

Advancing sustainable development goals: embedding resilience assessment

Zahra Assarkhaniki · Soheil Sabri · Abbas Rajabifard1 · Masoud Kahalimoghadam

<https://doi.org/10.1007/s11625-023-01372-7>

Supplementary Material

Appendix 1. The BRF indicators to measure resilience. Highlighted rows show the resilience variables that SDGs does not have any available indicators to measure them. The proposed indicators (that can be added from the BRF to the SDGs) along with the relevant target/goals have been defined in the table (source: adopted from [1]).

Dimension	Subdomain	variable	Indicators	Potential Goal/Target	Impact	Indicators from Resilience Literature
Social	Education and Knowledge (E&K)	Education level & quality (E&K.1)	Ratio of the % population with college education to the % population with less than high school education		+	[2],[3],[4],[5],[6],[7],[8],[9],[10],[11]
			% Population finished secondary level		+	[12],[13],[14],[15],[16],[5],[7],[17],[18]
			% Population finished tertiary education		+	[12]
			% Population who are illiterate		-	[19],[17],[20],[18]
			Pupil-to-teacher ratio at public schools		-	[21]
			School dropout rate of children		-	[20]
			Average years of education attainment of population 15 years and up		+	[22]
			Adult education and training program per 1,000 persons		+	[7],[11]
		Traditional knowledge (E&K.3)	No. of people 50 +years old and indigenous per capita	T 8.9, T 12.b	+	[13]
			No. of people with 30 +years residence per capita	T 8.9, T 12.b	+	[13]
		Public expenditure on education (E&K.2)	Per capita expenditure on education		+	[23],[19],[24]
Population and Demographics (P&D)	Population and Demographics (P&D)	Population structure (P&D.4)	% Population that is of working age (15-59)	G 1	+	[2],[3],[25],[4],[26],[27],[16],[22],[7],[8],[17],[9],[11],[14],[11]
			Ratio of men to women	G 1	+	[4],[27],[11],[14],[6],[18]
			% Population of elders (above 65)	G 1	-	[26],[6],[28],[29],[21],[15],[20],[18]
			% Children in population	G 1	-	[28],[29],[21]
			Total no. of population	G 1	-	[19]
		Population change (P&D.3)	Annual population change	G 11	-	[12],[25]
			Population change over the last five years	G 11	-	[11]
			Population growth rate	G 11	-	[30],[20]
		Household features (P&D.2)	% Households that are not single parents	G 1	+	[25],[29],[22],[11],[18]
			Average number of people per household	G 1	-	[29],[21]
			Household density	G 1	-	[30],[20]
		Urbanisation and density (P&D.5)	% Population living in urban areas	G 11	+	[19],[31],[7],[11],[14]
			People per sq. km of land area	G 11	-	[28],[10],[11],[32],[14],[15]
			% of rural population	G 11	-	[20]

Dimension	Subdomain	variable	Indicators	Potential Goal/Target	Impact	Indicators from Resilience Literature
		Workforce (P&D.6)	% Labor force employed		+	[19],[14],[11],[15],[30]
		Equality (P&D.1)	Female workforce participation		+	[29],[11]
			Gender Index		-	[25],[11]
			% Population whose income is below minimum wage		-	[22],[10],[11],[21],[20]
			Absolute difference between male and female median income		-	[11],[21]
			Ratio of nonminority population to minority population		+	[11]
	Health (H)	Health status (H.3)	% Population without sensory, physical, or mental disability		+	[2],[3],[25],[4],[21],[16],[6],[7],[8],[17],[9],[29],[26],[11],[29],[15],[18]
			All-cause mortality per 100k population		-	[21]
			3-year total low birthweight babies per 10,000 individuals		-	[29],[29]
			Average life expectancy		+	[21],[31]
		Health services (H.2)	% coverage among 1 –year olds		+	[23]
			Distance to nearest health facility (e.g., health post, hospital, clinic)		-	[28],[32],[20]
			%% Population with health insurance		+	[2],[3],[6],[8],[17],[9]
			% of uninsured adults		-	[21]
			Psychosocial support facilities per 10,000 persons		+	[2],[21]
			Child/elderly care program per 10,000 persons		+	[7],[11]
			Physicians/ nurses/ midwives per 10,000 persons		+	[23],[2],[3],[25],[21],[5],[7],[29],[29],[20]
			Hospital beds per 1,000 people		+	[23],[19],[21],[27],[14]
		Expenditure on health (H.1)	Per capita expenditure on health/security		+	[23],[19],[24]
		Sanitation (H.4)	% of population with access improved sanitation facilities		+	[23]
			Distance to nearest sanitation		-	[28],[32]
		Social welfare capacity (H.5)	Number of social welfare home beds per 10,000 persons (including homeless shelters and nursing homes)	T 1.5, T 1.3	+	[14]
	Community Strength (CS)	Land (CS.2)	% area of urban green space		+	[19],[28]
			Per capita expenditure on urban green space		+	[24]
			% of land area set aside in protected area status		+	[13],[32]
			Area of public open space		+	[10],[32]
			Distance to open space		-	[10]
			The ratio of the sidewalk length over total area		+	[10]
		Social engagement (CS.5)	% Population involved in red cross volunteering activities		+	[12],[2],[26],[8]
			Budget of volunteer organisations		+	[18]
			No. of registered volunteer/ volunteer organisations		+	[18]

