution of observation wells is quite uniform across the basin

Table: Sub-basin wise number of ground water observation wells

Sub Basin	No. of Observation Wells
Godavari Lower	214
Godavari Middle	**212**
Godavari upper Sub Basin	93
Indravati Sub Basin	215
Manjra Sub Basin	**229**
Pranhita and others Sub Basin	303

INTEGRATED STATE WATER PLAN FOR GODAVARI BASIN:

Manage disasters better at the ground level immediately, during the time taken for the government machinery to set in motion. However, care has to be taken that the process of grouping and forming such local level 'committees', does not become expensive, time consuming and cumbersome. More importantly, it should not lead to fragmentation in local water resources management.

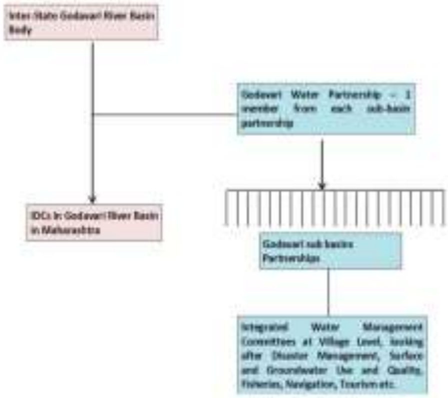


FIGURE: Community Level Institutional Structure

IV. RESULTS

The analysis of road infrastructure and cargo transportation across selected regions in the Godavari coastal belt reveals significant correlations between road sustainability issues and logistics inefficiencies. Field observations, stakeholder interviews, and performance metrics demonstrate the following key results.

Table 4.1: Impact of Road Conditions on Cargo Transportation (Sample Data)

Road Segment	**Season**	**Avg. Travel Time (hrs)**	**Fuel Cost (₹/trip)**	**Vehicle Downtime (days/month)**	**Cargo Loss Risk (%)**
Amalapuram to Kakinada	Summer	2.5	1,200	1.2	3%
Amalapuram to Kakinada	Monsoon	4.0	1,650	4.8	12%
Narasapur to Yanam	Summer	1.8	950	0.5	2%
Narasapur to Yanam	Monsoon	3.2	1,420	3.6	10%
Kakinada to NH-16	Summer	1.2	800	0.3	1%
Kakinada to NH-16	Monsoon	2.6	1,200	2.9	8%

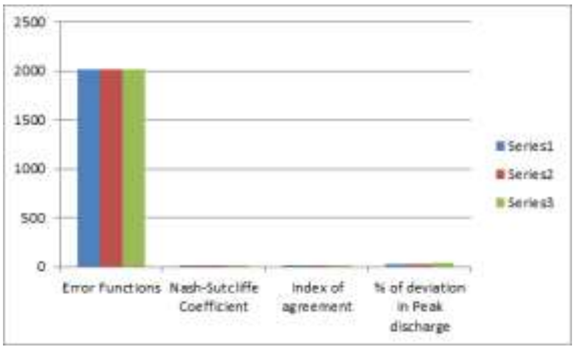
The data clearly shows that cargo transportation efficiency is compromised during monsoon months due to unsustainable road conditions. Delays and higher fuel consumption result in increased operational costs. More importantly, cargo loss risk for perishable goods increases by 3 to 5 times, severely affecting fisheries and agricultural supply chains.

Performance of the rainfall-runoff model:

It showed remarkable agreement between results predicted by the model and measured data. The value of Nash-Sutcliffe coefficient ranged from 0.785 to 0.938, it indicates that the model performed well. The value of index of agreement ranged from 0.962 to 0.987, which is almost 1, indicates that the model was in agreement. The percentage deviation in peak varies from 20.56% to 36.59% which suggested that model predicted actual discharge at gauging site.

Table: Details of the Validation results of the model at Polavaram

Error Functions	2014	2015	2016
Nash-Sutcliffe Coefficient	0.904	0.938	0.785
Index of agreement	0.981	0.987	0.962
% of deviation in Peak discharge	24.58	20.56	36.59



Graph: the Validation results of the model at Polavaram

Godavari river Trends and variability:

Rainfall is governed largely by the orography of the area, which lead to variations in the amount of precipitation. The Godavari basin receives its maximum rainfall during the south-west monsoon. The monsoon strike the west coast of the peninsula from the west and south-west, meet the Western Ghats or Sahyadri range which present almost an uninterrupted barrier. Before surmounting this barrier the currents deposit most of their moisture on its windward side, and then sweep across the interior of the peninsula on a westerly course. In crossing the Ghats, the monsoon winds lose a large part of their moisture. The monsoon currents follow the eastward slope of the country from the crest of the ghats which form the watershed. Conditions in the interior are therefore somewhat unfavorable for heavy precipitation except in association with the depressions from the Bay of Bengal.

