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Assessment of Vulnerability to Floods in Coastal Odisha: A District-Level Analysis

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ASSESSMENT OF VULNERABILITY TO FLOODS IN COASTAL ODISHA: A DISTRICT-LEVEL ANALYSIS

Niranjan Padhan[1] and S Madheswaran[2]

Abstract

The study deals with the assessment of flood vulnerability in Coastal districts of Odisha by adopting an integrated approach based on the factors (exposure, susceptibility and resilience) and domains (socio, economic, environmental and physical dimensions) of vulnerability. Both deductive and inductive methods have been adopted for the selection of proxy indicators from each of the domains of vulnerability. Based on the result of sub-indices of each domains, composite flood vulnerability index (FVI) has been developed to identify the intensity of vulnerability among the concerned districts of the state. From the analysis, Kendrapara district emerged as most vulnerable district and Cuttack the least vulnerable among the six coastal districts of the state.

Keywords: Flood vulnerability, coastal Odisha, components, domains of vulnerability.

Introduction

People in the developing countries are subject to face a variety of risks concerning their livelihoods, as agriculture is considered to be their major source of income. Agriculture is very sensitive towards the occurrence of natural disasters like flood and drought. A preliminary analysis by the Intergovernmental Panel for Climate Change (IPCC, 2007) revealed that flood is the most commonly occurring natural disaster in India. It causes large amounts of damage to people's lives and livelihood. Annually, the average area affected by floods is about 8 million hectares out of which 3.7 million hectare is cropped area. Among the various natural disasters, coastal floods are considered as one of the most dangerous and harmful natural disasters (Balica, *et al*, 2012). In India, the coastal districts of Odisha (Baleshwar, Bhadrak, Kendrapara, Jagatsinghpur, Puri and Cuttack) are affected by frequent occurrences of flood given their geographical location, number of perennial rivers (Mahanadi, Baitarani, Birupa, Rushikulya, Budhabalanga, Brahmani and Subarnarekha) and their tributaries that make the region vulnerable to floods. Overall the coastal districts of Odisha present a unique flood hazard-scape.

Being an agrarian economy, with roughly 40 per cent of its population under poverty and having an annual per-capita income of US$820, the occurrence of such disasters adversely affects the life and livelihood of the people in the state and becomes an obstacle in the growth path of the state economy. The social, political, economic, and institutional factors and their interplay shape the

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vulnerability of people and the places they reside. Although, the Odisha government has taken many steps through different policy measures to protect the region from the adverse impacts of such natural disasters, it often fails to provide a decent living condition to its people. Therefore, a district level vulnerability assessment becomes essential for the policymakers and the households to design appropriate mitigation strategies to cope-up with the adverse impact from flood via reducing the exposure and sensitivity and enhancing the adaptive capacities

There were some of the studies which quantified the intensity of vulnerability of natural disasters by using an integrated approach in the national as well as in the international arena. Balica (2007) developed Flood Vulnerability Index (FVI) to establish a comparative study between three cities namely Timisoara (Romania), Mannheim (Germany) and Phnom Penh (Cambodia) in term their degree of vulnerability due to flood. From the Rhine River Basin to Mannheim, the city of Mannheim was found to be most vulnerable with respect to both economically and physically compare to Timisoara and Phnom Penh. Messner & Meyer (2006) study showed that impacts of the flood was varied between region to region. It is observed that for some of the regions flood risk was very low. This might be due to rare occurrence of floods events and adoption of high flood protection measure through construction of dam and dyke in the region. On the other hand, due to lack of awareness, preparedness and poor flood protection measures, some of the regions found to be risky to the flood. Balica *et al* (2010) developed a general Flood Vulnerability Index (FVI) by considering the most significant indicators which is applicable to three different spatial scales i.e. river basin, sub-catchment and urban area. The composite FVI is the aggregation of the sub-indices (socio, economic, environmental and physical sub-indices) of vulnerability. Result of the study shows that environmental components of the river basin and sub-catchment are less vulnerable due to flood. Balica *et al* (2012) estimated vulnerability of the coastal cities using a host of exposure, susceptibility and resilience indicators in a hierarchical setup. It is observed that Shanghai was most vulnerable city due to coastal flood. The Rotterdam (Netherlands) and Osaka (Japan) were found to be the least vulnerable to the coastal flood.

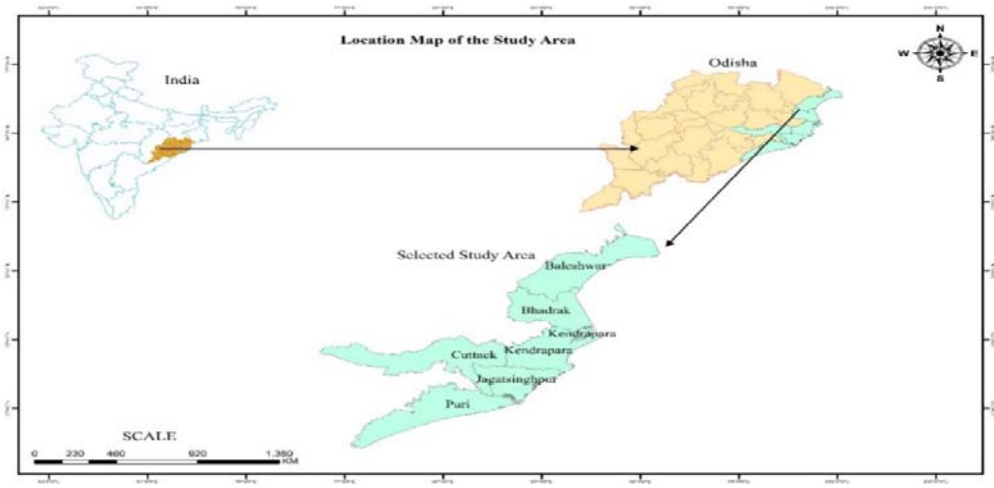
In the context of Odisha, there are studies available to assess vulnerability scenario of coastal districts of the state due to occurrence of flood and cyclones (Patnaik and Narayana, 2009; Kumar *et al*, 2010; Mohanty *et al*, 2008; World Bank, 2008; Bahinipati, 2014). However, these studies are aggregate in nature and fail to focus on the sub-indices components. The current work focuses on a dis-aggregate level. By adopting an integrated approach in this present study, we have tried to assess the vulnerability level of coastal districts of Odisha. This assessment is done through developing a composite flood vulnerability index $FVI_{(Total)}$. For this purpose, the present study develop the sub-indices for flood vulnerability at a domain basis (economic domain, environmental domain, social domain and physical domain). Further, the composite FVI is estimated based on the result of sub-indices of each domain. In doing so, not only the most vulnerable district can be identified, but this will also help us to understand the domain to which government should focus to reduce the vulnerability at district level. Therefore, this study will provide a comprehensive understanding of the intensity of flood among the coastal districts namely Baleshwar, Bhadrak, Cuttack, Jagatsinghpur, Kendrapara and Puri which are frequently affected by major and minor floods every one or two years.