Dimension	Subdomain	variable	Indicators	Potential Goal/Target	Impact	Indicators from Resilience Literature
			% Voting age population participating in presidential election		+	[13],[10],[2],[3],[25],[16],[29],[22],[11],[29],[22]
			Less than 3 parties are involved in the decision-making process		+	[11]
			*Park/Sports facilities/Cinemas persons/ Museums/libraries/zoos/ botanical gardens/ youth centres/clubs/child care centre per 1,000 persons		+	[32],[25],[7],[4],[22]
			Ratio of entertainment and recreation land uses/ Areas of public open spaces		+	[6],[10],[32]
			Persons affiliated with a religious organization per 10,000 persons		+	[2],[3],[21],[7],[8],[9],[10],[5],[4],[11],[12]
			Places of worship per 1,000 persons		+	[25]
			No. of religious organisations		+	[5],[6]
			% of population that is not minority		+	[7]
			No. of registered non-profit organizations		+	[5]
		Communication (CS.1)	% Population with access to phone		+	[12],[2],[4],[6],[7],[8],[9]
			% Population with access to internet/TV/radio		+	[12],[25],[21],[33],[7]
		Mobility (CS.3)	% Population proficient English speakers		+	[2],[3],[7],[8],[9],[11]
			% Households with at least one vehicle		+	[2],[3],[25],[4],[21],[16],[22],[7],[8],[9],[10],[22],[11]
			% who walk or cycle to work		+	[21]
			Mode Diversity (fixed-wing air, road, boat, ATV/trail)		+	[13]
			Regulation of transportation options		+	[13]
			Roads network density		+	[19],[28],[16]
			No. of traffic accidents		-	[19]
			Distance to nearest transport network		-	[28]
			Walkways length per total street length		+	[32]
		Place attachment (CS.4)	*% Population born in country of current residence		+	[28],[10],[11],[4],[29],[22],[15],[12]
			% Population who migrated to country within previous five/ten years		-	[2],[16],[7],[11],[22],
			Net in and out migration		-	[3],[25],[26],[8],[9]
	Social Protection (SP)	Expenditure (SP.3)	Public spending on social assistance as % of GDP		+	[23]
		Organisation (SP.5)	Civic organizations per 10,000 persons		+	[2],[3],[4],[16],[8],[9],[10],[5]
			No. of social advocacy organizations per 10,000 population		+	[7],[8],[9],[10],[21]
		Community disaster preparedness (SP.1)	Red cross training workshop participants per 10,000 persons		+	[2],[11]
			No. of courses in disaster risk reduction as part of the educational curriculum per schools and colleges		+	[11]
			No. of education programs on DRR and disaster preparedness per each local community by local government per year		+	[11]

Dimension	Subdomain	variable	Indicators	Potential Goal/Target	Impact	Indicators from Resilience Literature
Economic		Innovation (SP.4)	Percent population employed in creative class occupations (ex. architects, engineers, and scientific researchers)		+	[3],[25],[34],[7],[8],[9],[11]
			Research & development firms per 1,000 persons		+	[25],[7]
			Business and professional organisations per 1,000 persons		+	[7]
		Cultural heritage (SP.2)	National Historic Registry sites area per population		+	[11]
	Economic Capacity (EC)	Household economy (EC.2)	Median household income		+	[11],[15],[30]
			% Owner-occupied housing units		+	[11]
		Food capacity (EC.1)	Households saving value in bank		+	[15]
			Food security rate		+	[2],[32]
			Area of commercial establishment per 10,000 persons		+	[11]
	Household Capacity (HC)	Household assets (HC.1)	% Owner-occupied housing units		+	[2],[3],[4],[29],[16],[6],[7],[8],[17],[9]
			% Households with at least one vehicle		+	[2],[3],[29]
			% Households with telephone service available		+	[2],[3],[16]
			Households saving value in bank		+	[10],[19],[34],[31]
	Employment (E)	Workforce (E.2)	% Labor force employed		+	[12],[2],[25],[4],[11],[10],[26],[28],[29],[21],[16],[6],[22],[7],[8],[17],[9]
			% Employees not in farming, fishing, forestry, extractive industry, or tourism		+	[2],[3],[25],[4],[11],[10],[34],[6],[7],[8],[9],[29]
			% Labor force employed by federal government		+	[2]
			No. physicians/ nurses/ midwives per 10,000 persons		+	[8],[9]
		Equality (E.1)	% female labor force participation		+	[3],[25],[4],[16],[7],[9]
	Income (I)	Income features (I.2)	Average annual income per capita		+	[12],[10],[19],[29],[5],[6]
			Median household income		+	[29],[21],[5],[6],[7]
			Minimum wage rate per day		+	[22]
			% Population with multiple source of income		+	[17]
			Disposable income per capita		+	[19],[31]
			Income tax per capita		+	[19],[24]
		Equality (I.1)	% Population living below poverty		-	[29],[6],[17],[35]
			Gini coefficient		-	[26]
	Business Activity (BA)	Business features (BA.1)	Ratio income of top quintile to lowest quintile		-	[36]
			Ratio of large to small businesses		+	[2],[3],[11],[6],[7],[8],[9]
			Large retail stores per 10,000 persons		+	[2],[25],[4],[11],[21],[7]
			No. of business per capita		+	[24]
			No. of grocery stores per 100 square miles		+	[21]
			No. of banks per 1,000 persons		+	[25],[21]

