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Development of a GIS based hazard, exposure, and vulnerability analyzing method for monitoring drought risk at Karachi, Pakistan

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ABSTRACT

Droughts have an adverse influence on agriculture, the environment, water supplies, and the global economy. The drought risk was computed using an integrated prospective approach: drought hazard, exposure, and vulnerability based on biophysical and socio-economic conditions over Karachi, Pakistan during 2000–2019. Drought hazard map (DHM) was created using annual Palmer drought severity Index (PDSI). Drought exposure map (DEM) was derived using population density and gross domestic product (GDP), as well as land surface temperature (LST), Normal difference vegetation index (NDVI), Night light images (NTL), land use land cover (LULC), and Distance to water were used for drought vulnerability map (DVM). An estimation of drought Risk (EDR) was derived by integrating layers of DHM, DEM, and DVM. Results showed that Central, South, and East regions of Karachi were at high risk, whereas the North East and North were less affected by the drought. The estimated average drought hazard (EDH) was 0.84, with minimum (maximum) value of 0.68 (1). Similarly, the average estimated drought exposure (estimated drought vulnerability) for EDE (EDV) was 0.27 (0.42), with the maximum value of 0.55 (0.84) and the minimum value of 0 (0). The drought risk assessment map (DRAM) shows that the average risk values is 0.18 while highest value is 0.36.

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Abbreviations: DHM: Drought hazards map; PDSI: Palmer drought severity index; DEM: Drought exposure map; GDP: Gross domestic productivity; LST: Land surface temperature; NDVI: Normal difference vegetation index; NLT: Night light image; LULC: Land use land cover; DVM: Drought vulnerability map; EDR: Estimation of drought risk; EDH: Estimation of average drought hazard; EDE: Estimation of average drought exposure; EDV: Estimation of average drought vulnerability; DREM: Drought risk assessment map

1. Introduction

Water scarcity is a key concern in the twenty first century (Plummer and Baird 2021). In recent years, global warming, increasing water usage, decreased rainfall, and a lack of attention towards smart agriculture techniques affected the water resources crisis. The aforementioned factors lead to the occurrence of different types of droughts (Zhang et al. 2020; Farsani et al. 2021; Orimoloye et al. 2021; Shi et al. 2021). Droughts are also influenced climate changes, soil conditions, human activities (land use), overgrazing, and other factors in different parts of the world: hydrological, meteorological, Agricultural, and Socioeconomic (Mohsenipour et al. 2018; Deng et al. 2021; Mu et al. 2021; Shi et al. 2021). The socio-economic droughts are caused by the other three categories: agricultural, hydrological, and meteorological droughts (Kottek and Rubel 2007; Peel et al. 2007). Droughts are one of the world's most damaging and expensive natural disasters (Dumitraşcu et al. 2018; Pei et al. 2019). Drought has been become more severe and frequent in many parts of the world in recent years (Huang et al. 2019; Liu et al. 2019). Droughts are a common and complex natural disaster that has an adverse impact on people's life, economies, agriculture sector, water resources, and society (Rahman and Lateh 2016; Pei et al. 2018). Droughts resulted in probably 6–8 billion US dollar loss each year globally (Pei et al. 2019). Determining the degree of the occurrence of droughts may be effective in reducing the negative impact of droughts on wildlife and human. Different studies have been carried out to investigate the impact of droughts. According to an assessment of agricultural drought at the Pearl River Basin, China and revealed that drought risk has increased in most of the area of the basin (Dai et al. 2020). The results of agricultural drought risk evaluation by Zhang et al. (2020) in the Lancang Mekong region showed that the spatial distribution of high drought risk is consistent across the regions with extensive agriculture application (Liu et al. 2020). Agricultural drought was studied using GIS techniques in central and southern areas of Fars, revealing that northern areas are more prone to drought events (Zareiee and Masoudi 2014; Shamsnia and Dehkordi 2020). The agricultural drought in Bangladesh was computed using GIS, and it was discovered that north-west and south-west parts of the country are more prone to agricultural droughts, but central region of the country also affected by extreme agricultural droughts (Aziz et al. 2021). Drought vulnerability was assessed in the northwestern areas of Bangladesh using geospatial and AHP techniques, and it was resulted that 77% of the region is moderately to extremely vulnerable to drought events (Hoque et al. 2020). Drought management measures such as prevention, mitigation, and preparedness are more effective ways to minimize the adverse impacts

of droughts related natural disasters on the environment, society, and economy (Pei et al. 2018; Liu et al. 2019).

