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ASSESSMENT OF FLOOD RESILIENCE USING RAAAR FRAMEWORK: THE CASE OF NARMADA RIVER BASIN, INDIA

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Abstract

This paper proposes a framework for the assessment of flood resilience. The RAAAR framework is an acronym for 5 attributes or factors of Resist, Absorb, Accommodate, Adapt and Recover that define Resilience. The paper details this generic framework that can further be up-scaled for the entire districts, states or countries. The paper also illustrates the application of this framework by assessing reliance for the case of 21 districts along the River Narmada in central India, and discusses the results in the context of planning and policy. The RAAAR factors/attributes were represented by 16 physical, social, economic, demographic and infrastructure facilities-based indicators. Principal Component Analysis was then employed to assess the quantum of resilience represented by the Flood Resilience Index across 21 districts, for which Spatial mapping of the resilience was also undertaken. The RAAAR framework would be found useful by various stakeholders such as the urban planners and policy makers, disaster managers, district administrators, communities and the non-governmental organizations that are involved in managing the flood related risks.

Key words: flood related resilience, flood resilience index, planning and policy, RAAAR framework, spatial mapping of the resilience

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1. Introduction

Development of human activities and climate change are increasingly contributing to the floodrisks across the globe (Dash and Punia, 2019). Floods are amongst the most common natural disasters that cause immense damage to the natural environment, ecological habitats, and human constructions (Das, 2019) resulting in significant economic and environmental damage as well as casualties every year. This is despite our ability to forecast and forewarn the floods, and despite the recent progress in disaster science and management.

India is characterized by high-magnitude floods during the monsoon season which are typically recurring. The Narmada River in central India is characterized by intense flood regimes (Kale et al., 1994). The flooding is caused by the inadequate river banks' capacity to contain the high flow from the upper catchments and accumulating water resulting from heavy rainfall over other areas that have poor drainage characteristics (Kamat et al., 2007). As is typical to developing countries, the urban districts do not necessarily undergo planned development. Urban flooding therefore becomes an issue of significance with regard to the economy, livelihoods, and daily activities (Criado et al., 2019; Thanvisitthpon et al., 2020). Haphazard urban planning, climate change and expanding urbanization that also tests the limits of the capacity of urban drainage impose the danger of floods on an increasing scale (Heinzlef et al., 2019; Pal and Bhatia, 2017; Wang et al., 2019).

In this context, making the communities in any river basin better equipped in terms of facing the floods has emerged as a major challenge in recent times, as resilient communities remain far less vulnerable to hazards and disasters than the less resilient ones (Cutter et al., 2008). Flood resilience is

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therefore fast emerging as the new tool employed in the overall framework of flood risk management and Adaptation (Campbell et al., 2019; Disse et al., 2020; Leandro et al., 2020).

Resilience of any community or any society refers to the ability of the system exposed to some hazard to be able to resist, absorb, accommodate and recover from the effects of the hazard in an efficient manner such that preservation and restoration of the essential basic structures and functions of the system is carried out as early as possible (UNISDR, 2009). Alternatively, Resilience can also be defined as the ability of the system to confront a disaster while avoiding complete failure, and to be able to respond quickly and effectively such that the damage is minimal (Chiaia et al., 2019; Ribeiro and Gonçalves, 2019). Resilience may also be defined as the capability of any system to resist and/or adapt to a particular disaster event and recover its normal functioning or state of balance, which may set the initial baseline or a new situation (Kerner and Thomas, 2014; Ribeiro and Gonçalves, 2019). Resilience is now widely accepted as a strategy for ensuring sustainable development, and for reducing vulnerability (Song et al., 2019). Consequently, developing resilience has assumed central role in the process of flood risk assessment (Batica and Gourbesville, 2016).

Flood resilience is represented by three dimensions: physical, economic, and social among which the economic and social indicators seem to have a greater impact on the flood resilience assessment (Leandro et al., 2020; Liu et al., 2020). A resilience approach considers the entire possible spectrum of events – below and above the resistance threshold and up to and beyond the recovery threshold (de Bruijn et al., 2017). Hence, the measurement of resilience faces great challenges as it has to span disciplinary boundaries (Villamar et al., 2018).

While the measurement of urban disaster resilience has received much attention recently, so far there is no standard approach for determining flood resilience. This prohibits estimation of resilience, and in the absence of estimation of current resilience, it becomes difficult to find out what exactly can contribute to building resilience in communities and by how much. It is therefore necessary to conduct empirical studies on what constitutes disaster destruction and how to assess it (Moghadas et al., 2019), and to evolve standardized frameworks for assessment and estimation of Resilience. Moreover, measurement of disaster resilience can be used as a potential and essential basis for drafting future spatial and urban planning policies with regard to disaster diagnosis and minimization (Chan et al., 2014).

The literature reveals that there exist a number of multi-dimensional methodologies to quantitatively estimate flood resilience such as those suggested by Batica and Gourbesville (2016); Kotzee and Reyers (2016); Kusumastuti et al. (2014); Leandro et al. (2020); Lwin et al. (2020); Qasim et al. (2016) and Shirali et al. (2013). These studies propose dimensions of flood resilience in terms of social, demographic, economic, geographical and environmental factors.

"Resilience" may be defined in terms of the capacity to stand a flood disaster. In this sense the Resilience points to the capacity of infrastructure facilities or the capacity of population or the capacity of physical features of the region, etc to tolerate the floods. Any discussion on flood disaster management would be deemed incomplete without a critique on resilience. When considering resilience in flood risk management, two important issues when left unaddressed may potentially result in socio-spatial inequalities: i) differences in socio-spatial vulnerability and ii) a mismatch between responsibility and capacity (Forrest et al., 2020). In this context, White and O'Hare (2014), defend the intricacies within resilience as "to rebound" or "change". Similarly, according to Cerè et al. (2017), both quantitative and qualitative approaches of resilience from a built environment perspective should be considered. Likewise, discerning view of resilience is given by many other researchers (Disse et al., 2020; Forrest et al., 2019; Meerow et al., 2016).