Dimension	Subdomain	variable	Indicators	Potential Goal/Target	Impact	Indicators from Resilience Literature
		Commercial activities (BA.2)	No. of enterprises per 1,000 persons		+	[25],[11],[7]
			Area of commercial establishment per 10,000 persons	G 8	+	[4]
			Density of commercial infrastructure in each district	G 8	-	[4],[28],[7]
			Research & development firms per 1,000 persons	G 8	+	[11]
			% Commercial establishments outside of high hazard zones	G 8	+	[7]
		Income and expenditure (BA.4)	Total financial revenue from business		+	[19],[24],[34],[7],[11]
			Ratio of public finance income and expenditure (%)		+	[34]
			Total amount (\$) of imported and exported goods		+	[19],[34]
			% GDP from primary industry (farming, fishing, etc.)		-	[14]
			Amount of tax collected per capita		+	[18]
			Net per capita spending for mitigation projects		+	[18]
		Economy diversity (BA.3)	TRESS index	G 8	-	[16]
	Cost and Revenue of Development (C&R)	Land (C&R.2)	Ratio of business (CBD centers) within build-up area	G 8	+	[27]
			Price of land (RMB) per square meter	G 11	-	[28]
		Urbanisation and density (C&R.4)	% Population living in urban areas	G 11	+	[27]
			Cost of road construction	G 11	-	[10]
		Energy/water (C&R.1)	Energy use for residential, commercial and industrial land use		-	[10],[28]
			Water use by households in the area		-	[10],[28]
		Renewable energy (C&R.3)	Types of renewable sources		+	[10]
	Financial Services (FS)	Insurance (FS.1)	Crop insurance policies per square mile	T 8.10, T 1.5	+	[11]
			% Housing units covered by disaster insurance	T 8.10, T 1.5	+	[11]
	Production (P)	Production type and features (P.1)	Food security rate		+	[11]
			Gross regional domestic product per capita		+	[26],[19],[27],[34],[31],[14],[22],[16]
			Total farm cash flow		+	[16]
			Farm fixed assets investment density (amount of investment per area)		+	[34]
			Farms marketing products through		+	[11]
			Community Supported Agriculture per 10,000 persons			
			Density of manufacturing within built up area		+	[27]
			Proportion of cultivated land area		+	[14]
			Proportion of non-resource-based industrial output in total industrial output (%)		+	[31]

Dimension	Subdomain	variable	Indicators	Potential Goal/Target	Impact	Indicators from Resilience Literature
Institutional	Disaster Preparedness (DP)	Mitigation (DP.2)	Net per capita spending for mitigation projects		+	[2],[25],[11],[5],[17],[9]
			% Population within 10 miles of nuclear power plant		-	[2],[11]
			% governmental financial resources to carry out risk reduction activities		+	[11]
			% Population covered by a mitigation plan		+	[3],[11],[10],[7],[8],[17],[9]
			% of population living in hazardous area		-	[6]
			Existence of government plans (i.e. disaster, climate adaptation)		+	[7]
			Net operating surplus as a percentage of gross operating revenues		+	[25]
			% of employed persons working in public administration, defence, social security or municipal activities		+	[25],[11],[31],[7]
			Average number of early warning centers per each independent zone		+	[11],[10]
			No. of fire/ police/ambulance stations and shelters per 1,000 people		+	[10],[26],[20],[8],[9]
		Accessibility (DP.1)	Mean distance in meters from denser settlement areas to nearest county capital	G 11	-	[25]
	Disaster Experience (DE)	Disaster aid experience (DE.1)	Presidential disaster declarations divided by number of loss-causing hazard events	T 1.5	+	[2],[11],[5]
			No. of paid disaster declarations	T 1.5	+	[3],[8],[9]
			% Local schools, hospitals and health facilities that remained operational during emergencies in past events	T 1.5	+	[11]
		Disaster knowledge (DE.2)	% Population with access to local disaster training	G 4	+	[2],[3],[11],[7],[8],[17],[9]
			Red Cross training workshop participants per 10,000 persons	G 4	+	[11],[10]
			% Officials and leaders who are under regular training programs	G 4	+	[11]
			Per capita expenditure on education	G 4	+	[31],[29],[34]
		Income and expenditure (G.4)	Net per capita general expenditures		+	[29],[21]
			Total financial revenue from business		+	[29]
	Governance (G)	Performance regime (G.6)	Proximity of county seat to state capital	T 10.2, T 10.3	+	[2],[11]
			Proximity of county seat to nearest county seat within a Metropolitan Statistical Area	T 10.2, T 10.3	+	[2],[11]
			Governments and special districts per 10,000 persons	T 10.2, T 10.3	+	[2],[3],[11],[8]
		Social (G.7)	Local court convictions per capita		-	[12]
			% Voting age population participating in presidential election		+	[12],[15]
			Population change over previous five year period		+	[2],[4]
		Financial (G.3)	% Housing units covered by disaster insurance	T 8.10, T 1.5	+	[2],[3],[7]

Dimension	Subdomain	variable	Indicators	Potential Goal/Target	Impact	Indicators from Resilience Literature
Recovery		Development (G.1)	% Population under age 65 with health insurance	T 8.10, T 1.5	+	[11]
			Crop insurance policies per square mile	T 8.10, T 1.5	+	[2],[5]
			No. of building units constructed over the last ten years	G 11	-	[4]
			% Land area that consists of windbreaks and environmental plantings	G 11	+	[11]
			Percent of vulnerable shoreline protected by dykes/embankments	G 11	+	[20]
			% Designed structural damage - % actual structural damage	G 11	+	[11]
		Urban improvement (G.8)	Per capita expenditure on Urban improvement programs		+	[24]
			Area of residential, commercial, industrial and educational land uses (km ²)		+	[15]
			Existence of a current development plan		+	[24]
			Year of current development plan		+	[24]
			Existence of a current land use policy		+	[24]
			Year of current land use policy		+	[24]
		Infrastructure (G.5)	% building infrastructure not in high hazard zones		+	[11]
			% essential infrastructures that are under regular assessment programs		+	[11]
			% of population access to electricity/gas/safe water/radio/internet		+	[22]
			Hospital/hotel beds per 10,000 persons		+	[22]
			% Housing units that are not mobile homes		+	[22]
			Principle arterial miles per square mile		+	[10],[22]
			The ratio of the number of crossings over the length of roads (network connectivity)		+	[10]
			Daily average amount of marine cargo transported		+	[26]
			Average size of registered fishery vehicles		+	[26]
			No. of seamounts		+	[26]
			% State-owned and collective-owned households		-	[12],[34]
			No. of schools per 1000 students		+	[11]
			No. of fire/ police/ambulance stations and shelters per 1,000 people		+	[11]
		Environmental (G.2)	% of municipal wastewater treatment		+	[31]
			*Amount of solid waste by source		-	[31]
			The GDP growth rate of environment administration (%)		+	[31]
			Fixed assets investment density (amount of investment per area)		+	[31]
		Financial support (RR.2)	Microfinancing, cash aid, soft loans, loan guarantees available to affected households after disasters to restart livelihoods		+	[11]