Drought management strategies require spatial information, which includes the regulating factors of drought hazard, exposure, and vulnerability. Detailed drought hazards, exposure, and vulnerability are used to compute drought risk mapping. Drought risk mapping can be helpful for policymakers and administrators in implementing effective drought mitigation measures to reduce drought losses. Different concepts of drought risk assessment have been adopted such as Wilhite (2000) noted that the risk is defined as the product of the hazard and vulnerability (Wilhite 2000). Remote sensing and spatial analysis are potentially required for drought risk mapping (Murthy et al. 2015; Palchaudhuri and Biswas 2016). Remote sensing data can provide precise temporal and spatial information over larger regions (Hoque et al. 2019; Rahman et al. 2019). An effective weighting and ranking technique is required by multi-criteria spatial policy making (Ekrami et al. 2016; Hoque et al. 2018). Analytical hierarchy process (AHP) is best scheme which deals with multi criteria evaluation in drought to support decision making (Wu et al. 2017; Zarei et al. 2021). It has been recognized in recent years, that drought hazard alone would be insufficient for comprehensive understanding of drought risk consequences on human life and the economy that would not bring sufficient benefit for drought mitigation and management.

Drought risk assessment research has been conducted in Pakistan, however it has primarily focused on the spatiotemporal characteristics of drought, and trends in the occurrence of drought (Dilawar et al. 2021). For example, a study used Standardized Precipitation Evapotranspiration Index (SPEI) to study the characteristic of drought events, indicated that droughts occurrence were intensified during 1902–2015 and SPEI is best to assess droughts caused by evapotranspiration (Jamro et al. 2019). Furthermore, Standardized Precipitation Index (SPI) was used to exhibit drought trend using the ground station data in Balakot and Parachinar, Pakistan (Rahman and Dawood 2018). Historically, Pakistan is facing repeatedly drought events: Khyber Pakhtunkhwa (KPK) in 1992, and 1952; Sindh province in 1871, 1881, 1899, 1931, 1947, and 1999; Punjab province in 1889, 1920, and 1935 (Pakistan 2015). Drought indices, such as the Standardized Precipitation Index (SPI), Standardized Precipitation Evapotranspiration Index (SPEI), are extensively used (Blauhut et al. 2015; Kim et al. 2015). SPI uses only the precipitation to help in the drought severity assessment and provide early warning of drought events. Different timescales of SPI identify the different droughts such as meteorological, agricultural, and hydrological drought and it has been widely applied by many hydrological and meteorological centers to compute the dryness and wetness (Giddings et al. 2005). Study of Adnan et al. (2017) concluded that due to inter-annual precipitation changes, the central and southern parts of Pakistan is facing frequent drought spells (Adnan et al. 2017). In Pakistan, different studies have been carried out to study the drought characteristics using different useful drought indices (Ashraf and Routray 2015; Ahmed et al. 2018; Hina and Saleem 2019). The most significant drought index is the Palmer drought severity index (PDSI), that Palmer developed in 1965 (Palmer 1965). The PDSI is a most prominent index that extensively was used for observing drought events. It considers different conditions: precipitation, evapotranspiration and soil moisture (Alley 1984).

The PDSI is used to calculate the cumulative changes in atmospheric moisture supply and demand at ground surface compared to local average conditions, as well as to simulate the moisture content of the soil on a monthly and compare the anomalies in the different climate zones (Szép et al. 2005).

There is a need to develop a comprehensive approach to assessing drought risk that takes socio-economic aspects into account. Therefore, hazard and the present socio-economic factors of a certain area should be incorporated in comprehensive drought risk assessment. A systematic approach was developed for drought risk assessment by considering three parameters: hazard map, exposure map, and vulnerability map to understand and prioritize high risk regions for drought preparedness. Drought risk mapping (DRM) combines drought hazard map (DHM; the potential for drought conditions), drought exposure map (DEM; population, GDP in an area where a drought event may happen), and drought vulnerability map (DVM; human and natural potential sensitivity of a certain area when drought occur) (González Tánago et al. 2016; Vogt et al. 2018). This study attempts to address the limits of drought risk mapping in Pakistan by proposing a physical hazard, socioeconomics, and vulnerability factors, quantification method for drought risk assessment in Karachi, Pakistan. Recently, a study computed only drought hazard index using SPI to identify the drought prone regions in Pakistan (Adnan and Ullah 2020). In Pakistan, the effectiveness of management and planning related activities still limited while they remain based on single hazard approaches. Specifically, the current study provides a comprehensive spatial quantification method of drought risk assessment, including drought hazard, exposure, and vulnerability using remote sensing data. Drought hazard was calculated using the PDSI, socio-economic factors were used to compute the drought exposure, and a vulnerability map was computed by using factors such as LULC, NTL, LST, distance to water, and NDVI.