From a developing country context, research on resilience assessment is still in its infancy. The same applies to India also, despite it receiving heavy rainfalls during monsoons. The limitations are often imposed by lack of data and due to the reliability concerns on the quality of data wherever made available. Not many studies have therefore focused on assessing flood resilience, as data is often lacking on various socio-economic parameters in most developing nations. Based on the Disaster Management Act (2005), in India the disaster resilience as well as disaster response measures are being emphasized. Both resilience and response are related- any change in resilience can lead to a change in response too, and vice versa. This study however, lays more emphasis on resilience.

The current study is an attempt to evolve a framework on estimation of flood related resilience in conformity with the Goal 11 of Sustainable Development Goals (UNDP, 2018). The work has been carried out in the developing country context where data limitations and financial constraints exist. The evolved framework utilizes minimal data parameters to evolve a Principal Component Analysis (PCA) based methodology for assessment of the flood resilience by developing Flood Resilience Index (FRI), and exemplifies the methodology for the case of 21 districts in the Narmada river basin of the State of Madhya Pradesh, India. This study uses a framework that deploys 16 indicators categorized under five attributes/factors/parameters of Resist, Absorb, Accommodate, Adapt and Recover (hence the proposed RAAAR Framework) using a PCA based analysis to determine the resilience to Floods in any region. The 5 parameters deployed in the proposed RAAAR framework are derived from an extensive study of literature. The United Nations Office for Disaster Risk Reduction, UNDRR, defines urban resilience as the ability of an urban system with socio-ecological and socio-technical constituents to be able to rapidly return to its normal functions in the face of a disaster event. Essentially, resilience includes the capability to rapidly adapt to change, and to transform systems that limit the current or future adaptive capacities (Meerow et al., 2016). Similarly, flood resilience is the capacity of actors at the local level to mitigate and prepare (pre-flood), to resist and respond (during the flood), before being able to recover from, adapt and transform after a flood event (post-flood) (Forrest et al., 2019). According to Korhonen and Snakin (2015) the continuous challenge in the system is its capacity to adapt to changing circumstances including environmental, economic and social issues. Likewise, Recovery in the context of resilience signifies restoration and improvement of infrastructure facilities, livelihoods, and living conditions in a disaster event (UNISDR, 2009). Yet another parameter of importance with respect to determination of Resilience refers to system Absorb storage-based storm water management methods that can effectively absorb climate change impacts specially the flooding (Alexander et al., 2019). Correspondingly, Doberstein et al. (2019) have used "protect/accommodate/retreat/avoid" or the "PARA" framework to categorize and examine flood disaster risk reduction approaches to build climate change resilience in communities across Canada. This study takes the approach to the next level by proposing a RAAAR based framework laid out and described in the following sections. This proposed framework has been exemplified using the case of Resilience in the Narmada River across the State of Madhya Pradesh in India.

2. Study area description

The River Narmada, considered one of the holiest rivers of India, is the largest west flowing river of India. The river arises near the Amarkantak range of mountains in the central Indian State of Madhya Pradesh. River Narmada ranks as the 5th largest river of India, and flows for a length of 1312 kms (Sardar Sarovar Nigam Limited, 2020), while crossing 3 Indian States of Madhya Pradesh, Maharashtra and Gujarat. The river finally drains into the Gulf of Cambay in the Arabian Sea. The total river basin area is 97,410 square kilometers, which includes 85,858 square kilometers area in the State of Madhya Pradesh (Sardar Sarovar Nigam Limited, 2020). The 21 districts of Madhya Pradesh which come under Narmada river basin are Alirajpur, Annupur, Balaghat, Barwani, Betul, Chhindwara, Dewas, Dhar, Dindori, Harda, Hoshangabad, Indore, Jabalpur, Katni, Khandwa, Khargone, Mandla, Narsimhapur, Raisen, Sehore and Seoni marked on the map of India, are as shown in Fig.1.