Profile of the Study Area

The state of Odisha is one of the eastern Indian state located between 17.49’N and 22.34’N latitudes and 81.27’E and 87.29’E longitudes (Fig.1). Geographically the state is bounded by West Bengal in the northeast, Jharkhand in the North, Andhra Pradesh in the South, Chhattisgarh in the West and it is open to the Bay of Bengal on the East. It has a coast line of about 450 kilometres. In addition to this, number of perennial rivers i.e. Mahanadi, Baitarani, Birupa, Rushikulya, Budhabalanga, Brahmani and Subarnarekha and their tributaries flowing across the territory of Odisha, makes the state prone to the occurrence of floods. Odisha has history of occurrence of flood since 1960’s. The analysis of flood events in Odisha revels that the state had witnessed 30thflood occurrence events between1960-2017. And it is also evident that Baleshwar, Bhadrak, Kendrapara, Jagatsinghpur, Puri and Cuttack are the most flood affected districts compared the other districts of Odisha. Out of total area of the state, about 21 percent (3.34 million hectare) is considered as a flood prone areas and 75 percent of this spread across the coastal districts of Odisha. The estimated economic loss due to flood in between 2000-2009 is about Rs. 10,000 million. The economic loss associated with 2011 flood event was about Rs. 326.6 million in the state (Bahinipati, 2014).

According to 2011 population census of India, population density of the state is 270 persons per square kilometre and it is 530 persons per square km for the above mentioned six coastal districts. Agro-climatic data indicate that the average annual rainfall of the state is 1336.4 mm where as it is 1470.8mm for the chosen districts of the state. About 84% of rainfall is received during the period from June to September. However, apart from the state geographical location for the occurrence of drought, flood and cyclone with varying intensity, the distribution of rainfall during the monsoon period is highly uneven and erratic that also causes for the natural calamities. The western Odisha suffer from regular and frequent drought while the districts of coastal Odisha suffer from frequent occurrence of flood and cyclone. Being an agrarian economy, agriculture provide employment opportunities directly or indirectly to 58 percent of the population in the state (Economic Survey of Odisha, 2017). The principal crops grown in these districts are rice, jute, green gram, black gram, millets etc. In the present study we have selected six coastal districts Odisha namely Baleshwar, Bhadrak, Kendrapara, Jagatsinghpur, Puri and Cuttack as study regions which has been presented in the following figure 1.

Figure 1: Location of the Study Regions



Conceptual Framework

The intensity of flood vulnerability has been assessed in a comprehensive way by taking into account the factors (exposure, sensitivity and resilience) and the domains of vulnerability (social, economic, physical and environment) that are most likely to effect the occurrence of flood (Balica *et al*, 2009). We have adopted the indicator based method to construct the district wise vulnerability sub-indices at domain basis and also for composite FVI (Balica & Wright, 2010). By doing so, conditions that enhance the flood damage would be identified which may help in framing the programme and policies to take appropriate actions to reduce the vulnerability at regional level. The methodology involves two concepts, firstly factors of vulnerability (IPCC, 2007) and components of vulnerability (Balica & Wright, 2010) which are explained as follows.

Factors of Vulnerability

IPCC (2007) defined "exposure as extent to which household's economic system adversely impacted due to occurrence of natural hazards". Here, we have defined exposure as the extent to which human and physical items i.e. goods, infrastructure and agricultural field will be adversely affected by occurrence of flood.

McCarthy *et al* (2001) defined "susceptibility is defined as the household which experience either positively or negatively due to occurrence of climate extreme events." The study observed two types of impacts i.e. (i) direct impacts: changes in the crop yield due to variability of temperature and rainfall (ii) indirect effect occurred due to increased frequency of coastal flooding as a result of sea level rise. Sensitivity can be understood as extent to which an element of the system is exposed which in turn influences the chance of being harmed at the time of occurrence of flooding events.

Resilience or adaptive capacity is the ability of a system to mitigate/cope up with the adverse impacts from the occurrence of flood (IPCC, 2007).

The above three constituents are considered as factors of vulnerability which influence the vulnerability and thereby FVI also. The four components of the system relate the vulnerability in different ways in which the system is vulnerable. So the interaction between the factors and components of vulnerability serve as the base for our vulnerability methodology. The components of vulnerability are explained as below.

Components of Vulnerability

The social component is related to the presence of human beings, individual and communities and their coping capacity to deal with the adverse impact of flood. Some of the indicators taken into consideration under this component are -percentage of rural families below poverty line, density of population, decadal growth rate of population (2001-2011), percentage of rural area out of total area of the district, infant mortality rate, percentage of old age population, percentage of female population, percentage of rural population, percentage of child population out of total district population, numbers of shelters and the percentage of households possessing communication devices i.e. TV, internet connected computer, laptop, lane line phone and Mobile phone out of total number of district households.

Economic components address the potential impacts of a hazard on economic assets. It tries to explain the production capacity and distributional aspect of goods and services that may be vulnerable to flood in the study region. Indicators available under this component are size of operational land holding (hectare), Net sown area, percentage of cultivators, percentage agricultural labour, dependency ratio, literacy rate (%), percentage of people having membership in Primary Agricultural Credit Society (PACS), gross irrigated area, fertilizer application (kg/ha), workforce participation rate and per capita district gross domestic product (DGDP).

Physical components explain how the physical infrastructure i.e. natural or manmade can influence the vulnerability due to occurrence of flood. The indicators under the physical components are number of house damages, road damages (km), frequency of flood occurrence, number of commercial banks, number of medical institutions and numbers of beds available per hospital, percentage of electrified villages and frequency of flood occurrences in the study region.

Environmental components account for the potential impact on the natural environment and ability of ecosystems to cope and recover from the hazard impacts. Activities namely urbanisation, deforestation, agriculture can explain the vulnerability of the system due to occurrence of flood which may create more environmental damage (Balica & Wright, 2010). Indicators taken into consideration under this component are percentage of urbanized area, average annual rainfall (mm), decadal urban growth rate (2001-2011), average annual temperature, percentage of forest area, percentage of reserve forest area and decadal growth rate of forest.

In this formulation vulnerability of system is seen as a function of exposure, susceptibility and resilience. In this paper vulnerability of a system due to flood event is expressed in terms of the following equation.

$$\text{Vulnerability} = \text{Exposure} * \text{Sensitivity}/\text{Resilience} \ldots\ldots\ldots\ldots\ldots\ldots \text{eq. 1}$$

Methods and Data Sources

Many communities start adopting their own prevention techniques without clear knowledge of the territorial vulnerability (Moris –Oswald and Sinclair, 2005; Barroca *et al*, 2006). Keeping this in mind, Balica & Write (2010) opined that FVI is useful if it is based on indicator methodology and not only a subject of discussion after the occurrence of flooding events. They try to address why we need a proper vulnerability study through developing FVI by taking appropriate indicators.