The study aimed to prepare a comprehensive drought risk assessment approach incorporating climatic and physiographic factors of risk with their relevance criteria using geospatial technique to generate spatial drought hazard, exposure, and vulnerability indices for Karachi, Pakistan. A GIS based technique for assessing drought risk map that is expected to improve the rationality and accuracy of results. The spatially drought risk results can be used as a framework for a timely implementation of mitigation measures and effective monitoring system. The main objectives of this research are to: (1). develop a comprehensive drought risk assessment approach incorporating all factors of drought risk using the overlay technique; (2) use the developed approach for monitoring the spatial pattern of drought risk of Karachi, Pakistan; and (3) evaluate the generated drought risk assessment results. The results of current study will help for sustainable development to disaster managers, policy makers to develop drought contingency and food security plans of adaptation and mitigation.

2. Material and methods

2.1. Study area

The study focuses on Karachi, Pakistan, which is located between 24.8607°N and 67.0011°E, as shown in [Figure 1](#). The study area is 3780 km², with an altitude of 10 m

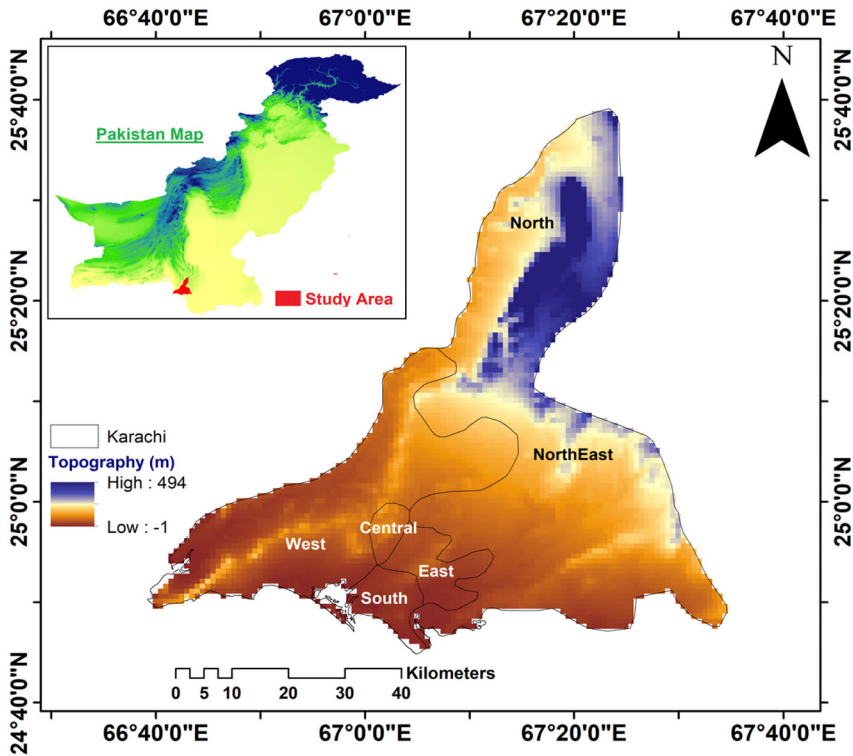


Figure 1. Study Area with topographic information.

above sea level. There are rocky outcrops, coastal marshlands, and mountains. The Karachi hills, form a major part of the Kirthar range with a maximum elevation of 528 m. Karachi is the world's second most populous city, after Shanghai. According to the climate Koppen Geiger zone rating, Karachi is rated as BWh (Tropical and subtropical desert climate). The annual average temperature is 25.9°C per annum. It has a humid, arid environment in the winter and hot in summers.