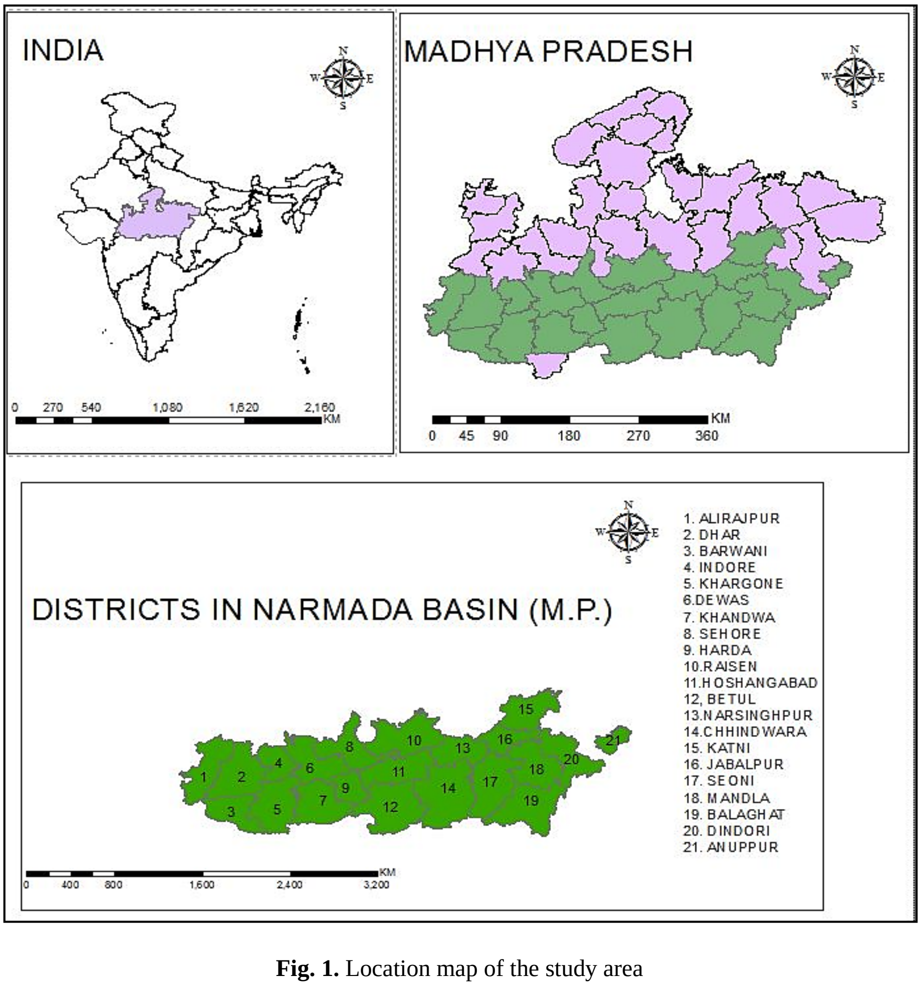

Fig. 1. Location map of the study area

The Narmada valley experiences extremes of hydro-meteorological and climatic conditions and hence supports diverse nature of vegetation due to its huge water resource potential with an annual flow of over 90% during the monsoon months (Kathal, 2018).The study region witnessed severe flooding events in the recent times, particularly in the year 2012, 2013, 2016 and 2019, although minor flooding events occur quite regularly. The districts therefore remain significantly susceptible to flood risks as has been reported in literature also (example, Kamat et al, 2007), and hence there exists an urgent need to develop a model that possibly can be up-scaled to cover entire river basin in order to alleviate the sufferings and agony of millions of people who live along its banks, not just because of it being a perennial water source, but also because the river Narmada is culturally regarded amongst the most sacred of the rivers in India.

3. Case study

3.1. The RAAAR Framework

For the development of the Flood Resilience Index (FRI), Principal component analysis (PCA) based method was employed. PCA, a statistical technique for reducing the dimensionality of such datasets, increases the interpretability of data with minimal information loss (Jolliffe and Cadima, 2016). PCA has the advantage that it yields Principal Components that are independent of one another, and have no correlation amongst them. It reduces over-fitting that may occur when there are too many variables in the dataset. PCA additionally has the advantage of providing higher visualization by reducing the data to low dimensions that human brain can understand and visualize, enabling us to comprehend which Principal Components result in high variances and greater impacts as compared to other Components.

The methodology was evolved based upon the development of FRI and the usage of various indicators in literature, specifically Cutter et al. (2008), Batica and Gourbesville (2016), Wang et al. (2019), Stigler et al. (2018), Rumbach (2014), FAO (2012), Kusumastuti et al. (2014) and Luh et al. (2017). The literature survey indicated that the indicators used by these studies fall into parameters that are designated as resist, absorb, accommodate, recover, and adapt. These parameters are frequently used by various researchers for the flood resilience assessments, in varying combinations of indicators.

Specifically, in the development of the RAAAR framework, the parameters resist, absorb, accommodate and recover were adopted from the UNISDR definition of resilience. Only “adapt” is adopted from the UNDRR definition, while ‘transform’ stands excluded. The reason for inclusion of ‘adapt’ lies in its wide usage in the literature as well as the fact that in the developing country context like that of India, the concept of flood resilience is often seen in terms of ‘adapt’ rather than ‘transform’ since people do not often have the capacity to pay for these ‘transform’ measures such as flood proof housing, activation of flood prevention insurance, etc., and therefore are unwilling to put their personal money for such use. The ‘adapt’ measures like literacy, drinking water source, households with vehicles and televisions form better measures in the developing country context. A further constraint to the usage of ‘transform’ lies in lack of data availability. In countries like India, data on ‘adapt’ is relatively easily available and conventionally collected in household surveys, while ‘transform’ parameters are rarely collected as flood proof housing and insurance are relatively newer concepts in traditional societies- implemented by a few who can afford such measures or who are updated enough about the newer policies and construction practices. For countries where mechanisms like flood proof housing and flood insurance exist, one may add ‘transform’ to the RAAAR framework for greater precision with regard to determination of Resilience. However, in the developing country context, the proposed RAAAR framework appears to adequately provide a measure of resilience.

The Model framework developed has been named RAAAR framework, the acronym for the 5 parameters of Resist, Absorb, Accommodate, Adapt and Recover. A total of 16 indicators were employed and PCA was applied to assess the Resilience for the case study presented as an application of the RAAAR framework. The methodology adopted for the case study is presented in Fig.2.

The 16 indicators comprising the 5 RAAAR parameters for the construction of Flood Resilience Index (FRI) for each of 21 districts covered the social, economic, demographic and environmental and infrastructure dimensions of the study area within the constraints of data availability. The equivalent weights/weighted values of floods resilience indicators were computed using the communalities obtained in the PCA analysis, and the ranking of resilience indicators were generated to construct the Flood Resilience Index (FRI). The FRI values thus obtained were subjected to the cluster analysis in SPSS which was used for spatial mapping of resilience in the study area.

3.2. Selection of indicators

The usefulness of quantitative indicators for reducing complexity, measuring progress, mapping, and setting priorities makes them an important tool for decision makers (Cutter et al., 2008). The choice and selection of indicators is vital and determines the accuracy of the assessment of resilience. After a careful study of literature cited in Section 1, relevance of indicators, and taking due cognizance of field data constraints, a total of 16 indicators were found appropriate and shortlisted as shown in Table 1.

Besides showing the selected indicators, Table 1 also exhibits their units, the source of data, literature source recommending the indicator, and the period for which the data was collected. These 16 indicators were broadly categorized amongst the 5 group Parameters of Resist, Absorb, Accommodate, Adapt and Recover, which are illustrated in Table 1. The indicators classification under each of the parameter was also based upon a careful review of literature as tabulated in Table 1.

The parameter "Resist" included the indicators which can withstand the action or effect of flood on community or households. For instance, districts with higher elevation can resist more to the floods than the districts with lower elevations that remain more vulnerable to flood risk. Similarly, households having *Pucca* houses ie., houses with wall and roof made of material mainly of bricks or concrete that are less vulnerable to disasters (Stigler et al., 2018). Also, for lower income groups the flood-resistant construction can significantly help to improve the quality standards of non-engineered buildings and hence considerable reduction in loss of human lives and properties during floods (ADPC, 2005). Likewise, the statutory notified towns that have local bodies like municipal corporations, municipalities, or municipal committees, etc (Census of India, 2011), have lower disaster risks due to provision of facilities such as primarily because of better buildings designed as per approved construction practices, designated parks and green spaces, and established communication networks (Rumbach, 2014). The indicators under the parameter of "Resist", thus intend to measure the resilience of community and the infrastructure facilities for floods belong to the physical and infrastructure category.