Following Balica & Write (2010) study we have adopted the indicator based method to construct the district wise vulnerability sub-indices at domain basis and also for composite FVI to identify the most and least vulnerable districts of coastal Odisha. By following relevant proxies for each of the domains are expressed in quantitative terms. Under each domain there are a number of indicators that possess certain characteristics which have been explained in appendix 1.

The present study completely relies on secondary sources of data namely district census data, agricultural statistics of Odisha 2013-14, Economic survey of Odisha for various years, Annual Handbook of statistics at district level for various years, Statistical abstract Odisha; 2012, Odisha State Disaster Management Authority(OSDMA), India Metrological Department (IMD) etc. The period of analysis is for five years where flood damage data and socioeconomic statistics have been collected during the time period 2011 to 2015. The secondary data sources for each indicators has been mentioned in appendix 1.

Indicators selection

It is important to consider appropriate indicators for developing a vulnerability index which is as close as possible to represent the reality. In this paper we have adopted both deductive and inductive approach for indicators selection. For developing the sub-indices, we have segregated all the chosen indicators in vulnerability factors and domains wise after reviewing the literature of some of the vulnerability studies (Balica & Wright, 2010; Bahinipati, 2014)

Initially, a total of 48 indicators were chosen for computation of FVI by following deductive approach (e.g., understanding vulnerability literature, conceptual framework). Finally, a total of 37 significant indicators have been selected from four domains for computation of composite FVI and the rest of the indicators were taken out from our computation due to redundancy of definitions, to avoid the multicollinearity problem between the indicators and difficulty in obtaining the required data. These 37 significant indicators have been selected by examining the pair wise correlation between the indicators under each separate domain of vulnerability in the study regions (Balica, *et al*, 2009; Balica & Wright, 2010). Correlation coefficient is a single number that describes the degree of correlation between two variables. The value of the Pearson correlation coefficient lies between -1 to +1. The closer the correlation to +1 or -1, the closer the two variable are to a perfect relationship. Simon, (2005) pointed out that a strong positive correlation between the variables is interpreted as correlation between +0.7 and +1.0.

From the correlation coefficient result we have observed that there exists significant correlation (r>0.7) between some of the chosen indicators and that these strongly correlated indicators are not independent to each other, Therefore, by choosing one indicator from each group we are able to reduce the total number of indicators without affecting the FVI (Balica & Wright, 2010). By considering these 37 indicators we have tried to represent the vulnerability status of the study districts in an effective manner. This in turn may help to the policymaker to formulate plans and policies to cope up with the adverse impacts from the flood.

Calculation of Vulnerability

Indicators can be analysed through two ways i.e. (i) by giving equal weight to each and every indicator and (ii) assigning weights to each indicator by taking into consideration expert judgement, through principle component analysis and by analysing the correlation with the past disaster events (Deressa *et al*, 2008). "Assigning appropriate weights to each indicator is a challenging task and there are no such standard weighting methods which we can test or precision" (Deressa, 2010). However, by considering all the possible limitations of both the approaches, we have analysed the indicators by assigning equal weights.

Since indicators are measured in different units they need to be normalized in order to bring them to a single scale. We have used Iyengar & Sudarsan (1982) method for normalization of each indicator of vulnerability which is shown in eq. 2.

$$\text{Indicator index score} = \frac{X(i) - x\,(min)}{X\,(max) - X\,(min)} \text{ ....eq.2}$$

Where, X_i is the original value of the indicator for the district
$X\,(max)$is the maximum value of the indicator for the district
$X\,(min)$ is the minimum value of the indicator for the district.

The numerical value of the indicator indicates the relative status of vulnerability of the selected districts. By following the above method of normalization for an indicator the numerical value lies between 0 and 1. Here we have adjusted the maximum and minimum value in order to avoid a value of more than one.

Once the indicator index values are obtained, we have assigned equal weights to each indicator by taking the arithmetic mean of each vulnerability factor. The choices of the equal weighting to all the sub-indices are based on normative judgement that all the four sub-indices are equally important for developing composite flood vulnerability index (FVIs).

After normalization of all the proxy indicators, we have calculated the sub-indices at domain basis following the proposed methodology of Balica (2007) as explained as eq. 3.

$$\text{FVI} = \frac{\text{Exposure} \times \text{Suceptibility}}{\text{Resilience}} \text{................eq.3}$$

According to Balica *et al* (2009) the above method of FVI links the values of all indicators to flood vulnerability components and factors. The factors namely exposure and susceptibility of vulnerability is placed in the numerator as this leads to increase in vulnerability and resilience indicators leads to decrease in vulnerability and therefore placed as denominator.

After calculating the flood vulnerability sub-indices for each component, we have developed standardized FVI for each sub-index as well as for composite FVI for easier interpretation and comparison between each component by following the proposed methodology used by Sullivan (2002).

The standardized formula is presented as a FVI of a system divided by maximum FVI within one system as follows.

$$\mathrm{FVI}_{(\mathrm{Std})} = \frac{\mathrm{FVI(specific)}}{\max_{i=1}^{n}(\mathrm{FVI})_i} \quad \text{................eq.4}$$

Where $\mathrm{FVI}_{(\mathrm{Specific})}$ means estimated FVI for particular district

$Max_{i=1}^{n}\,(FVI_i)$: represent the maximum estimated FVI value of that particular component among the coastal districts of Odisha, n= six coastal districts.

$FVI_{(Std)}$: standardized FVI.

The standardized FVI value lies between 0 to 1; indicating 1 being the most vulnerable due to flood and 0 being the least vulnerable to flood.

Through the application of the above formula explained in eq.4 we have computed four district FVI indices for each component i.e. $FVI_{(social)}$, $FVI_{(economic)}$, $FVI_{(physical)}$ and $FVI_{(environmental)}$. Finally $FVI_{(Total)}$ is computed by taking the 4th square root of the multiplication of the four FVI components which is represented as eq.5. The logic behind geometric mean is that changes in the maximum value will not affect the ranking of a district.

$$FVI_{(total)} = \sqrt[4]{FVI_{(social)}.FVI_{(economic)}.FVI_{(physical)}.FVI_{(environmental)}} \quad \text{................eq.5}$$

Balica, *et al* (2009) and Balica & Wright (2010) have computed total FVI by taking composite additive index based on four vulnerability components i.e. $FVI_{(total)} = FVI_{(social)} + FVI_{(economic)} + FVI_{(physical)} + FVI_{(environmnetal)}$ which will not give a comprehensive picture about the ranking of districts/system according to vulnerability of flood. In the same way, one of the major limitations of the composite index based on arithmetic mean is that it allows the compensation of the indicators or indices i.e. if one index has a low value can be compensated for by the other indices i.e. methodology used for calculation of Human Development Index (HDI) up to 2010. Throughout the time non-compensatory approaches of indices have been developed where it is assumed that all the indicators themselves have equal importance. For the non-compensatory approach, non-linear methods like geometric mean or multi-criteria analysis are generally used i.e. methodology used for HDI calculation after 2010, Santos & Alkire (2011).