2.2. Datasets

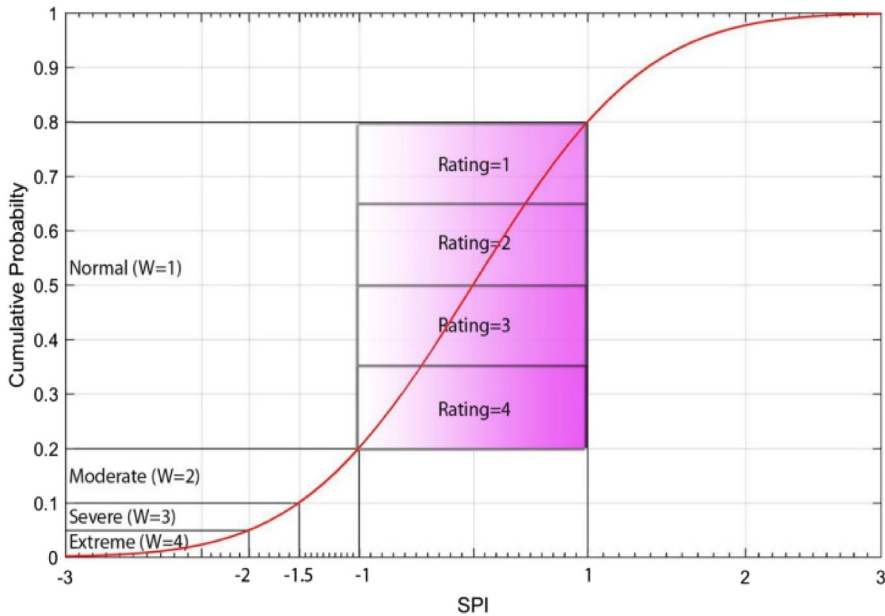
To carry out the analysis of drought risk assessment in Karachi, Pakistan the main datasets are used as presented in Table 1. The PDSI maps 2000–2019 were extracted and annually aggregated. Likely, Population density and Gross Domestic Productivity (GDP) were used for exposure map. For the vulnerability different datasets were used as summarized in the Table 1. Normal difference vegetation index (NDVI) and Land surface temperature (LST) were annually averaged during 2000–2019.

2.3. Estimation of drought hazard (EDH)

Hazard accounts the probability of occurrence of potential damaging. Hazard shows the probability, it has ranges from 0 to 1. Hence, it is calculated by the product of frequency of drought event's occurrence and associated magnitude with adopting the

Table 1. Details of data sources used in the drought risk assessment.

Category	Indicators	Years	Resolution	Source
Hazard	PDSI	2000–2019	0.05°	https://app.climateengine.org/climateEngine
Exposure	Population density	2019	100 m	https://www.worldpop.org
	GDP	2015	100 m	https://data.tpdc.ac.cn/
Vulnerability	NDVI	2000–2019	30 m	https://app.climateengine.org/climateEngine
	NLT	2000–2013	80m	http://www.eogdata.mines.edu
	LST	2000–2019	30m	https://app.climateengine.com/
	Dis to water	2015	100m	http://www.diva-gis.org/gdata
	LULC	2015	300 m	https://www.esa-landcover-cci.org/ Climate change initiative

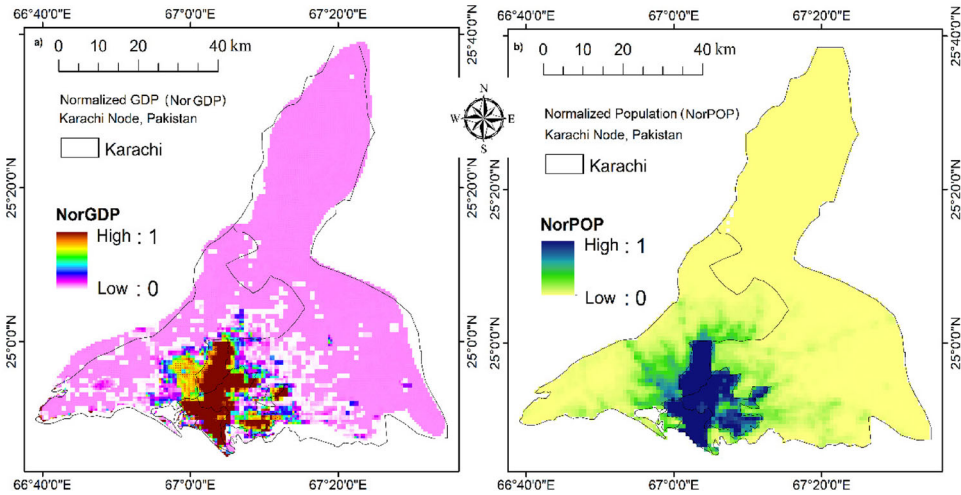

Figure 2. Weight and rating scores based on normal cumulative probability distribution of PDSI source: (Dabanli 2018).

weighting system based on the cumulative distribution function [Figure 2](#), rating (R) and Weight (W) scores are assigned according to the cumulative probability function. PDSI interval determines the weighted scores such as weight = 1 for normal drought, weight = 2 for moderate drought, weight = 3 for severe drought, and weight = 4 for extreme drought condition.