Dimension	Subdomain	variable	Indicators	Potential Goal/Target	Impact	Indicators from Resilience Literature
Infrastructural		Ecosystem support (RR.1)	Local government plan to support the restoration, protection and sustainable management of ecosystems services Coastal setback, shoreline restoration		+	[11]
		Psychosocial support (RR.3)	Local government access to resources and expertise to assist victims of psychosocial impacts of disasters	G 3	+	[11]
	Energy, Water and Sanitation	Electricity (EW&S.1)	% Population with access to electricity		+	[23]
		Plumbing and sewage (EW&S.2)	% Households with access to plumbing/piped water/flush toilet		+	[29],[21],[16]
		Public establishment (EW&S.3)	% Infrastructure area per area (transportation, park, power, water services (ha.))	T 9.1	+	[15]
	Housing (Ho)	Housing features (Ho.1)	% Housing units that are not mobile homes	G 11	+	[2],[3],[4],[11],[29],[21],[7],[8],[9]
			Median number of room	G 11	+	[4]
			% Average housing age	G 11	-	[2],[3],[4],[11],[21],[7],[9]
		Temporary housing availability (Ho.2)	% Vacant units that are for rent	G 11	+	[2],[3],[11],[7],[8],[9]
			Hotels/motels per 10,000 persons	G 11	+	[2],[3],[25],[4],[11],[28],[7],[8],[9],[15]
			Distance to nearest public shelter	G 11	-	[28]
	Health Infrastructure (HI)	Health services (HI.1)	Hospital beds per 10,000 persons		+	[2],[3],[4],[11],[8],[9],[15]
			Senior centers per 1,000 persons		+	[24]
	Land (L)	Social engagement (L.3)	% Area of community services (recreational facilities, parks, historic sites, libraries, museums) total area		+	[11]
			Area of public open space		+	[27]
		Urbanisation and density (L.4)	% Population living in urban areas	G 11	+	[25]
		Agriculture (L.1)	% of agricultural land to total land area		+	[15]
		Informal settlements (L.2)	Area of informal settlements (ha.)		-	[15],[16]
	Economic Infrastructure (EI)	Commercial establishment (EI.1)	% Commercial infrastructure area per area	G 8	+	[11]
			% Commercial establishments outside of high hazard zones ÷ total commercial establishment	G 8	+	[11]
	Education Infrastructure (Ed.I)	School restoration potential (Ed.I.1)	Public schools per 10,000 persons/or per square mile	G 4	+	[2],[3],[25],[4],[11],[16],[6],[7],[8],[9]

Dimension	Subdomain	variable	Indicators	Potential Goal/Target	Impact	Indicators from Resilience Literature
	Emergency Response (ER)	Emergency stations and shelters (ER.1)	No. of fire/ police/ambulance stations and shelters per 1,000 people		+	[25],[4],[5],[7]
			Mean distance in meters from denser settlement areas (tettsted N50) to the nearest /hospital/fire/police station (log-transformed)		-	[25],[28],[27],[6]
		Emergency workforce capacity (ER.2)	No. of firefighters/ police officers/ medical staff per 1,000 people		+	[26]
			Transportation access (ER.4)	No. of vehicle registrations per capita	G 9	+
			Annual increasing rate of privately possessed cars (%)	G 9	-	[31]
		Infrastructure (ER.3)	% Building infrastructure not in high hazard zones	G 9	+	[7]
	Transportation (T)	Industrial re-supply potential (T.3)	Rail miles per square mile area	G 9	+	[2],[11],[26],[7]
		Evacuation potential (T.1)	Principle arterial miles per square mile		+	[3],[25],[4],[11],[7],[8],[9]
			Major road egress points per 10,000 persons		+	[2],[11],[27],[32]
			Roads network density		+	[23],[25],[37],[31]
		Road safety (T.4)	Traffic accidents per 1,000 persons	T 3.6	-	[25],[37]
		Accessibility (T.2)	Mean distance in meters from denser settlement areas to the nearest airport (only airports operated by Avinor or the military were included)		-	[25]
			No. of vehicles per 1,000 persons		+	[37]
			Extra travel time invested yearly or daily		-	[37]
			Total cost of carbon for private and public transport		-	[37]
			Economic benefit of street provides cycling/walking (\$/year)		+	[37]
	Communication (C)	High speed internet (C.1)	% Population with access to broadband internet service		+	[2],[4],[11]
		Telecommunication (C.2)	Average number of Internet, television, radio, telephone, and telecommunications broadcasters per household		+	[11],[29]
	Infrastructure Workforce (IW)	Public utility sector (IW.1)	% of employed persons working in public utilities (electricity, water, waste, transportation, communication)	T 11.1	+	[25],[29],[15]
	Efficiency (Ef)	Electricity (Ef.1)	Megawatt hours per energy consumer		-	[11]
		Water (Ef.3)	Ratio of water production to demand	T 6.4	+	[11]
		Gas (Ef.2)	Ratio of gas production to gas demand		+	[11]
Environmental	Agriculture (A)	Local food suppliers (A.5)	Farms marketing products through Community Supported Agriculture per 10,000 persons		+	[2],[38],[29]
			No. of farms per square mile		+	[39]
			% of agricultural land to total land area		+	[19]