Similar justifications exist for choosing indicators across the other parameters. "Absorb" refers to the absorption of excess rainfall/runoff. It includes the numbers of households with open drainage available (the Indian cities often lack a separate storm water drainage network). Similarly, the land-use patterns such as forest and agricultural land absorbs flood water to certain extent (FAO, 2012; Jadidi et al., 2019), thereby constituting indicators for "Absorb".

"Accommodate" is related to resilience as greater the accommodation capacity of the area, greater would be the resilience. This attribute refers to the capacity of urban areas and citizens to cope up with, and even accommodate, flooding whilst minimizing the flood impacts (Forrest et al., 2020). Based on the indicators chosen by Kusumastuti et al. (2014), the indicators under the parameter of accommodate include houseless census, population density and district-wise household below poverty line. These indicators have negative functional relation based on the fact that, as the poverty, population density etc. increases, the accommodation capacity of area (district) decreases.

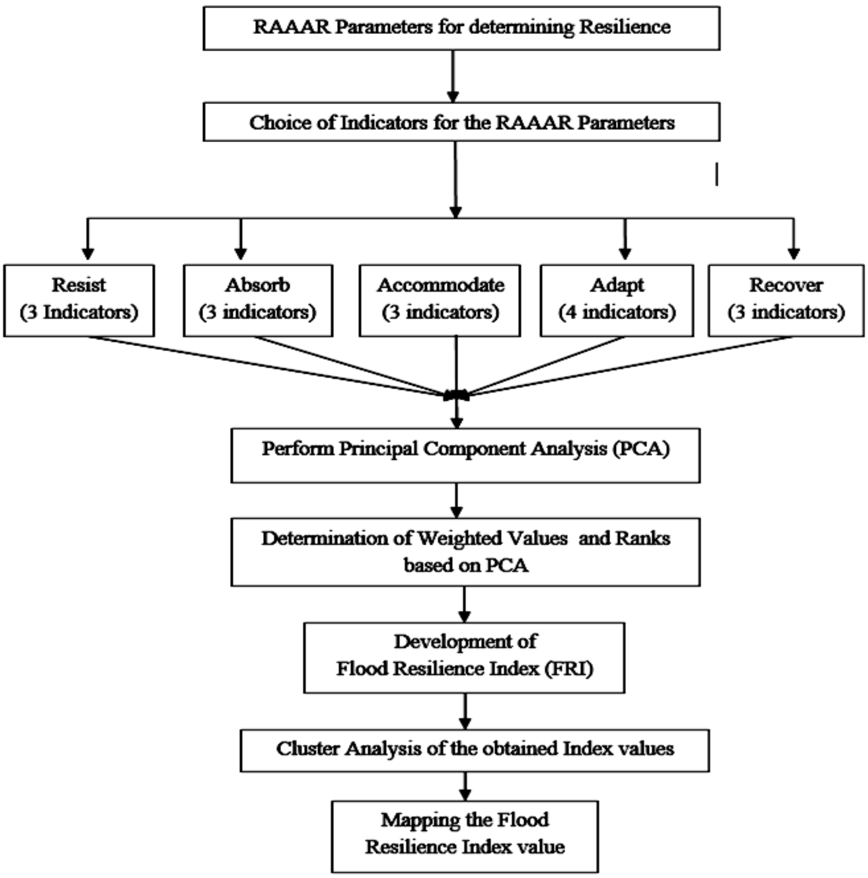

Fig. 2. The application of RAAAR based framework for assessment of Resilience

Table 1. Indicators for Flood resilience based on RAAAR parameters

Parameter		*Indicator*	*Unit/ Dimension*	*Data Source for the current study*	*Indicator employed by*
Resist	1	Average elevation of districts (AE)	Meter (Physical)	District portal of Madhya Pradesh (2019)	Wang et al. (2019)
	2	Household having Pucca House (PH)	Nos. (Infrastructure)	Census of India (2011)[1]	Stigler et al. (2018)
	3	District wise number of Statutory towns (ST)	Nos. (Socio-economic)	Census of India (2011)	Rumbach (2014)
Absorb	4	No. households having wastewater outlet connected to open drainage (OD)	% (Infrastructure)	Census of India (2011)	FAO (2012)
	5	District wise Cultivated area (Gross Cropped Area) (GCA)	100000 Hectare (Physical)	State Agricultural Plan (2017)	FAO (2012)
	6	Forest area as percentage of total geographical area of district (FA)	% (Physical)	Forest survey of India (2017)	FAO (2012)
Accommodate	7	District wise Population Density (PD)	Persons / km^2	Census of India (2011)	Kusumastuti et al. (2014)
	8	Households below poverty line (BPL)	% (Socio-economic)	Census of India (2011)	Kusumastuti et al. (2014)
	9	Houseless Census (HC)	% (Socio-economic)	Census of India (2011)	Kusumastuti et al. (2014)
Adapt	10	Literacy Rate (LR)	% (Socio-economic)	Census of India (2011)	Kusumastuti et al. (2014)
	11	Households by main source drinking water (hand pump + tubewell) (HDW)	% (Infrastructure)	Census of India (2011)	Luh et al. (2017)
	12	Households with scooters/ motorcycle/moped (HSM)	% (Socio-economic)	Census of India (2011)	Batica and Gourbesville (2016)
	13	Households having televisions (HT)	% (Socio-economic)	Census of India (2011)	Batica and Gourbesville (2016)
Recover	14	District wise schools as emergency Shelters (SES)	Nos. (Infrastructure)	Relief and Revenue Dept (M.P.) (2019)	Cutter et al. (2008)
	15	District wise numbers of Health Centres (HCC)	Nos. (Infrastructure)	Relief and Revenue Dept (M.P.) (2019)	Cutter et al. (2008)
	16	District wise numbers of Panchayat Ghar (PG)	Nos. (infrastructure)	Revenue Dept (M.P.) (2013)	Kusumastuti et al. (2014)

[1] The Census of India was last conducted in the year 2011. This is an exercise that is conducted every 10 years by the government of India, and the next Census is likely in the year 2021

The "Adapt' refers to the adaptive part of the resilience, and is a process involving social learning with a measureable outcome (Cutter, 2016). However, the ability to learn and the capacity to adapt are crucial to cope with gradual, but uncertain changes (de Bruijn et al., 2017). In this paper, televisions have been used as a proxy for means of raising the social awareness about the disasters (the government programmed often focus on such issues, as has been the case during lockdowns in recent Covid related pandemic) and as a communication medium to warn the community of any impending disaster warning. Similarly, the households with motor-bikes are more likely to have better connectivity with the community, and are proportionately more likely to be better informed than those who stand isolated. Also, the vehicles increase their chances to move out faster and decisively during the times of a disaster related emergency. Further, WHO (2009) emphasizes that resilience needs to be integrated into drinking-water and sanitation management to cope up with any disaster event. Thus, in the parameter of "Adapt" are included the literacy rate, households with access to television, motor cycle and drinking water amenities.