The drought hazard index map was generated by using the annual PDSI maps 2000–2019. The annual PDSI maps were reclassified using the ArcGIS 10.3. The pixel value was weighted based on probability. The PDSI probability classification was allocated as the same methods used in previous studies (Dabanli 2018; Zhong et al. 2019). In the present study during the PDSI classification, the adopted weight and probability rate are shown in [Table 2](#). The weighting and rate scores were assigned according to the intervals that are represented in [Figure 4](#). Drought hazard is generated by multiplying of weight and rate scores. The drought hazard is computed for each PDSI values from 2000 to 2019. The final aggregated EDH is calculated by using

TABLE 2. Palmer drought severity index classification and probability rate (Dabanli 2018).

PDSI range	Drought severity	Weight	Probability rate
≥ 0	No drought	0	75
-2 to -1	Mild drought	1	35
-3 to -2	Moderate drought	2	15
-4 to -3	Severe drought	3	7.5
< -4	Extreme drought	4	5

**Figure 3.** Drought Exposure factors (a) normalized GDP and (b) normalized population.

Eq. 1. The final generated hazard map for the Karachi node area was resampled to 100 m using the bilinear method.

$$(EDH)_j = \sum_{j=1}^{N_{PDSI}} (W_j \times R_j) \quad (1)$$

Where EDH_j is hazard of j th location, W_j is given weight of j th pixel and R_j is the given rate of j th pixel.

2.4. Estimation of drought exposure (EDE)

According to the IPCC (2014), exposure is defined as the presence of society, people, resources, infrastructure which hazards can affect adversely (PCC 2014). In the present study, we have been using two indicators to estimate the exposure, including the population density and gross domestic probability (GDP) with spatial resolution 100 m shown in Figure 3. Besides, using the Raster Calculator and Spatial Analyst tool in ArcGIS 10.3 the input data: population density and GDP were normalized within the range 0–1 to keep the identical. Lastly, the resulted exposure map was in the range of 0–1 which means lesser and higher exposed the pixels to the drought risk. The computation of exposure index was performed by the multiplication of weighted population density and GDP within the range of 0–1.

2.4.1. Weighting of factors

We calculated weights after obtaining normalizing factor values using the method proposed by (Iyengar and Sudarshan 1982), through Eq. 2. This weighting approach prevents abnormally large variations in 1 or many factors from overshadowing the contribution of the rest of the indicators (Ortega-Gaucin et al. 2018).

$$W_i = \frac{1}{(\sigma_i) \sum_{i=1}^n \left(\frac{1}{\sigma_i}\right)} \quad (2)$$

where W_i is the normalized indicator weight i , σ_i is the standard deviation of the set of values for indicator i , and n is the number of selected indicators.

The exposure can be calculated by the following Eq. 3.

$$EDE = \frac{\text{weighted population density} + \text{weighted GDP}}{2} \quad (3)$$

2.5. Estimation of drought vulnerability (EDV)

Vulnerability is described as the relative measure and shows the degree to that a system is vulnerable to harm because of drought events (Smit et al. 1999). Vulnerability to drought is a predisposition to be badly affected; it is calculated from the combination of economic, social, environmental, and physical factors (Infrastructure). In the past, many studies have been conducted vulnerability assessment in relation to climate change impact on the water regimes (Gramberger et al. 2015), but they do not reflect the reasonable drought scenarios, especially on a local scale (Fontaine and Steinemann 2009). Moreover, the selection of vulnerability indicators depends on geographical location and particular hazard. In the present study, infrastructure was given higher weight as compared to other factors (Shahid and Behrawan 2008; Cardona 2011). The detail of the LULC classes' weight rate is summarized in Table 3. The other indicators of drought vulnerability used in this present study are LST, Night light time imageries (NLT), Distance to water bodies, and NDVI. These indicators were normalized using the Raster Calculator and reclassify with the spatial Analyst tool in ArcGIS as in Figure 4. All normalized indicators were in the range of 0 to 1 to overcome the different unit effects, and are multiplied using the drought vulnerability Eq. (4) as follows. Lastly, the final result of drought vulnerability was the range of 0–1. 0 means less vulnerable to drought risk and 1 shows higher vulnerable to drought risk.