Dimension	Subdomain	variable	Indicators	Potential Goal/Target	Impact	Indicators from Resilience Literature
Ecosystem Functionality (EF)			% of agricultural lands not treated with herbicide/pesticide		+	[38]
		Connectivity (A.2)	% Farm operations with internet access	T 9.c	+	[38]
		Assets (A.1)	% Family and individual farm ownership		+	[39]
			Agricultural holdings per 1,000 persons		+	[25]
		Income (A.4)	% of farms paying interest (real estate/ non-real estate)		-	[39]
			% farms with expenses (animal/ chemical/ labor/ feed/rent/tax/fuel/energy)		-	[39]
			Per capita revenue/ farm products per square meter		+	[29]
		Self-organisation (A.6)	% Principal operators living on farm	G 2	+	[38]
			% Operations with on-farm packing/ direct marketing to retail	G 2	+	[38]
		Diversity (A.3)	Average % of operations producing across seven different row crop options	G 2	+	[38]
		Safe zones (EF.5)	% Land in wetlands (natural flood buffer zone)	T 2.4	+	[2],[25],[11],[7]
			% Land in wetlands in not slide area	T 2.4	+	[25]
			% Land area with no wetland decline	T 2.4	+	[11],[7]
			% Land area that consists of windbreaks and environmental plantings	T 2.4	+	[7]
		Air (EF.1)	Air quality index (AQI)		-	[12],[11],[30]
			No. of days per year with pollution concentration above the local norm or standard		-	[37],[31]
			Health cost of air pollution (\$/year)		-	[37]
			% of acid rain per total precipitation		-	[31]
		Soil (EF.6)	Soil erosion ton/year/person		-	[12]
			% Land that is not impervious		+	[2],[12],[25],[11],[16]
			% Availability of quality agricultural land		+	[23],[11]
			% People accessing quality agricultural land and forests		+	[23],[30]
		Land and Sea (EF.3)	Normalized difference vegetation index (NDVI)		+	[11]
			Ratio of land that turned to urban areas to total land area		-	[37],[31],[4]
			% of forest to total land area		+	[23],[11],[7],[19]
			% Land area that is developed open space		+	[25],[4],[7]
			% Land area that is arable (cultivated) land		+	[25],[7]
			Ratio of built and unbuild spaces		-	[4]
			% Land area with no land-use change		+	[11],[7]
			% Land area under protected status		+	[11],[7],[37],[31],[18]
			% Land area of urban green space		+	[26],[27],[37]
			% of population with access to a green urban area less than 300 m away.		+	[37]
			% area of beach		+	[26]
			Average elevations in the area		-	[29],[18],[15],[28]
			Degree of slope		-	[27],[18],[28]

Dimension	Subdomain	variable	Indicators	Potential Goal/Target	Impact	Indicators from Resilience Literature
			Areas of potential debris flow torrents and landslides		-	[15]
			Distance from rivers less than 100 m		-	[15]
			Height in digital elevation model (DEM)		-	[27]
			% Land area that does not contain erodible soils		+	[19],[11],[7]
			% Natural vegetation		+	[16]
			% of species susceptible to extinction		-	[11]
			% Indigenous vegetation cover (protected biomass)		+	[12],[23]
		Water (EF.7)	% of availability of quality water resources for agriculture		+	[23],[30]
			No. of rainy days		+	[18]
			Averaged annual rainfall more than 1000mm		-	[15],[31]
			% of people accessing quality water resources for agriculture		+	[23],[37],[31]
			% Dam capacity		+	[23]
			Number of river miles whose water is usable		+	[11],[27]
		Natural disasters (EF.4)	Frequency of natural disasters	G 11	-	[18]
	Environmental Policies (EP)	Efficiency (EP.1)	Megawatt hours per energy consumer		-	[2],[37],[31]
			% Heating fuel		-	[39]
			Annual crude oil withdrawals, bbl per capita		-	[39]
			Annual natural gas withdr., 1000 ft3 per capita		-	[39]
			% of renewable energy to total energy production		+	[23]
			Degree of resource depletion		-	[34],[30]
			Water supply stress index		-	[2]
			Total water consumption		-	[19],[37],[31]
			% of total renewable water resources		+	[39], [23]
			% Ground water withdrawals (agriculture, public supply, industry)		-	[39]
		Recycling (EP.3)	Recycling ratio of wastes		+	[26]
		Emission (EP.2)	NO/SO ₂ emissions		-	[19],[31],[18]
			GHG emissions per capita per year		-	[37]
		Sewage and waste (EP.4)	Amount of daily sewage treatment		+	[19],[37]
			*Amount of solid waste by source		-	[19],[37],[31]
	Social Impact (SI)	Crime (SI.1)	Environmental violations case	G 15	-	[31]
		Gross production (SI.2)	Gross regional domestic product per capita		+	[37]
		Population (SI.3)	Population density	T 11.7	-	[18]