Soils: Soil is composed of minerals, mixed with some organic matter, which differ from its parent materials in terms of its texture, structure, consistency, and color, chemical, biological and other characteristics. Information on the soil profile is also required for simulating the hydrological character of the basin. Map 6 to Map 9 shows the main soil classification based on soil texture, soil erosion, soil slope and soil productivity in the basin, respectively (National Bureau of Soil Survey and Land Use Planning). About 68.10 % falls under moderately shallow to deep (>50 cm) followed by 16.65% Very Shallow (10-25 cm) based on the depth of the soil groups. Based on texture major part falls under fine texture category (57.61%), with rocky and water bodies accounting for the minimum of 2.04%. Soil erosion is moderate in more than 64.92% of the basin area with severe erosion in 24.86% of the basin area and slight in area falling near the Bay of Bengal. Soil productivity ranges from highly productive to non-productive area i.e., 28.5% and 11.15% of the basin area respectively. The important soil types found in the basins are black soils, red soils, lateritic soils, alluvium, mixed soils and saline and alkaline soils.

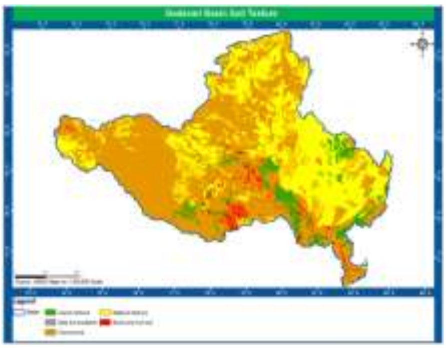


Figure: Soil texture

Figure: Soil erosion

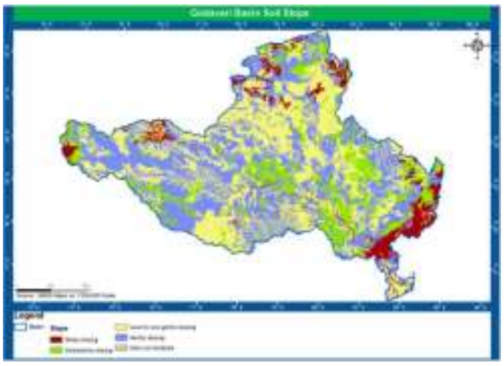


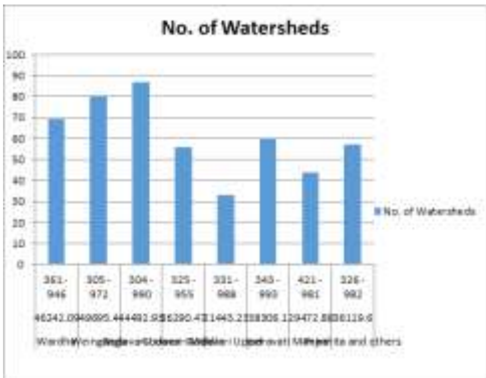
Figure: Soil slope

Godavari river Sub-basins: Hydrological unit wise assessment of water resources is a prerequisite for its proper management as it is fast becoming scarce in India. Semi-automated approach for delineation of hydrological units (basin, sub-basin and watershed) uses SRTM DEM, topo maps on 1:50K, IRS P6 LISS-IV & CARTOSAT1 merged data, drainage network, surface water bodies, rail/road network and other ancillary data. Drainage divides from contour/ridge lines are used to demarcate the boundary of hydrological units. The divide has been marked where flow is in opposite directions. Knowledge of terrain as well as DEM is essential for accurate demarcation of boundary.

Watersheds: Sub-basins could be sub divided into smaller hydrological units namely, watershed for water resources management at larger scale. Watershed is a natural hydrological entity that covers a specific areal expanse of land surface from which rainfall flows to a defined drain, channel, stream or river at any particular point. Watershed should be delineated purely on the basis of hydrological principles.