Since, the resilience is not just the ability of a system to resist and/or adapt to a particular disturbance, but also its capacity to recover its normal functioning or state of balance, there needs to be the parameter of "Recover" with its indicators demonstrating the ability to handle or undertake recovery to bring back the community to a better and safer level than the pre-disaster stage (SDMP, 2012). In this study, "recover" as a parameter reflects and includes the disaster 'response' also. Recovery and response are dependent on basic infrastructure such as the roads, water services, telecommunication, power etc play a critical role in disaster response and recovery. These may even be included as indicators to assess resilience. However, in the Indian context, and specifically for the study area chosen, these were not relevant for making comparisons of resilience as the government claims indicate that electricity has a reach of 100% households, a mobile connection is available in most households, water connections exist in most legal houses (slum areas often are illegal occupations), and roads have reached almost every village under the PMGSY scheme of the Government. These were therefore not appropriate for making comparison of resilience, though these infrastructure facilities play a critical role in 'response'. For comparison, the indicator choices need to be seen under specific socio-economic-cultural context, further subject to the data availability.

The indicators that have been employed in 'recover' in this study include the Schools, Health Centers, and Panchayat Ghars (building housing the

Village Council), all of which contribute to response too. According to DDMP (2012), Panchayat Ghars, Health centers, and School buildings serve as emergency shelters during disasters. As they are also equipped with basic medical facilities, these can even act as first aid centers during any flooding event. Hence, districts with higher number of emergency shelters as Schools, Panchayat Ghars, and Health centers would be expected to be more resilient. Their use has been witnessed in recent times too when these have been used as isolation centers to accommodate suspected covid patients.

3.3. Flood Resilience Index Calculations

The data of 21 districts collected from sources listed in Table 1, was tabulated (columns representing indicators and the rows representing districts), and analyzed. The data thus collected was in different units depending upon the indicator employed, and hence the Max–Min normalization was utilized for fixing a particular range for the data as endorsed by Anbarasan et al. (2020). The Eqs. (1-2) were used for data normalization, such that the normalized values ranged from 0 to 1.

For indicators having positive (increase in resilience) functional relationship.

$$NV = \frac{[I - Minimum(I)]}{[Maximum(I) - Minimum(I)]} \quad (1)$$

For indicator having negative (decrease in resilience) functional relationship.

$$NV = \frac{[Maximum(I) - I]}{[Maximum(I) - Minimum(I)]} \quad (2)$$

where, *NV* is the Normalized Value and *I* is the Indicator.

The SPSS - Statistical Package for Social Sciences, version 22, was subsequently applied to compute Principal Component Analysis for the normalized values of the indicators. The communalities extracted from the Principal Component Analysis were used to determine the equivalent weight of every district against each indicator. The value of communalities was observed to be greater than 0.5, implying better measurement of factors. Similarly, components with Eigen values more than 1 were only extracted. Weighted value $\bar{X}$, for each district, was calculated using Eq. (3).

$$\overline{X} = \sum_{n=1}^{m} W_n NV_i \text{ st } 0 < W < 1 \quad (3)$$

where, 1, ..., *m* are the number of indicators (in the present case-study, m=16); 1,...,*i* are the number of districts; *NV* is the normalized value of the indicator; and W_n are the weights or the extracted communalities from PCA.

The weighted value of each district was obtained using Eq. (3). After this, the districts were prioritized based on Ranks and weighted values. Finally, the cluster analysis was performed on the weighted values of each district and the districts categorized in 3 distinct categories labeled Low, Medium and High Resilience for the purpose of spatial mapping. The resilience values were compared relative to each other and categorized using K-means cluster analysis that aims to group n observations into k clusters such that each observation belongs to a cluster with the nearest mean cluster centroid value. The analysis minimizes the within-cluster variances to yield distinct categories.

4. Results and discussion

Table 1 was prepared for each district for its specific data-set spread over 16 indicators, and normalization process was carried out as per the Eqs. (1-2). The sums of normalized values for each indicator for the RAAAR Parameters in each of the 21 districts are represented in Fig. 3.

Fig. 3 illustrating the spider web diagram of the scores of RAAAR parameters is a useful description as from this composite diagram it is possible to find not only the relative lag for each district as compared to other districts, but also to pinpoint where be exactly the district and other authorities need to focus most amongst the 5 RAAAR parameters of Resilience. For instance, in terms of the Resist parameter, both Indore and Chhindwara districts have very high scores, while Alirajpur and Harda have the least scores, which can be primarily be attributed to the presence/absence of infrastructure based upon the chosen indicators of Pucca houses. It is also observed that districts with higher elevations such as Chhindwara and Betul have higher resilience scores, thereby signifying the importance of elevation with respect to flood resilience. Thus, the policy-makers need to focus on developing greater degree of pucca houses in the least performing districts for ensuring better resistance. Policy-makers may also focus on policies that encourage settlements on higher elevations by tweaking with the municipal and property taxes favorably in areas with higher elevations. Similarly, with regard to the parameter of Absorb, Khargone (West Nimar), Sehore and Chhindwara districts have highest scores as these are the districts which have above average land area under cultivation and forest, while the districts of Alirajpur and Annupur being remote and significantly less developed districts lack the agricultural and forest area, providing valuable tips to the policy-makers and district administrators to adopt appropriate policies for better resilience in terms of Absorb parameter.