Appendix 2. SDG indicators and their relevance to resilience dimensions

Dimension	Sub-domain	SDGs	Indicators
Social	Community Strength	G2	2.1.2, 2.4.1., 2.5.1, 2.a.2
		G3	3.6.1
		G5	5.b.1
		G9	9.1.1, 9.c.1
		G10	10.7.4
		G11	11.7.1
		G15	15.1.2, 15.4.1
		G17	17.6.1, 17.8.1
	Economic capacity	G1	1.4.2
		G2	2.1.2, 2.4.1, 2.5.1, 2.a.2
	Education & Knowledge	G1	1.a.2
		G4	4.1.1, 4.1.2, 4.2.2, 4.3.1, 4.4.1, 4.6.1, 4.b.1, 4.c.1
	Health	G1	1.a.2
		G2	2.1.1, 2.1.2, 2.2.1, 2.2.2, 2.2.3
		G3	3.1.1, 3.1.2, 3.2.1, 3.2.2, 3.3.1, 3.3.2, 3.3.3, 3.3.4, 3.3.5, 3.4.1, 3.4.2, 3.5.1, 3.7.1, 3.8.1, 3.9.1, 3.9.2, 3.9.3, 3.b.2, 3.c.1, 3.d.1, 3.d.2
		G5	5.2.1, 5.2.2, 5.3.1, 5.3.2
		G6	6.2.1
		G11	11.5.1
		G13	13.1.1
		G16	16.1.2
	Population & Demographics	G1	1.1.1, 1.2.1
		G8	8.5.2
	Social Protection	G1	1.3.1, 1.a.2
		G9	9.5.2
		G11	11.3.2, 11.4.1, 11.b.2
Economic	Business activity	G8	8.1.1, 8.9.1, 8.10.1
		G16	16.6.1
	Cost and revenue of development	G12	12.a.1
		G7	7.3.1
	Employment	G5	5.5.1, 5.5.2
		G8	8.5.2, 8.7.1
		G9	9.2.2
		G16	16.7.1
	Financial Services	-	-
	Household Capacity	G1	1.4.1, 1.4.2
	Income	G1	1.1.1, 1.2.1, 1.2.2
		G2	2.3.2
		G5	5.4.1
		G8	8.5.1
		G10	10.1.1
	Production	G2	2.3.1, 2.3.2, 2.4.1
		G9	9.3.1, 9.b.1

Dimension	Sub-domain	SDGs	Indicators
Institutional	Disaster Preparedness	G1	1.5.3, 1.5.4
		G11	11.b.2
		G13	13.1.3
	Governance	G5	5.b.1
		G11	11.6.1, 11.a.1
		G 16	16.1.1, 16.1.2, 16.1.3, 16.2.1, 16.2.3, 16.3.1
		G17	17.1.1, 17.1.2
	Disaster experience	-	-
	Recovery response	G1	1.3.1
		G2	2.4.1
Infrastructural	Communication	G17	17.6.1, 17.8.1
	Economic infrastructure	-	-
	Education infrastructure	-	-
	Efficiency	G7	7.3.1
	Emergency response	G3	3.8.1, 3.c.1
	Energy, water & sanitation	G1	1.4.1
		G6	6.3.1
		G7	7.1.1
	Health infrastructure	G 3	3.8.1
	Housing	-	-
	Land	G2	2.4.1
		G11	11.1.1, 11.7.1
	Transportation	G9	9.1.1
		G11	11.2.1
	Infrastructure workforce	-	-
Environmental	Agriculture	G2	2.3.2, 2.4.1
		G5	5.a.1
	Ecosystem functionality	G2	2.5.2
		G3	3.9.1
		G6	6.1.1, 6.3.2, 6.6.1
		G11	11.7.1
		G14	14.5.1
		G15	15.1.1, 15.1.2, 15.3.1, 15.4.1, 15.5.1, 15.8.1
	Environmental policies	G6	6.6.1, 6.a.1
		G7	7.1.2, 7.2.1
		G12	12.5.1, 12.a.1
		G13	13.2.2
		G14	14.1.1
	Social Impact	G8	8.1.1

Appendix3:

Overlap coefficient [40] is calculated by dividing the size of the intersection by the minimum size of the two sets in a cluster:

$$Overlap(R_b, S_b) = \frac{|R_b \cap S_b|}{\min(|R_b|, |S_b|)}$$

Since the aim of this study is to measure what extent of resilience indicators are covered by SDGs, we have not included the irrelevant indicators of SDGs in our measurement. In this case, SDG indicators to measure resilience are always a subset of resilience indicators in a cluster based on the following equation:

$$S_b \subseteq R_b \text{ if } \forall x (x \in S_b \rightarrow x \in R_b)$$

Consequently, the cardinality of the intersection of resilience and SDGs is equal to the cardinality of SDGs:

$$S_b \subseteq R_b \Leftrightarrow |R_b \cap S_b| = |S_b|$$

Also $\min(|R_b|, |S_b|) = |S_b|$. Therefore, the overlap of the two frameworks is always 1 and so the method has not been considered in this research.

The second popular method is the Jaccard coefficient [41]. The Jaccard coefficient measures similarity between two sets in a cluster, and is formally defined as the size of the intersection divided by the size of the union of the sets:

$$J(R_b, S_b) = \frac{|R_b \cap S_b|}{|R_b| + |S_b| - |R_b \cap S_b|}$$

The Jaccard Index is a value between 1 (objects are the same) and 0 (objects are indefinite).

The third method is Cosine similarity [40], which measures the similarity of vectors as the cosine of the angle between two vectors:

$$Cosine(\vec{R}_b, \vec{S}_b) = \frac{\vec{R}_b \bullet \vec{S}_b}{|\vec{R}_b| |\vec{S}_b|} = \frac{\sum_{i=1}^N r_{b_i} \times s_{b_i}}{\sqrt{\sum_{i=1}^N r_{b_i}^2} \sqrt{\sum_{i=1}^N s_{b_i}^2}}$$

Where r_{b_i} and s_{b_i} are respectively the components of $\vec{R}_b$ and $\vec{S}_b$, and i is the number of vectors' components.

Both Jaccard and Cosine can be employed to measure the similarity of the frameworks but generate a different level of similarity. For instance, the similarity of SDGs with RVF to measure social resilience has been 67.86% and 82.38%, respectively, based on the Jaccard and Cosine methods. To explore the importance of $\vec{R}_b$ and $\vec{S}_b$, or R_b and S_b , which have resulted from the coding process, in the similarity of frameworks, initially, a sensitivity analysis has been conducted applying the following formula [42] [43]:

$$Sensitivity = \frac{dx}{dp} \frac{p}{x}$$

Where x is one of the methods to measure similarity and p is either $\overrightarrow{R_b}$ or $\vec{S_b}$ when calculating the sensitivity of Cosine, or R_b and S_b for Jaccard.