We have computed composite FVI based on geometric mean of four sub-indices which may give an improvised result compared to additive composite FVI (Balica *et al*, 2009; Balica& Write, 2010) and composite FVI based on arithmetic mean method (Ahsan & Waner, 2013; Bahinipati, 2014). However, it has been pointed out that there is no universal method that exists for developing the composite index. The construction is dependent upon the particular application incorporating some expert knowledge on the phenomenon.

Result and Analysis

This section deals with the findings of the flood vulnerability index and mapping out the intensity of vulnerability in each domain with the spatial analysis. From the obtained results it is observed that both exposure and susceptibility are directly related to vulnerability, whereas an inverse relationship persisted between resilience and vulnerability. A highly vulnerable district was associated with either higher value of exposure or susceptibility or both or a less adaptive capacity score. The result of the domain wise vulnerability has been explained as below.

Social Domain

The empirical result of social domain vulnerability due to flood among the coastal districts of Odisha has been presented in the table: 1. We have found that Kendrapara is the most socially vulnerable district among the coastal districts of Odisha. It's possessed the highest standardize FVI score (Std FVI=1) and Cuttack is found to be the least socially vulnerable having a standardize FVI score equal to 0.084.

Table 1: Districts-wise Vulnerability Index in Odisha (Social Domain)

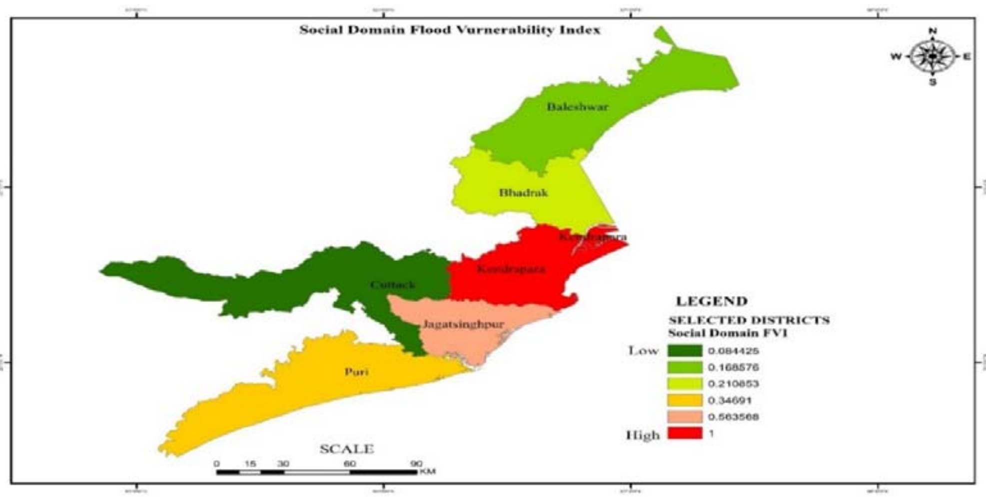
Districts	Exposure	Rank	Susceptibility	Rank	Resilience	Rank	FVI	Std. FVI	Rank
Baleshwar	0.55	4	0.476	3	0.62	2	0.43	0.169	5
Bhadrak	0.65	2	0.448	4	0.55	3	0.54	0.211	4
Cuttack	0.51	5	0.403	5	0.96	1	0.21	0.084	**6**
Jagatsinghpur	0.40	6	0.398	6	0.11	6	1.43	0.564	2
Kendrapara	0.61	3	0.683	1	0.16	5	2.54	1.000	**1**
Puri	0.71	1	0.524	2	0.42	4	0.88	0.347	3

Source: computed from secondary data source

It has been observed from our results that the resilience capacity of Kendrapara district is very low (0.16). It is found that both susceptibility and exposure indicators are major contributors to vulnerability due to occurrence of flood in this particular district. Among the susceptibility indicators, the share of female population (50.17%) as well as the share of rural population (94.17%) to the total district population are highest among the other coastal districts of Odisha. The share of female population out of total district population for Kendrapara district is reported to be more than other concern districts of Odisha. Duddy (2002) study showed that women possess the comparative less strength to combat natural disaster. Because of their traditional socialisation and work related practices women are more vulnerable to natural disasters than their male counterparts. Being an agrarian economy occurrence of natural disaster poses a potential threat to the lives and livelihood of the farmers. This is because flood takes away their livelihood at the first instance and leaves them with little resources to overcome such situation. Studies show that during the flood event there is a decline in income from agriculture by 2/3rd amount compared to the normal time period (Parvin *et al*, 2016). Share of old age and child population in this district is 11.8% and 16.38% respectively. The children and old age population are faced difficulties for easy evacuation as a result they cannot immediately be evacuated from the flood affected area and, therefore, they are more vulnerable than others.

On the other hand Cuttack district was found to be less vulnerable in social domain among the selected districts as the resilience capacity (0.96) of this district is found to be very high compared to other districts. Considering the shelter security, there are about 254 multi-cyclone and flood shelters constructed by government of Odisha; OSDMA for the provision of providing shelter facilities and saving lives and livelihoods of the people during the occurrence of flood and any cyclone events in this district. Apart from that people uses school, college buildings for shelter purpose during these events. Percentage of households possessing communication devices are also found to be high in this district. This helps them to immediately spread information and bring about awareness with regard to the occurrence of any natural disaster among the people. Warning system about rainfall, river flow rate helps in forecasting about river water flow and extent of flood. It has been pointed out that prior community awareness about the flood risk make the warning systems more effective. The government of Odisha disseminate both pre and post warning systems to reduce the risk due to occurrence of flood. And this warning system disseminated through TV, radio and other communication technology. Therefore, it is assumed that the district which possesses more communication technology is less vulnerable to the occurrence of flood. This has further been substantiated from our vulnerability result.

Figure 2: Vulnerability map among the coastal districts of Odisha (Social domain)



Source: Computed from table 1

Economic Domain

It is observed from table 2 that in the economic domain Bhadrak is reported to be a highly vulnerable district followed by Kendrapara while Cuttack is reported to be the least vulnerable among the others study districts. From the exposure determinant the average size of operational land holding among the households in Bhadrak district is 0.89 ha, which is higher than other coastal district of Odisha. However, the size of average operational land holding for Cuttack is 0. 86 ha which is second highest and for Kendrapara it is 0.78 ha. The Flood makes the land unsuitable for agricultural production until the water recede and by increasing the salinity in the soil and thereby it reduces the productive capacity of the land. It is expected that higher the net sown area are more exposed to the flood. From our study, it is observed that Bhadrak district has recorded the third highest net sown area (162 thousand ha) while Cuttack district has the least net sown area (62 thousand ha) among the study districts. The highest net sown area can be observed in Jagatsinghpur district (255 thousand ha) followed by Baleshwar district (204, thousand ha).