$$EDV = \frac{\text{weighted LST} + \text{weighted NLT} + \text{weighted NDVI} + \text{weighted LULC} + \text{weighted Dis to water bodies}}{5} \quad (4)$$

2.6. Estimation of drought risk (EDR)

The incorporation of drought hazard, drought exposure, and drought vulnerability investigate drought risk estimation. Many quantitative approaches are continuously evolving to risk the assessment. This concept integrates and links all associated factors with risk for example, physical/social, Natural, and environmental aspects (Sebesvari et al. 2016, Hagenlocher et al. 2018). Drought risk is the function of different factors

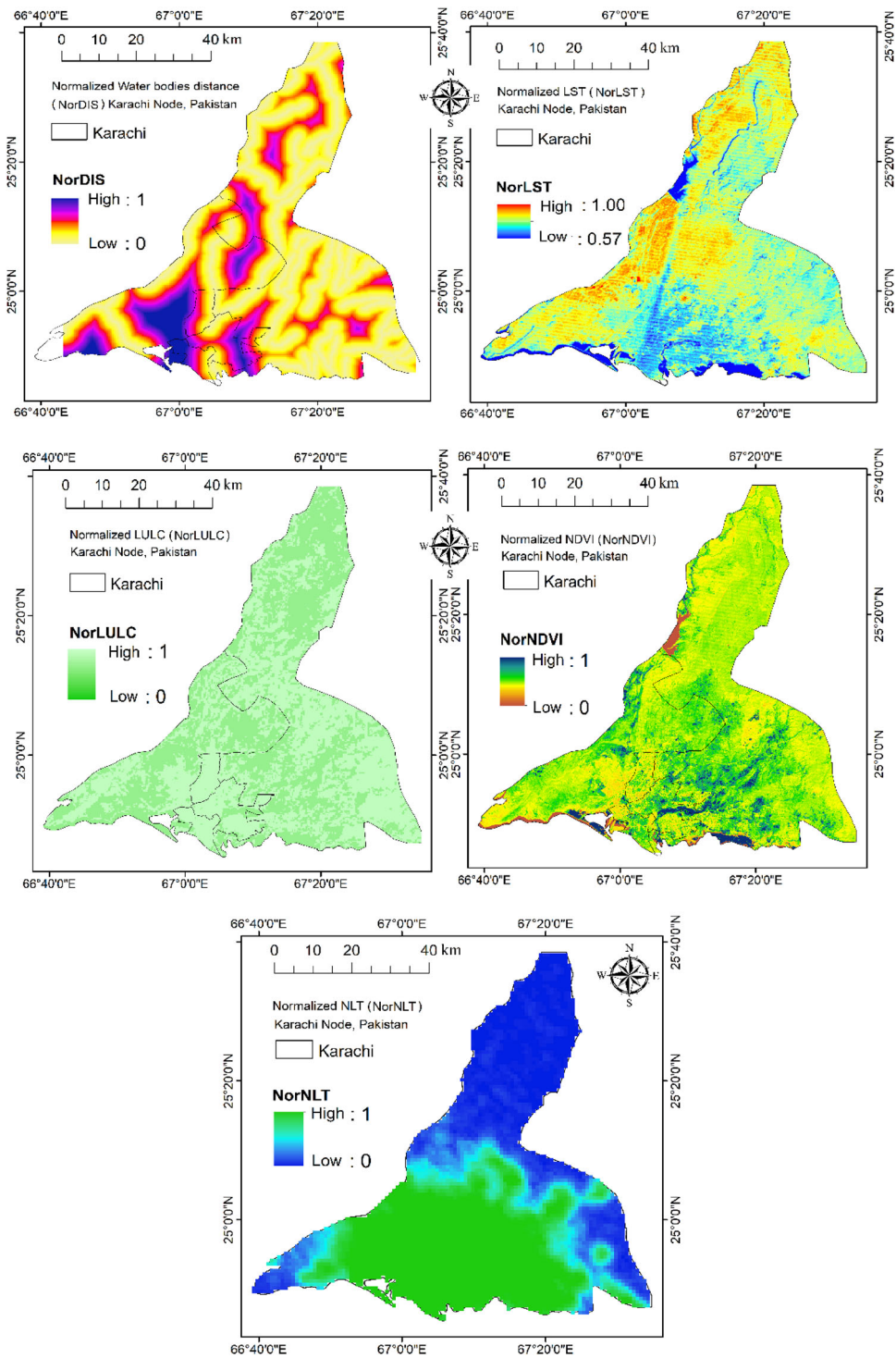
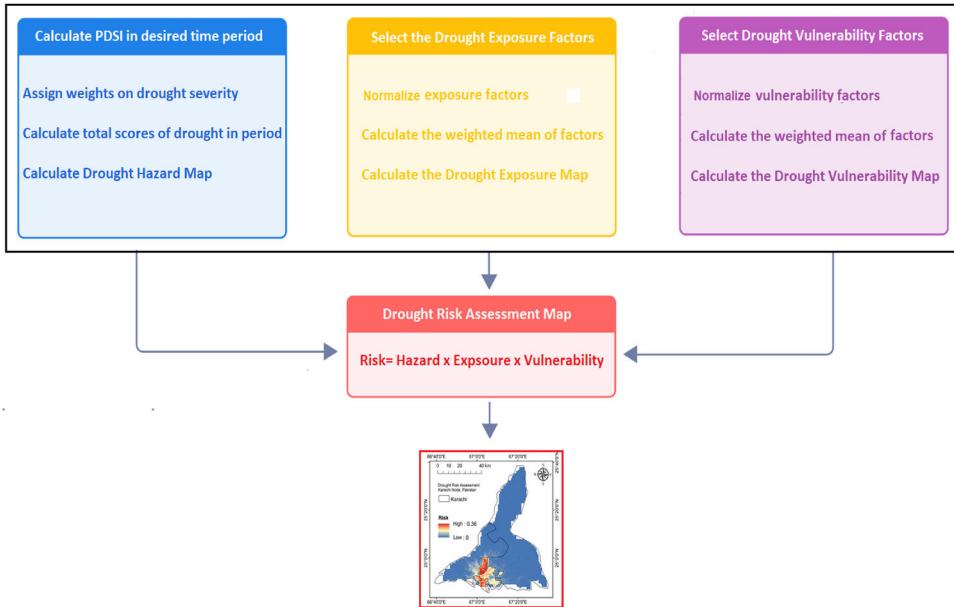