Sensitivity analysis in our case reveals the impact of uncertainty that may have occurred through the coding process (in our case selected indicators) on the output (similarity of frameworks) where lower sensitivity means the lower impact of the input (lower bias). However, the results of this test showed equal sensitivity for both, and therefore equal validity.

After obtaining similar sensitivity (Appendix3), the literature on the intersection of Jaccard and Cosine similarity has been explored and, based on research conducted by Zahrotun (2016) [44], Cosine was selected to measure the similarity. Zahrotun has compared the validity of Jaccard, Cosine, and the combination of them when measuring the similarity obtained from the NN method. The research has concluded that the highest accuracy can be achieved utilising Cosine similarity. Matching their approach to defining similarity (NN method) with the method applied here, Cosine has been selected here as the method to measure the similarity of frameworks.

References

- [1] Z. Assarkhaniki, A. Rajabifard, and S. Sabri, "The conceptualisation of resilience dimensions and comprehensive quantification of the associated indicators: A systematic approach," *International Journal of Disaster Risk Reduction*, vol. 51, p. 101840, Dec-2020.
- [2] S. L. Cutter, K. D. Ash, and C. T. Emrich, "The geographies of community disaster resilience," *Glob. Environ. Chang.*, vol. 29, pp. 65–77, 2014.
- [3] S. L. Cutter, C. G. Burton, and C. T. Emrich, "Disaster Resilience Indicators for Benchmarking Baseline Conditions," *J. Homel. Secur. Emerg. Manag.*, vol. 7, no. 1, 2010.
- [4] M. Moghadas, A. Asadzadeh, A. Vafeidis, A. Fekete, and T. Kötter, "A multi-criteria approach for assessing urban flood resilience in Tehran, Iran," *Int. J. Disaster Risk Reduct.*, vol. 35, no. January, p. 101069, 2019.
- [5] S. L. Cutter, "The landscape of disaster resilience indicators in the USA," *Nat. Hazards*, vol. 80, no. 2, pp. 741–758, 2016.
- [6] A. Asadzadeh, T. Kötter, and E. Zebardast, "An augmented approach for measurement of disaster resilience using connective factor analysis and analytic network process (F'ANP) model," *Int. J. Disaster Risk Reduct.*, vol. 14, pp. 504–518, 2015.
- [7] C. G. Burton, "A Validation of Metrics for Community Resilience to Natural Hazards and Disasters Using the Recovery from Hurricane Katrina as a Case Study," *Ann. Assoc. Am. Geogr.*, vol. 105, no. 1, pp. 67–86, 2015.
- [8] L. Singh-Peterson, P. Salmon, N. Goode, and J. Gallina, "Translation and evaluation of the Baseline Resilience Indicators for Communities on the Sunshine Coast, Queensland Australia," *Int. J. Disaster Risk Reduct.*, vol. 10, no. PA, pp. 116–126, 2014.
- [9] M. Hiete, M. Merz, T. Comes, and F. Schultmann, "Trapezoidal fuzzy DEMATEL method to analyze and correct for relations between variables in a composite indicator for disaster resilience," *OR Spectr.*, vol. 34, no. 4, pp. 971–995, 2012.
- [10] X. Fu and X. Wang, "Developing an integrative urban resilience capacity index for plan making," *Environ. Syst. Decis.*, vol. 38, no. 3, pp. 367–378, 2018.