Table 2: Districts-wise Vulnerability Index in Odisha (Economic Domain)

Districts	Exposure	Rank	Susceptibility	Rank	Resilience	Rank	FVI	Std. FVI	Rank
Baleshwar	0.41	4	0.92	1	0.72	1	0.53	0.424	3
Bhadrak	0.76	1	0.80	2	0.49	5	1.25	1.000	**1**
Cuttack	0.38	5	0.02	6	0.69	2	0.01	0.012	**6**
Jagatsinghpur	0.53	2	0.29	5	0.63	3	0.25	0.198	5
Kendrapara	0.21	6	0.76	3	0.22	6	0.72	0.572	2
Puri	0.47	3	0.31	4	0.57	4	0.25	0.203	4

Source: computed from secondary data source

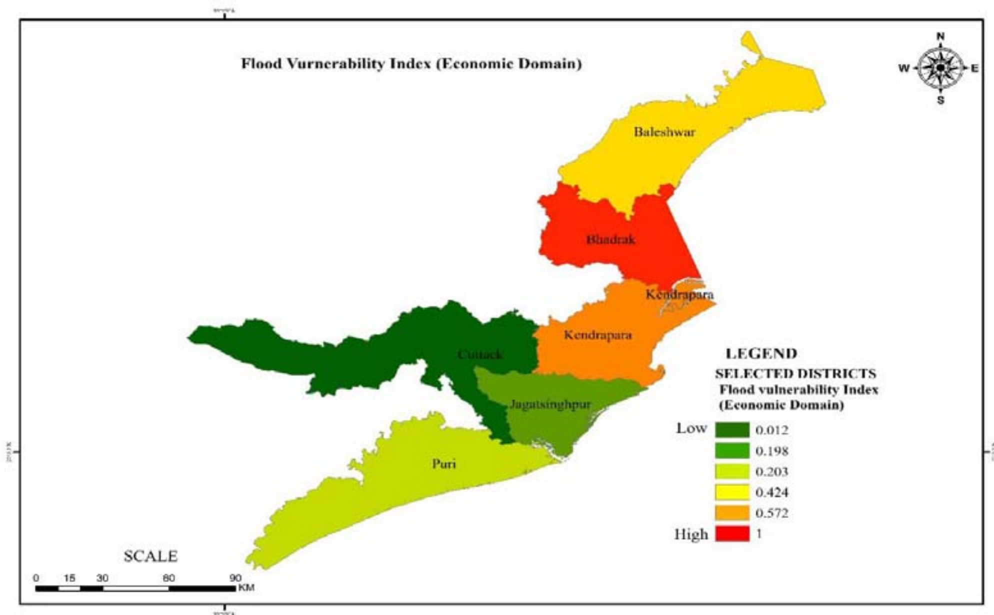
Among the susceptibility factor the indicators namely the percentage of cultivators out of total workers (33.28) and percentage of agricultural labour (32.30%) are found to be highest in Bhadrak district and it is found to be less in Cuttack districts i.e. the percentage of cultivators out of total workers (14.81%) and percentage of agricultural labour (26.52%) among other study districts of the state. The occurrence of flood leads to the reduction of the employment opportunities for agricultural labourers and cultivators which in turn adversely affect their lives and livelihoods. The high dependency rate in Bhadrak district makes it more vulnerable than others. High dependency means more number of children and older age population depending upon the few income earning members in a family or in a system. The contribution of elders and children is very less to their family income and therefore family having highest dependencies are assumed to possess less adaptive capacity. Adaptive capacity of a family is dependent upon economic status of that family.

The resilience indicators like the DGDP per-capita (Rs. 35970.73) and gross irrigated area (194.83 ha) and literacy rate (86%) are found to be highest in the Cuttack district. Due to the presence of low value susceptibility indicators and more resilience capacity, the district is seen to be less vulnerable to flood. The adaptive capacity of the district is dependent upon its economic status and since this district possesses the highest per-capita income and it is assumed that their adaptive capacity is more. Brain *et al* (2004) found that "district with higher irrigation rate have the higher adaptive capacity in India. Mostly the irrigated area has more productive capacity than unirrigated area and therefore it is found that districts having high production per unit area presume to be less vulnerable than the less productive districts." Higher membership of Primary Agricultural Cooperative Societies (PACS) is higher in Cuttack district.

Apart from the Gross irrigated area, fertilizer application may be considered as important as the increase in fertilizer application leads to increase in the productive capacity of the agricultural land and thereby increase the income earning capacity of the farm households. It is also found that, according to agricultural statistics (2013), both the fertilizer application and agricultural yield are high in the Cuttack district among the other study districts.

The role of education in risk reduction have been pointed out by many literature. Bahinipati (2014) opined that education can enhance the awareness and understanding among the people about the risk associated with occurrence of any natural disaster and thereby it may help them to access the information of potential risk reduction measures and it will also can increase the chances of getting a formal job and moving out of a risky area. It is also assumed that educated workers are more productive and efficient than uneducated workers. Therefore, the earning capacity of the educated workers is more compared to others which in turn helps them to increase their adaptive capacity to flood. This could be a possible reason why Bhadrak district is more vulnerable as it is the lowest in literacy and Cuttack is least vulnerable as literacy rate is found to be highest in this district.

Figure 3: Vulnerability map among the coastal districts of Odisha (Economic domain)



Source: Computed from table 2

Physical Domain

The result of vulnerability in the physical domain is presented in the table 3. From our analysis Kendrapara district was found to be physically more vulnerable, and Bhadrak found to be least vulnerable among the selected districts of the state. Kendrapara district possesses the highest average score of exposure and susceptibility determinant i.e. 0.78 and 0.57 respectively which indicates that exposure and susceptibility indicators are the major driver of physical vulnerability in this particular district. The average score of resilience determinant is 0.07 which is least among the districts. Considering the houses damaged out of total number of house damage due to flood (2011) Bhadrak district has reported to be highest in number i.e. 33, 683. Numbers of house damage are one of the important indicators under exposure factor of vulnerability in our study.