Under the “Adpat” parameter districts that appeared to possess higher adaptive measures seemed to have having higher literacy rates. Thus social changes such as the literacy levels seems to bring about greater resilience, and bigger districts like Indore and Jabalpur where better educational opportunities exist therefore fared better with regard to 'adapt'. The governments need to focus upon driving the literacy upwards for strengthening resilience particularly in districts like Alirajpur, Barwani and Dindori that currently have lower literacy levels. The provisioning of government infrastructure facilities also plays an important role. Districts like Dhar and Chhindwara which have highest number of Panchayat Ghars and primary schools stand to gain in terms of the Recover parameter. The least provisioned districts of Dindori, Annupur and Alirajpur lack such infrastructure facilities that may cater to serve as emergency health centers at the time of flood events. Thus, the government needs to ensure that equity prevails in making infrastructure provisions amongst the districts. It would be relevant to point out here that the planners and policy-makers are not always the ones who dictate policies of provisioning in developing countries like India. It is often the stronger political backing that decides the provisioning as has been the case of Chhindwara in the present study. Thus, provisioning policy needs a relook, and an independent authority or a Regulator should have the ultimate say in deciding infrastructure provisioning in a fairer and equitable manner.

These insights at district level are needed for formulating micro-level policies. However, a broad framework would also need to rate and estimate the overall resilience in terms of an index. The FRI or the Flood Resilience Index was measured by employing PCA on a set of 16 indicators defined in Table 1. The PCA analysis led to extraction of 4 principal components, explaining 85.10% of cumulative variance of the variables.

The extracted communalities are illustrated as weights in Table 2, and these were then multiplied to the normalized values of the indicators to get the weighted values for each indicator of the districts. Summation of these equivalent weights or weighted values for a particular district gave the resilience index for that particular district.

In the PCA analysis, the Scree plot representing Eigen values on Y-axis and components on the X-axis, obtained from the PCA helps in visualizing the dimensionality of data. In the current case, the Scree plot, as shown in Fig. 4, indicates the 4 principal components represent most of the information of data.

Table 3 explains the total variance of each component based on the extraction sums of squared loadings, as obtained from the PCA analysis. The sum of squared loadings section of table explains nearly 85% of the variability in the original 16 variables, so the complexity of the data set is reduced by loss of barely 15% information. The rotation section leads to the generalization of cumulative percentage of variation which is spread evenly over the components.

The value of resilience index of each district was then prioritized based on the rank, such that the highest rank (rank 1) indicated the highest index value and the lowest rank (rank 21) indicated the lowest index value. For instance, the district Chhindwara secured rank 1 and obtained the highest resilience index value of 0.642, while Alirajpur district got the rank 21 and obtained lowest resilience index value of 0.287, indicating large relative scope for relative improvement of resilience.

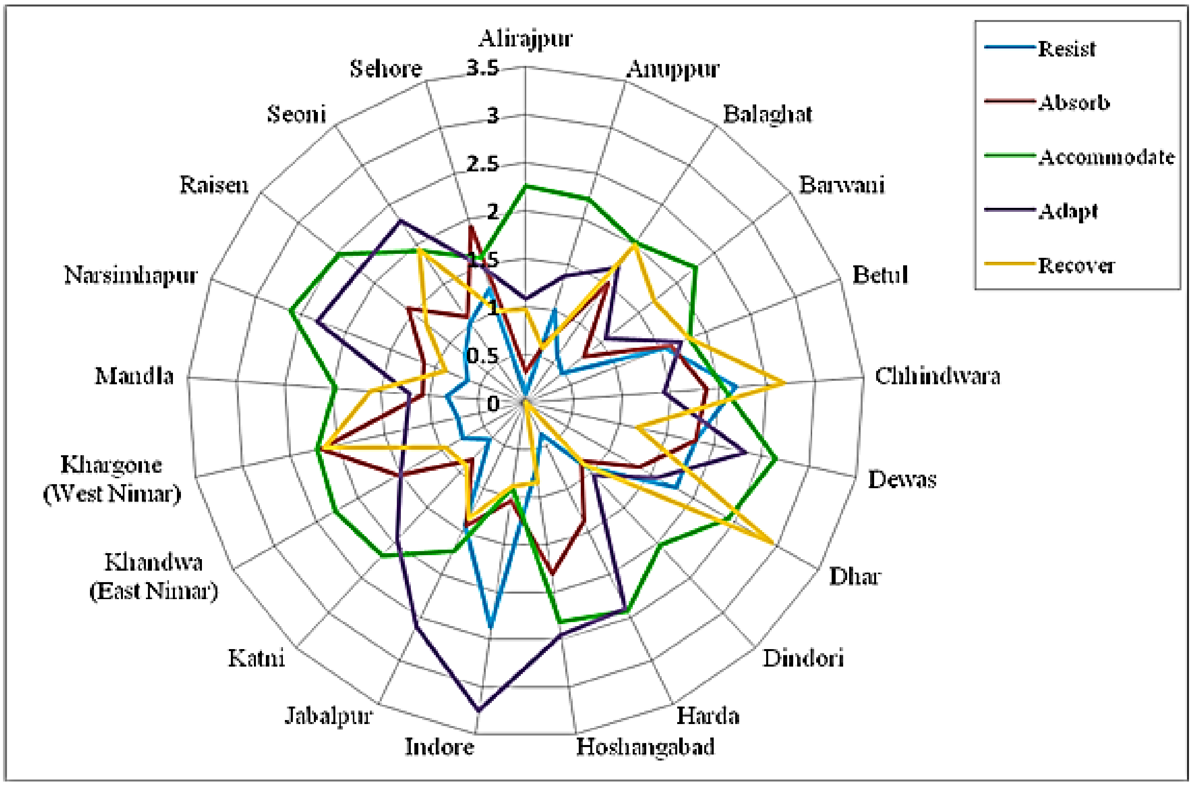

Fig. 3. Spider Web Diagram representing the scores of RAAAR parameters as sum of normalized indicator values for 21 districts

Table 2. Communalities for resilience data analysis

Indicator	*Initial*	*Extraction*
AE	1	0.542
PH	1	0.957
ST	1	0.869
OD	1	0.729
GCA	1	0.856
FA	1	0.861
PD	1	0.922
BPL	1	0.874
HC	1	0.941
LR	1	0.872
HDW	1	0.538
HSM	1	0.948
HT	1	0.978
SES	1	0.927
HCC	1	0.932
PG	1	0.871