Figure 4. The detail of vulnerability input indicators NDVI, NLT, LULC, LST, and Dis to water.

TABLE 3. The LULC classification detail and weight rate information.

No	LULC class	Weighted rate
1	Cropland	0.9
2	Forest	0.2
3	Grassland	0.5
4	Wetland	0.1
5	Urban	1
6	Shrubland	0.4
7	Sparse vegetation	0.3
8	Barren land	0.4
9	Water	0


Figure 5. Conceptual flowchart of drought risk mapping.

that are: hazards, exposure, and vulnerability (Cardona 2011; Koks et al. 2015). In the present study, a mathematical relation was used to find a risk that is the product of three components: hazards, exposure, and vulnerability (Kron 2002). There will be no risk when either of hazard/exposure or vulnerability is zero, consequently, a higher value will result in increased risk by occurrence of drought event. Therefore, drought hazard, drought exposure, and drought vulnerability are essential components to quantify the drought risk. Drought risk assessments are vital to cope with consequences of drought hazard events; therefore, Drought risk assessment is done by using a conceptual framework as shown in the Figure 5 using three indicators.

$$\text{EDR} = \text{Hazard} \times \text{Exposure} \times \text{Vulnerability} \quad (5)$$

3. Results and discussion

3.1. Drought hazard map (DHM)

The drought hazard index map was generated based on annual PDSI 2000–2019. As shown in Figure 6. The drought hazards spatial distribution is in the range of 0.84–1