- [11] S. A. Kammouh, O., Zamani Noori, A., Cimellaro, G.P., Mahin, "Resilience Assessment of Urban Communities," *ASCE-ASME J. Risk Uncertainty Eng. Syst.*, vol. 5, no. 1, 2019.
- [12] W. Kaye-Blake, K. Stirrat, M. Smith, and S. Fielke, "Testing indicators of resilience for rural communities," *Rural Soc.*, vol. 28, no. 2, pp. 161–179, 2019.
- [13] A. Kliskey, P. Williams, J. T. Abatzoglou, L. Alessa, and R. B. Lammers, "Enhancing a community-based water resource tool for assessing environmental change: the arctic water resources vulnerability index revisited," *Environ. Syst. Decis.*, vol. 39, no. 2, pp. 183–197, 2019.
- [14] X. Li *et al.*, "Measuring County Resilience After the 2008 Wenchuan Earthquake," *Int. J. Disaster Risk Sci.*, vol. 7, no. 4, pp. 393–412, 2016.
- [15] H.-C. Hung, C.-Y. Yang, C.-Y. Chien, and Y.-C. Liu, "Building resilience: Mainstreaming community participation into integrated assessment of resilience to climatic hazards in metropolitan land use management," *Land use policy*, vol. 50, pp. 48–58, 2016.
- [16] I. Kotzee and B. Reyers, "Piloting a social-ecological index for measuring flood resilience: A composite index approach," *Ecol. Indic.*, vol. 60, pp. 45–53, 2016.
- [17] S. Ainuddin and J. K. Routray, "Earthquake hazards and community resilience in Baluchistan," *Nat. Hazards*, vol. 63, no. 2, pp. 909–937, 2012.
- [18] D. K. Yoon, J. E. Kang, and S. D. Brody, "A measurement of community disaster resilience in Korea," *J. Environ. Plan. Manag.*, vol. 59, no. 3, pp. 436–460, 2016.
- [19] M. Hu, J. Zhang, and J. Huang, "Assessing social-ecological system resilience in Mainland China," *Polish J. Environ. Stud.*, vol. 27, no. 3, pp. 1085–1096, 2018.
- [20] R. DasGupta and R. Shaw, "An indicator based approach to assess coastal communities' resilience against climate related disasters in Indian Sundarbans," *J. Child Fam. Stud.*, vol. 24, no. 3, pp. 85–101, 2015.
- [21] J. M. Links *et al.*, "COPEWELL: A Conceptual Framework and System Dynamics Model for Predicting Community Functioning and Resilience after Disasters," *Disaster Med. Public Health Prep.*, vol. 12, no. 1, pp. 127–137, 2018.
- [22] L. Siebeneck, S. Arlikatti, and S. A. Andrew, "Using provincial baseline indicators to model geographic variations of disaster resilience in Thailand," *Nat. Hazards*, vol. 79, no. 2, pp. 955–975, 2015.
- [23] B. Manyena, F. Machingura, and P. O'Keefe, "Disaster Resilience Integrated Framework for Transformation (DRIFT): A new approach to theorising and operationalising resilience," *World Dev.*, vol. 123, p. 104587, 2019.
- [24] D. P. González, M. Monsalve, R. Moris, and C. Herrera, "Risk and Resilience Monitor: Development of multiscale and multilevel indicators for disaster risk management for the communes and urban areas of Chile," *Appl. Geogr.*, vol. 94, no. April, pp. 262–271, 2018.
- [25] S. Scherzer, P. Lujala, and J. K. Rød, "A community resilience index for Norway: An adaptation of the Baseline Resilience Indicators for Communities (BRIC)," *Int. J. Disaster Risk Reduct.*, vol. 36, no. March, p. 101107, 2019.
- [26] E. Kim and H. Park, "Two-stage approach to quantify the resilience of maritime hazardous and noxious substance spill accidents," *Int. J. Disaster Risk Reduct.*, vol. 28, no. January, pp. 595–601, 2018.
- [27] J. Song, B. Huang, and R. Li, "Measuring recovery to build up metrics of flood resilience based on pollutant discharge data: A case study in East China," *Water*, vol. 9, no. 8, 2017.
- [28] J. Song, B. Huang, and R. Li, "Assessing local resilience to typhoon disasters: A case study in Nansha, Guangzhou," *PLoS One*, vol. 13, no. 3, pp. 1–22, 2018.
- [29] V. V. Mihunov *et al.*, "Community Resilience to Drought Hazard in the South-Central United States," *Ann. Am. Assoc. Geogr.*, vol. 108, no. 3, pp. 739–755, 2018.
- [30] M. A. Abdrabo and M. A. Hassaan, "An integrated framework for urban resilience to climate change - Case study: Sea level rise impacts on the Nile Delta coastal urban areas," *Urban Clim.*, vol. 14, pp. 554–565, 2015.
- [31] C. Zhang, Y. Li, and X. Zhu, "A social-ecological resilience assessment and governance guide for urbanization processes in east China," *Sustainability*, vol. 8, no. 11, 2016.
- [32] I. Tumini, P. Villagra-Islas, and G. Herrmann-Lunecke, "Evaluating reconstruction effects on urban resilience: a comparison between two Chilean tsunami-prone cities," *Nat. Hazards*, vol. 85, no. 3, pp. 1363–1392, 2017.
- [33] Y. Wei, S. Wang, Y. Fang, and Z. Nawaz, "Integrated assessment on the vulnerability of animal husbandry to snow disasters under climate change in the Qinghai-Tibetan Plateau," *Glob. Planet. Change*, vol. 157, no. September, pp. 139–152, 2017.
- [34] J. Tan, P. Zhang, K. Lo, J. Li, and S. Liu, "Conceptualizing and measuring economic resilience of resource-

- based cities: Case study of Northeast China,” *Chinese Geogr. Sci.*, vol. 27, no. 3, pp. 471–481, 2017.
- [35] J. Luh *et al.*, “Vulnerability assessment for loss of access to drinking water due to extreme weather events,” *Clim. Change*, vol. 133, no. 4, pp. 665–679, 2015.
 - [36] A. L. Brenkert and E. L. Malone, “Modeling vulnerability and resilience to climate change: A case study of India and Indian states,” *Clim. Change*, vol. 72, no. 1–2, pp. 57–102, 2005.
 - [37] G. C. Delgado-Ramos and L. Guibrunet, “Assessing the ecological dimension of urban resilience and sustainability,” *Int. J. Urban Sustain. Dev.*, vol. 9, no. 2, pp. 151–169, 2017.
 - [38] J. J. Green, J. Worstell, and C. Canarios, “The Local Agrifood System Sustainability/Resilience Index (SRI): Constructing a data tool applied to counties in the southern United States,” *Community Dev.*, vol. 48, no. 5, pp. 697–710, 2017.
 - [39] V. V. Mihunov, N. S. N. Lam, R. V. Rohli, and L. Zou, “Emerging disparities in community resilience to drought hazard in south-central United States,” *Int. J. Disaster Risk Reduct.*, vol. 41, no. August, p. 101302, 2019.
 - [40] M. K. Vijaymeena and K. Kavitha, “A survey on similarity measures in text mining,” *Mach. Learn. Appl. An Int. J.*, vol. 3, no. 1, 2016.
 - [41] F. Alqadah and R. Bhatnagar, “Similarity measures in formal concept analysis,” *11th Int. Symp. Artif. Intell. Math. ISAIM 2010*, pp. 1–7, 2010.
 - [42] S. E. Jorgensen, *Fundamentals of Ecological Modelling*, 2nd ed. Netherlands: Elsevier, 1994.
 - [43] S. Liu, *Global Sensitivity Analysis: The Primer* by Andrea Saltelli, Marco Ratto, Terry Andres, Francesca Campolongo, Jessica Cariboni, Debora Gatelli, Michaela Saisana, Stefano Tarantola, vol. 76, no. 3. 2008.
 - [44] L. Zahrotun, “Comparison Jaccard similarity, Cosine Similarity and Combined Both of the Data Clustering With Shared Nearest Neighbor Method,” *Comput. Eng. Appl. J.*, vol. 5, no. 1, pp. 11–18, 2016.