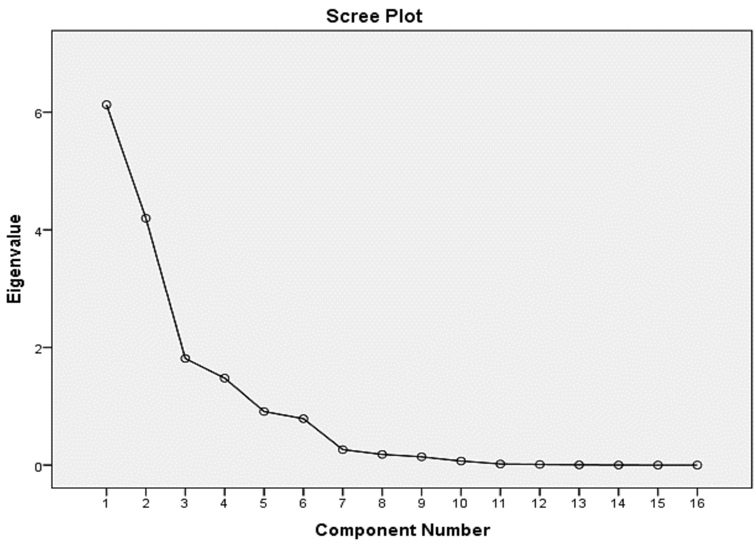

Fig. 4. Scree plot from PCA

Table 3. Total variance explained by PCA

Component		*Initial Eigen values*			*Extraction Sums of Squared Loadings*			*Rotation Sums of Squared Loadings*		
		Total	*% of Variance*	*Cumulative %*	*Total*	*% of Variance*	*Cumulative %*	*Total*	*% of Variance*	*Cumulative %*
AE	1	6.128	38.300	38.300	6.128	38.300	38.300	5.411	33.821	33.821
PH	2	4.196	26.226	64.527	4.196	26.226	64.527	4.152	25.949	59.770
ST	3	1.813	11.330	75.856	1.813	11.330	75.856	2.298	14.362	74.132
OD	4	1.479	9.244	85.101	1.479	9.244	85.101	1.755	10.969	85.101
GCA	5	.910	5.690	90.790	-	-	-	-	-	-
FA	6	.788	4.928	95.718	-	-	-	-	-	-
PD	7	.262	1.636	97.354	-	-	-	-	-	-
BPL	8	.181	1.129	98.484	-	-	-	-	-	-
HC	9	.139	.872	99.355	-	-	-	-	-	-
LR	10	.068	.428	99.783	-	-	-	-	-	-
HDW	11	.019	.117	99.900	-	-	-	-	-	-
HSM	12	.010	.065	99.964	-	-	-	-	-	-
HT	13	.004	.027	99.991	-	-	-	-	-	-
SES	14	.001	.007	99.999	-	-	-	-	-	-
HCC	15	.000	.001	100.000	-	-	-	-	-	-
PG	16	0.000	0.000	100.000	-	-	-	-	-	-

The results from the K-means cluster analysis, which is a method of vector quantization, are shown in Table 4 and 5, and these results depict that the districts can be divided in 3 categories. Districts with least weighted values as obtained for Cluster 1 were marked with Low Resilience, while districts clubbed in Cluster 2 having highest weighted values were marked under High Resilience category. The remaining districts under Cluster 2 and possessing intermediate equivalent weight/weighted value fell into the Medium Resilience category. These categories can subsequently be labeled on a Map representing various districts to indicate the spatial variation of resilience categories as illustrated in Fig. 5.

Table 4. Number of cases in each cluster

Cluster	***Number of cases***
1	7.000
2	3.000
3	11.000
Valid	21.000
Missing	0.000

Table 5. Final cluster centers

Cluster	1	2	3
Weighted value	0.37	0.63	0.50

On the basis of Fig. 5, micro-level studies may further need to be conducted to draw appropriate policy measures in order to improve resilience, particularly for the Low Resilience cluster comprising the districts of Mandla, Harda, Barwani, Katni, Anuppur, Dindori and Alirajpur that have secured lowest ranks with least index values. Micro-level studies look for pockets of best or worst resilience existing within a district that as a whole may be demonstrating average resilience. Policy makers need to be aware of such anomalies for drawing appropriate policy measures.

It is interesting to note that in Fig. 4 the districts on the border areas ie, both the eastern and western ends of the State of Madhya Pradesh seem to be least resilient as compared to the ones in center. While it is a fact that the districts at the east and west end are under-developed as compared to rest of the districts in the study area, it is also possible that geography of any State or a country plays an important role in building the resilience of communities to face disaster events. Though this hypothesis would need confirmation from larger number of studies, it appears a reasonable conjecture when one considers that the mainland ie, the central part of any State is almost without exception more well-developed in terms of provisioning of infrastructure facilities, has better connectivity and communication primarily because of geographic advantage of being in the center, and is usual focus of the newspapers and social media as well.

Table 6 exhibits the FRI values which are the weighted values for districts in the study area. The district of Chhindwara emerged as the most flood resilient district with comparatively higher scores to resist and ability to recover from the flood events. These better performing districts may act as benchmarks and their models and policies may be followed as best practices to be replicate in less resilient districts.