Table 3: Districts-wise Vulnerability Index in Odisha (Physical Domain)

Districts	Exposure	Rank	Susceptibility	Rank	Resilience	Rank	FVI	Std.FVI	Rank
Baleshwar	0.23	5	0.97	2	0.63	2	0.36	0.057	4
Bhadrak	0.59	3	0.02	6	0.37	4	0.03	0.005	**6**
Cuttack	0.67	2	0.79	3	0.96	1	0.55	0.087	3
Jagatsinghpur	0.02	6	0.45	5	0.23	5	0.04	0.006	5
Kendrapara	0.78	1	0.57	4	0.07	6	6.26	1.000	**1**
Puri	0.38	4	1.00	1	0.44	3	0.85	0.136	2

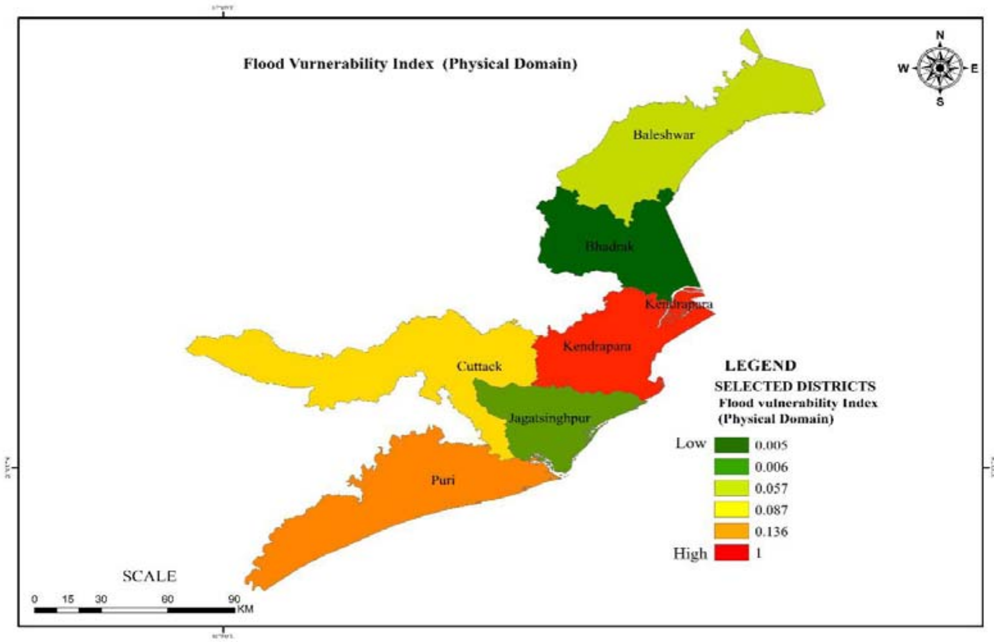
Source: computed from secondary data source

Among the determinants of susceptibility factor, it is observed that the average frequency of occurrence of flood in the Kendrapara districts (1960-2017) is about two times in a year where as for Bhadrak district it is about once in a year. Occurrence of flood will lead to adverse impacts on the live and livelihood of the people. So, it is expected that higher the frequency of flood in a region, higher the susceptibility to vulnerability. From the view point of resilience capacity, we found that percentage of villages having electrification for Kendrapara district is lowest (89.6%) where as it is highest for Bhadrak district (99.5%). According to Bach *et al* (2013) availing of critical infrastructure (electricity) determine the infrastructural development of an economy. Most infrastructures such as transport, waste water management, telecommunications etc. are dependent on electricity as input and are thus negatively affected in case of electricity supply failure. So, it is assumed that village having higher electrification, has the higher disaster resilience capacity.

Total number of government medical institution (which include community health centre, primary health centre (PHC), mobile health centre; MHC) found in the Kendrapara district is 56 which is second lowest after the Jagatsinghpur district (48) and it is 62 in Bhadrak district among the coastal districts of the state. Total number of beds in government hospital for Kendrapara is 268 which is lowest and it is 409 for Bhadrak district. Higher number of beds per hospital can help to reduce the mortality rate due to occurrence of flood in the study regions while fewer beds per hospital may increase the mortality. Here, we have taken in to account only government hospitals as an indicator by assuming that it is more accessible for all the people including the poor to get treatment from these hospitals at a lowest cost which is not in the case of private hospitals. So, these are the resilience indicators which depict the overall infrastructure development of the studied districts which may help mitigates or acts as supportive instruments to enhance the adaptive capacity among the households in the study regions of the state. According to Bahinipati (2014), "the generic adaptation measure i.e. development of physical infrastructure in this case may increase the ability of a system to stand against the wide range of risk associated with the occurrence of natural disaster like flood and cyclone."

We have observed that the highest number of commercial banks (391) in Cuttack district and less in the Bhadrak district among all costal districts. It is expected that higher the number of formal banking institutions (commercial banks) helps more beneficiaries in terms of gaining steady income and consumption. The farmers are benefited by getting loans and different credit facilities which in turn helps them to purchase the land and other agricultural inputs like seeds, fertilizers, insecticides etc., for their cultivation. In this way the financial institution will helps them to gaining a steady income and thereby improving their consumption as well.

Figure 4: Vulnerability map among the coastal districts of Odisha (Physical domain)



Source: Computed from table 3

Environmental Domain

It is observed from table 4 that Puri is the highest environmentally vulnerable district and Baleshwar reported to be the least environmentally vulnerable district among the concerned districts of Odisha. We can notice that the score of the susceptibility determinant of Puri district is second highest (0.592) and on the other hand score of the resilience determinant is low which indicates that Puri has less resilient capacity to cope up with adverse impact from the occurrence of flood. One of the possible reasons for least environmental vulnerability of Baleshwar district may be due to its high resilience capacity (0.726) although it is moderately susceptible and highly exposed (0.775) towards the occurrence of flood.

Table 4: District-wise Vulnerability Index in Odisha (Environmental Domain)

Districts	Exposure	Rank	Susceptibility	Rank	Resilience	Rank	FVI	Std.FVI	Rank
Baleshwar	0.775	2	0.108	6	0.726	2	0.116	0.032	**6**
Bhadrak	0.591	3	1.000	1	0.185	5	3.191	0.892	2
Cuttack	0.408	1	0.415	4	1.000	1	0.169	0.047	5
Jagatsinghpur	0.240	6	0.472	3	0.387	4	0.294	0.082	3
Kendrapara	0.745	5	0.114	5	0.401	3	0.213	0.059	4
Puri	0.335	4	0.592	2	0.056	6	3.576	1.000	**1**