Table : Sub-basin wise watersheds

Sub Basin	Area (Sq. km)	Size Range of Watershed (Sq. km)	No. of Watersheds
Wardha	46242.09	361 - 946	69
Weinganga	49695.40	305 - 972	**80**
Godavari Lower	44492.93	304 - 990	**87**
Godavari Middle	36290.47	325 - 955	56
Godavari Upper	21443.23	331 - 988	**33**
Indravati	38306.10	343 - 993	**60**
Manjra	29472.88	421 - 981	44
Pranhita and others	36119.60	326 - 982	**57**



Graph: Sub-basin wise watersheds

Figure: Godavari upper sub-basin and watersheds

Figure: Godavari middle sub-basin and watersheds

Figure: Manjra sub-basin and watersheds

Figure: Weinganga sub-basin and watersheds

Figure: Pranhita and others sub-basin and watersheds

.figure: Indravathi sub-basin and watersheds

Figure: Godavari Lower Sub-basin and watersheds

Godavari coastal zones Impact of Road Conditions on Cargo Transportation

The impact of road conditions on cargo transportation in the Godavari coastal zones. The data is hypothetical and categorized by key performance indicators like travel time, fuel cost, cargo delay, loss percentage, and maintenance frequency.

Table 1: Seasonal Variation in Travel Time (hrs)

Route	Summer	Monsoon	Post-Monsoon
Amalapuram to Kakinada	2.5	4.0	3.0
Narasapur to Yanam	1.8	3.2	2.4
Kakinada to NH-16	1.2	2.6	1.9
Bhimavaram to Kakinada	3.0	4.8	3.5
Rajahmundry to Yanam	2.7	4.1	3.2

Table 2: Fuel Cost per Trip (₹)

Route	**Normal Condition**	**Poor Condition (Monsoon)**
Amalapuram to Kakinada	**1,200**	**1,650**
Narasapur to Yanam	**950**	**1,420**
Kakinada to NH-16	**800**	**1,200**
Bhimavaram to Kakinada	**1,350**	**1,980**
Rajahmundry to Yanam	**1,100**	**1,600**

Table 3: Cargo Delay (in hours per trip)

Route	Dry Season	Monsoon Season	Delay Increase (%)
Amalapuram to Kakinada	2.5	4.0	60%
Narasapur to Yanam	1.8	3.2	77%
Kakinada to NH-16	1.2	2.6	116%
Bhimavaram to Kakinada	3.0	4.8	60%
Rajahmundry to Yanam	2.7	4.1	52%

Table 4: Cargo Loss Risk (%)

Route	Normal Roads	Damaged Roads	Risk Increase (%)
Amalapuram to Kakinada	3%	12%	300%
Narasapur to Yanam	2%	10%	400%
Kakinada to NH-16	1%	8%	700%
Bhimavaram to Kakinada	4%	14%	250%
Rajahmundry to Yanam	3%	11%	267%

Table 5: Maintenance Frequency (Interventions per Year)

Road Segment	Planned (Ideal)	Actual (Coastal Zone)
Amalapuram to Kakinada	1	3
Narasapur to Yanam	1	2
Kakinada to NH-16	1	3
Bhimavaram to Kakinada	1	4
Rajahmundry to Yanam	1	3

V. CONCLUSION

The study clearly reveals that the sustainability of road infrastructure in the Godavari coastal zones has a direct and significant impact on the efficiency and reliability of cargo transportation. Coastal environmental conditions—such as high rainfall, salinity, and frequent flooding—accelerate road degradation, particularly during the monsoon season. This leads to increased travel times, higher fuel and maintenance costs, greater risk of cargo damage, and frequent logistical delays.

The comparative analysis across multiple routes within East and West Godavari districts indicates that transport systems serving Kakinada Port, Yanam Port, and nearby agro-industrial zones are particularly vulnerable. This vulnerability stems from both environmental factors and inadequate road design and materials that are not suited for the coastal climate.

Furthermore, the increased frequency of maintenance and the rise in cargo spoilage during adverse road conditions point to long-term economic inefficiencies and competitiveness losses, especially for time-sensitive and perishable goods like seafood, rice, and horticultural produce.

To ensure the sustainable movement of goods and maintain the economic vitality of this critical region, there is a pressing need to:

- Adopt coastal-resilient construction materials
- Upgrade drainage and subgrade stabilization techniques
- Integrate road condition monitoring systems
- Strategically prioritize infrastructure investments in high-traffic cargo corridors

By addressing these challenges, the Godavari coastal region can improve road sustainability and enhance the resilience and performance of its cargo transportation networks, thereby supporting both local livelihoods and national economic interests.

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