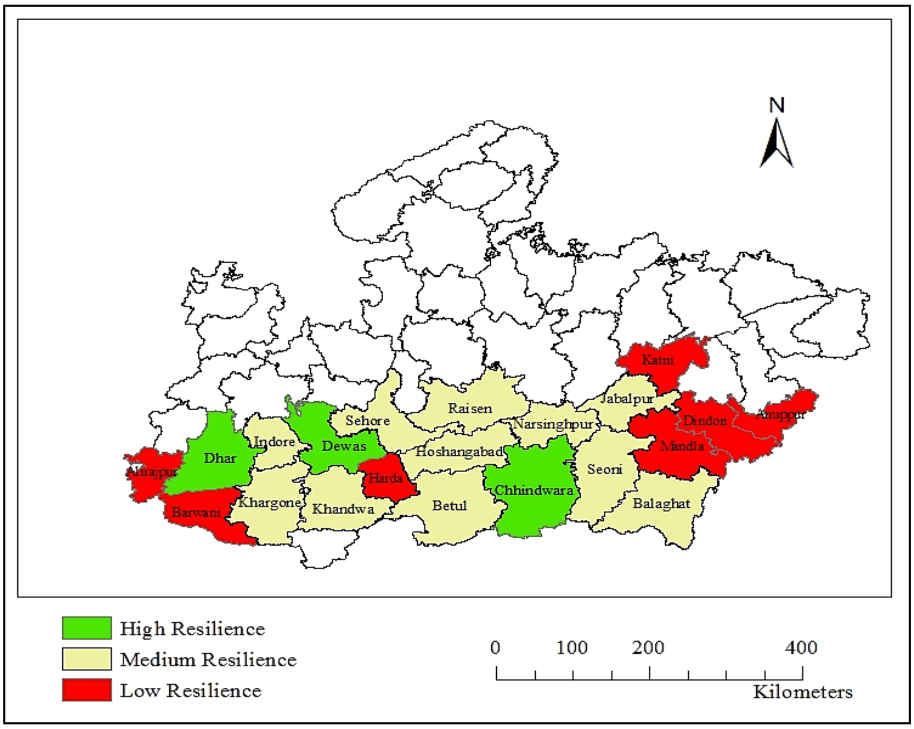

Fig. 5. Spatial variation of Resilience

Table 6. District-wise FRI values

Districts	*FRI value*
Alirajpur	0.287
Anuppur	0.365
Balaghat	0.495
Barwani	0.402
Betul	0.526
Chhindwara	0.642
Dewas	0.602
Dhar	0.631
Dindori	0.345
Harda	0.408
Hoshangabad	0.514
Indore	0.532
Jabalpur	0.537
Katni	0.395
Khandwa (East Nimar)	0.442
Khargone (West Nimar)	0.551
Mandla	0.418
Narsimhapur	0.465
Raisen	0.525
Seoni	0.508
Sehore	0.441

The outcomes of the study are in line with the Sustainable Development Goals (SDGs), which talks about making human settlements inclusive, safe, resilient and sustainable (UNDP, 2018). More specifically, the results are linked to the targets 11.5 and 11.b, of the SDG Goal 11. These targets aim for significant reduction in the number of deaths due to disasters through increased resource efficiencies, mitigation and adaptation, and resilience to disasters despite a trend of increasing urbanization, growth in numbers of cities, and growth of human settlements. Increased disaster resilience comprises a primary step in the international efforts to bring about a sustainable world around us.

5. Conclusions

Resilience to flood risks corresponds to the capability of both the governments and the communities to be able to stand up to the menace of floods in a world that is likely to see such disasters at an ever-increasing pace due to the onslaught of global warming and associated climate change. Moreover, there is growing reorganization in disaster science about developing frameworks that lead to strengthening of resilience, as highlighted by Sendai Framework for DRR 2015–2030 and by researchers such as Mohanty et al. (2019). Since these disasters are likely going to increase over time, making the system resilient and resistant should indeed be the top priority of all stakeholders - the governments, communities, disaster management authorities, planners, policy-makers and district administrators, non-governmental organizations etc.

This paper proposes a RAAAR Framework based on 5 parameters of Resist, Absorb, Accommodate, Adapt and Recover to define resilience and assess its quantum. The paper exemplifies the proposed framework using 16 indicators using data on floods in River Narmada flowing across 21 Districts of the Indian Central State of Madhya Pradesh. The proposed framework may be replicated and upscaled for any other vulnerable area for the sake of testing and refining the assessment of Resilience. Up-scaling is possible through inclusion of more indicators, or a different set of indicators under the 5 parameters, as may be relevant to the specific case. Similar frameworks can also be potentially replicated and developed further to assess the resilience or vulnerability for other hazards, not related to floods.

The proposed framework would be of use to various stakeholders involved in the in the management of floods, but would be of utmost use for the respective disaster management and local administrative authorities to identify and determine the resilience along the river basins, and to adopt policy-measures that over time reinforce resilience to bring about a vastly improve flood management regime. This paper identifies 16 such indicators, though the numbers of indicators might vary from one instance to another depending upon local socio-economic, infrastructure, and flood conditions, and the data availability for the proposed set of indicators. The latter is often a constraint in the developing country context, but transparent availability of quality data is essential and vital to bring about any significant improvement in the ability to face floods while minimizing its damage.

It would also be relevant to point out that the proposed RAAAR framework would be pertinent from the viewpoint of flood management principles and policies expounded in National Disaster Action/Management Plans envisaged across most countries (example, the National Disaster Management Plan (NDMP, 2016) enumerated by the Government of India) in consistency with the approach and priority of understanding disaster risk under the Sendai Framework for Disaster Risk Reduction 2015-2030 (UNDRR, 2019). At the micro-level, studies such as the present one can help to make it easier for the “District Authorities” such as the District Disaster Management Authority constituted under sub-section (1) of section 25 of The Disaster Management Act (2005) emitted by India’s Government, to identify various crucial and significant aspects of flood resilience in order to strengthen decision and policy making.

A highly flood resilient society can only be achieved when both the government and stakeholders demonstrate response to the floods events by appropriately introducing various socio-economic interventions that bring about greater scores in terms of the RAAAR parameters. This then sets the agenda to prioritize these 5 parameters based on a defined set of indicators that represent these 5 RAAAR parameters. While communities may be free to choose their own sets of indicators depending on local conditions and data availability, the policy-makers and planners have their agenda cut and well-defined ie, to make interventions that enhance the scores for each of the indictor that they choose to fit in the RAAAR framework.

The analysis carried out under the RAAAR framework can reveal not just the relative resilience rankings, but can also help the authorities to find out what is going wrong in terms of individual indicators, so that corrective measures can be adopted to increase resilience. However, the evolved framework assesses relative resilience performances within a chosen sample of districts revealing the best and the worst performances amongst only the selected number of districts. The sample bests may not necessarily be indicative of the best practices in absolute terms. Therefore, while interpreting the results for any case study, the policymakers and practitioners need to be cautious about the fact that their interpretations are limited by the sample, and even the districts with a higher resilience scores may still have plenty of scope for improvement of reliance. Micro-studies at the district levels may also be further required to take care of variation in resilience performances within the district, particularly where the districts are large-sized or have distinct variations in social-economic levels.

The present study highlights the necessity of rigorous and in-depth study of resilience performances that may aid the planners, policy makers and disaster managers who, based on the analysis, can devise appropriate incentive measures as well as channelize the government focus to improve overall resilience performances in any basin.

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