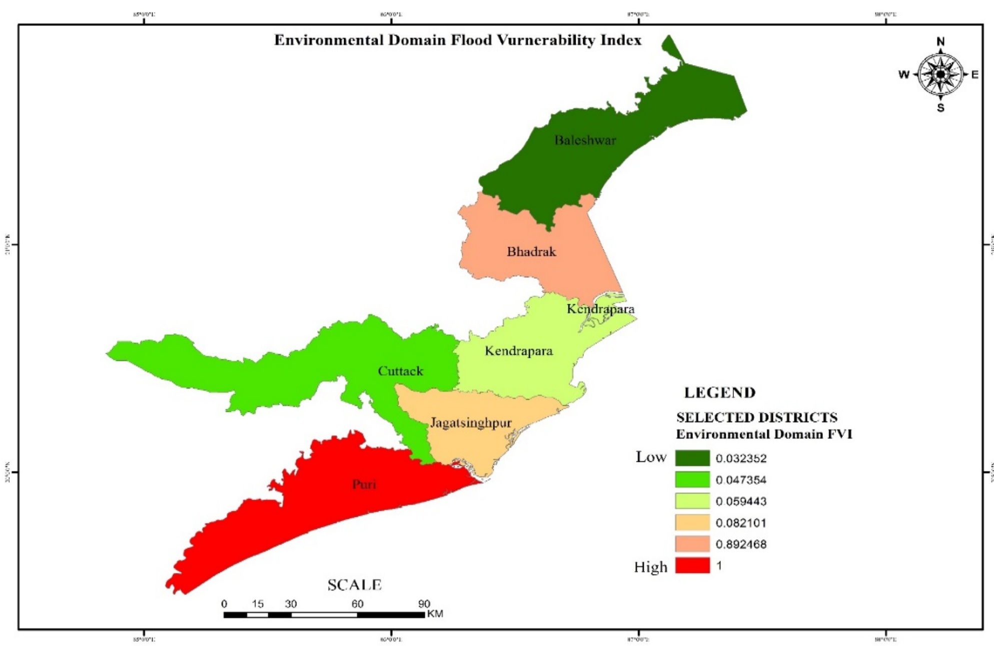
Source: computed from secondary data source

Cuttack is the second least vulnerable district in environmental domain to flood than other chosen districts of Odisha. It has been reported that Cuttack is the one of the hottest districts of Odisha. It is observed that the average annual temperature for Cuttack district is highest (32^{0}C) than other study districts of the state.

Coming to resilience capacity, Baleshwar district is reported as highest forest area out of total geographical area. Forests can soak the excess rainfall, preventing the runoff and damage from flooding. District having highest forest area (Baleshwar, which is recorded 8 percent forest area of the total district geographical area) is assumed to be less vulnerable than districts having less forest area (Puri which is recorded 3 percent of forest area out of the total district geographical area). Therefore, districts having highest negative growth of forest area may be highly vulnerable to occurrence of flood. Puri district reported to be the second highest negative growth of forest among the other concern districts of the state.

From our analysis, decadal urban growth rate for Puri district is found to be highest compared to others study districts of Odisha. Konrad (2003) pointed out that common consequences of urban development are increased peak discharge and frequency of floods. Typically, the annual maximum discharge in a stream will increase as urban development occurs. The changes in land use associated with urban development affect the flooding in many ways. Removing vegetation and soil, grading the land surface, and constructing drainage networks increase runoff to streams from rainfall and snowmelt. As a result, the peak discharge, volume and frequency of floods increase in nearby streams. Bahinipati (2014) viewed that fast urban growth may result in poor quality of infrastructure, thus making the people more vulnerable.

Figure 5: Vulnerability map among the coastal districts of Odisha (Environmental domain)



Source: Computed from table: 4

Composite Flood Vulnerability Index (FVI)

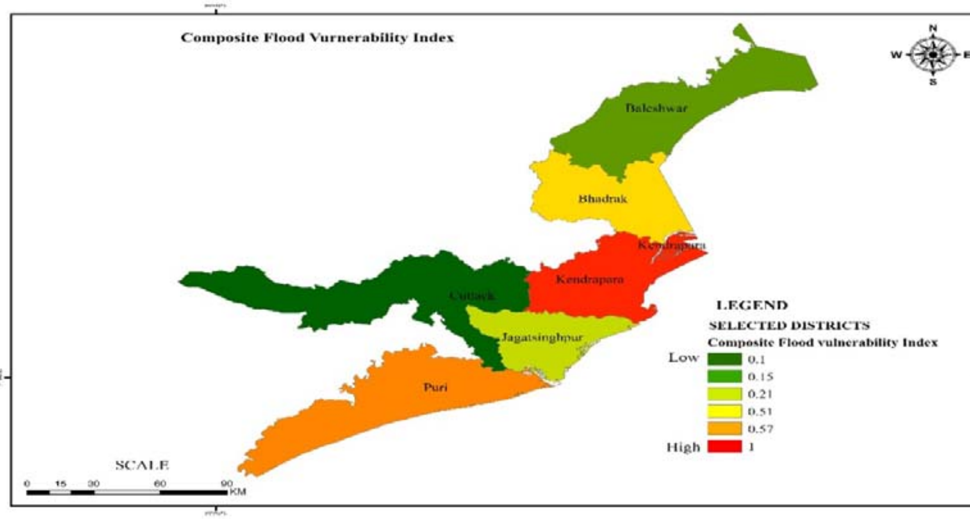
Table 5: District-wise overall flood Vulnerability Index (FVI) in Odisha

Districts	FVI (social)	FVI (eco)	FVI (phy)	FVI (env)	FVI (total)	Std.FVI	Rank
Baleshwar	0.43	0.53	0.36	0.116	0.36	0.15	5
Bhadrak	0.54	1.25	0.03	3.191	1.25	0.51	3
Cuttack	**0.21**	**0.01**	**0.55**	**0.169**	**0.23**	**0.10**	**6**
Jagatsinghpur	1.43	0.25	0.04	0.294	0.50	0.21	4
Kendrapara	**2.54**	**0.72**	**6.26**	**0.213**	**2.43**	**1.00**	**1**
Puri	0.88	0.25	0.85	3.576	1.39	0.57	2

Source: computed from secondary data source

Following the geometric mean method (Eq. 5) we have estimated composite FVI, the results of which is given in Table 5. It is observed that Kendrapara is ranked as 1st (highest) and Cuttack is ranked as the 6th (least) vulnerable districts among the other selected districts of the state. Vulnerability in both physical and social domains contribute more to overall vulnerability of the Kendrapara district. On the other hand, we have observed that Cuttack is less vulnerable in term of social domain, economic domain and environmental domain, and this could be a probable reason for least vulnerability of Cuttack district in overall aspect. However, it is the 3rd highest vulnerable district in term of physical domain**.** In this way the composite vulnerability index at a district level, has an advantage of informing policy makers about the specific source of vulnerability. The outcome of the study may help to develop location specific strategies, policies and programs to address adverse impacts of flood at ground level which is missing from the existing vulnerability literature. It is likely that the findings and recommendation of the study will be applicable to other economy or natural resource dependent countries having the similar socio-economic profile as the state of Odisha.

Figure 6: Vulnerability map among the coastal districts of Odisha (Composite FVI)



Source: Computed from table: 5

Conclusion

We have developed a composite FVI for the coastal districts of Odisha on the basis of flood damage data and socioeconomic status (data) during the time period of 2011-2015. The flood vulnerability sub-indices and composite FVI can provide multifaceted information regarding flood vulnerability which can help in deepening the understanding of the pattern of flood vulnerability and provide a scientific base for policy making and policy implementation of flood prevention and mitigation.

The methodology involves two concepts. First part tries to analyse the factors of vulnerability such as exposure, susceptibility and resilience and the second part tries to understand the components of the system that suffers from the occurrence of natural disasters such as social, economic, environmental and physical components. Therefore, the interaction of vulnerability factors and components serve as the base for our FVI methodology. From the result it is observed that Kendrapara district is highly socially vulnerable and Cuttack district is least vulnerable among the study districts of the state. On the other hand, in economic domain, Bhadrak district found to be more vulnerable and Cuttack district is least economically vulnerable district due to flood. Kendrapara district observed to be more physically vulnerable and Bhadrak is the least vulnerable to the flood in this aspect. From the environmental domain it is found that Puri district is highly vulnerable and Baleshwar district is least vulnerable to occurrence of the flood. However, the composite FVI result suggest that in overall aspect Kendrapara is the most vulnerable district and Cuttack is the least vulnerable district to the flood. It has been also observed that strength or weakness in the sensitivity and adaptive capacity plays an important role in shaping and reshaping the vulnerability of the region. Hence, a comprehensive understanding about attributes of the above is crucial to intergrade vulnerability assessment. According to this study, the heterogeneous impacts are mainly due to the differences in vulnerability conditions of the studied districts because of their varying socio, economic, environmental and physical conditions. Therefore, these differences in the vulnerability conditions need to take in to consideration in the policy design while forecasting future vulnerabilities.

Though our study follows a systematic procedure to measure the vulnerability intensity of the study regions, it does suffer from some of the limitation due to the lack of required data. We have faced difficulty to gather the socio-economic information like HDI, hydrological information such as flood peaks, river discharge, and water level in the rivers which are crucial for flood vulnerability from available secondary data sources and therefore incorporating these information is beyond the scope of our paper. Finally concerning the socio, economic, physical and environmental indicators (used for developing sub-indices and composite vulnerability index) we have limited our analysis for the period of five years (2011-2015).

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Appendix 1: Description on Factors, Major Components and Indicators of Vulnerability

Domain 1: Social Component				
Indicators	**FVF**	**Definition of Indicators**	**FRV**	**Data Source**
Rural BPL	E	Rural families below poverty line (%)	+	District Statistical Hand Book (2011)
Density of Population	E	There is an important exposure to a given hazard if the population concentration is more (People per Sq.km)	+	Office of the Registrar General and Census Commissioner, India.
Population growth	E	Growth rate population: 2001-2011. (%)	+	
Rural Area	E	Total area which is rural (%)	+	
Infant mortality rate	S	Deaths of children under one year of age per 1000 live births (Number)	+	Economic Survey of Odisha (2015-16)
District population	S	Share of district population to total population of the state (%)	+	http://www.desorissa.nic.in/pdf/dist-at-a-glance-2018.pdf
Female population	S	Female population out of total population of the district (%)	+	
Rural population	S	Rural population out of total population of the district (%)	+	Office of the Registrar General and Census Commissioner, India.
Old age population	S	Old age population (above 60 years of age) out of total population of the district (%)	+	
Child Population	S	Child population (less than 6 years of age) out of total population of the district (%)	+	
Shelters	R	Shelter of the district (Number)	-	District Disaster Management Plan Reports (2014)
Communication	R	Household having TV, internet connected computer, laptop, lane line phone and Mobile phone out of total number of district households (%)	-	Office of the Registrar General and Census Commissioner, India.
Domain 2: Economic Component				
Land Holding	E	Average size of operational land holding (Hectare)	+	Agricultural Census of Odisha 2011, Ministry of Agriculture Govt of Odisha
Net Sown Area	E	This represent the total area sown with crops and orchards out of total cultivated area of districts. Area sown more than once in the same year is counted only once. (Hectare)	+	Directorate of Economic and Statistics, Odisha; Economic Survey Odisha (2015-16)
Cultivators	S	Cultivator out of total worker (%)	+	Statistical Abstract of Odisha; Government of Odisha(2012)
Agricultural Labour	S	Agricultural labour out of total (%)	+	
Dependency	S	Child population (less than 14 years) and old age population (above 60 years) depends upon the working age population (15-59) (%)	+	Office of the Registrar General and Census Commissioner, India.
Membership in PACS	R	People having membership in Primary Agricultural Credit Society (%)	-	District Statistical Handbook, 2011
Fertilizer	R	Consumption of fertilizer (kg/ha)	-	Odisha Agricultural Statistics 2013-14
Gross irrigated area	R	Gross irrigated area out of total cultivable areas of each district (Hectare)	-	Economic Survey of Odisha, 2014-15
Work force participation rate	R	People employed (%)	-	Economic Survey of Odisha, 2015
DGDP per-capita	R	District gross domestic product in (Rs)	-	Directorate of Economics & Statistics, Odisha. http://www.desorissa.nic.in/ddp.html
Literacy rate	R	Literate people out of total district population (%)	-	Office of the Registrar General and Census Commissioner, India.

Domain 3: Physical Component				
House damage	E	Houses damage (Pucca +Kuchha+Huts): (Number)	+	Annual Report on Natural Calamities: Govt. of Odisha, 2011-12
Road damage	E	Damage to PWD Roads in each concern district (Km)	+	
Flood Occurrence	S	flood occurrence in a year in each concern district (Numbers of time)	+	Author's calculation from different report, literature and journal/Articles
Medical Institutions	R	Government medical institution established in each district (Number)	-	Economic Survey, Odisha 2015-16
No. of Beds	R	Beds available per hospital (Number)	-	
Electrified Village	R	Villages Electrified in each district (%)	-	Statistical Abstract of Odisha: 2012
Commercial Bank	R	Commercial bank in the district (Number)	-	Economic Survey 2015-16 Odisha
Domain 4: Environmental Component				
Urban Area	E	Urbanised area out of total geographical area of the district (%)	+	Office of the Registrar General and Census Commissioner, India.
Rainfall	E	Average Actual Rainfall (mm)	+	http://www.imdorissa.gov.in/
Urban Growth	S	Fast urban growth may result in poor quality of infrastructure (house, drainage & so on) and thus make the people more vulnerable (%)	+	Office of the Registrar General and Census Commissioner, India.
Temperature	S	Increase in temperature may cause increase in evaporation and intense precipitation caused flooding (Celsius scale)	+	Annual Handbook at District level: Directorate of Economic & Statistics, Odisha
Forest Area	R	Forest area out of total geographical area of the district (%)	-	Odisha Economic Survey 2014-15
Reserve Forest Area	R	Reserve forest area out of total forest area (%)	-	
Growth rate of forest	R	Growth rate of forest area in last 10 years (%)	-	Odisha Economic Survey 2001-02 & 2014-15

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