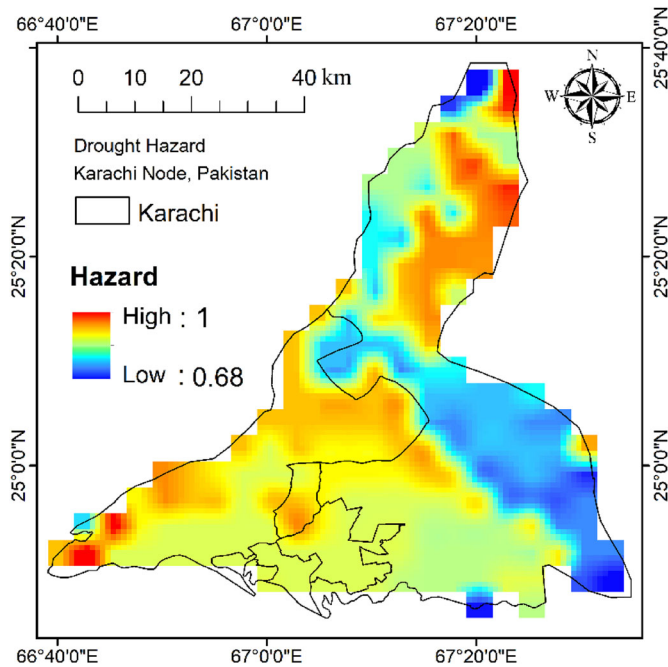


Figure 6. Drought hazard map for Karachi.

which implies that low to high hazard classes. The Karachi node area is most of the area highly exposed to hazards, particularly the southwest part of node area is having high drought hazard events as compare to the southeast part which is a low occurrence of drought hazard events. Most of the south costal area is facing the moderate hazards events and northeast part is suffering from the severe hazards incidences.

3.2. Drought exposure map (DEM)

The two major indicators, namely population density and GDP were used to compute the exposure index map based on statistical data of indicators. From [Figures 3 and 7](#), it has been observed from the DEM that the most populated area is badly exposed to drought exposure as compared to other areas (less populated). The GDP showed that the pixel value, higher is characterized by severe drought exposure while the low GDP area is having weak drought exposure. DEM in [Figure 7](#) demonstrates that central and southern region of Karachi has is more exposure to drought compared to other regions. In these two regions; Central region of Karachi is most exposed. The higher magnitude of exposure index may be attributed to high proportion of population density and assets in the region.

3.3. Drought vulnerability map (DVM)

In terms of susceptibility, in the present study, we used five indicators: Land surface temperature (LST), Night light time imageries (NLT), Normal difference vegetation index (NDVI), Distance to the water body, and Land use land cover (LULC) map to

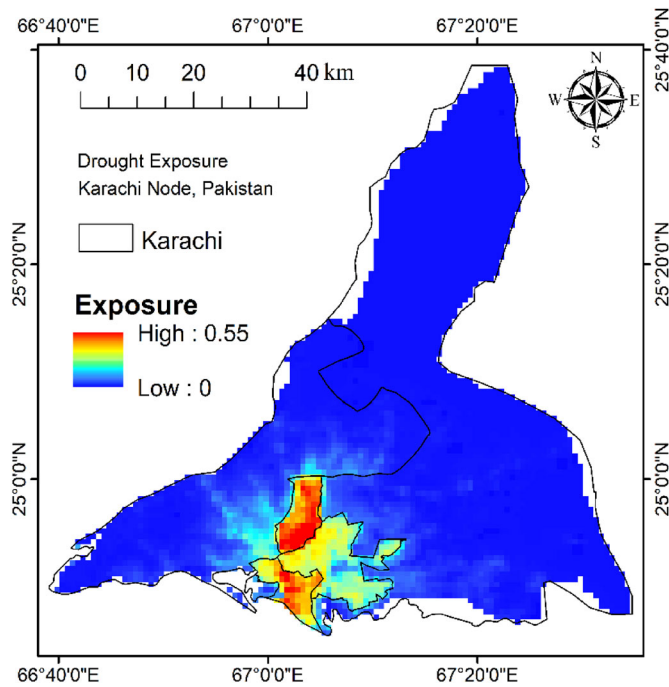


Figure 7. Drought exposure map for Karachi, Pakistan.

compute the drought vulnerability in the Karachi node area. The area that is apart from the water bodies is higher exposure to the drought vulnerability and the spatial pattern of vegetation phenology is showing the low vegetation leads to vulnerability to drought as shown in Figure 8. The vulnerability map indicates that central, east, and south region of Karachi is most vulnerable to drought. This region has high urban land, and poverty rate. In addition, these regions have, the less adaptation capacity to drought because of the poor socio-economic condition. In contrast, the least vulnerable regions are Malir, some part of the west region of Karachi. In general, the southeast and southwest area is highly prone to drought. For the areas with high vulnerability, following measures should be taken by enhancing water conservancy facilities, promoting the industrial transformation, reducing the agriculture dependency, and promoting the use of livestock products (Pei et al. 2018).

3.4. Drought risk assessment map (DRAM)

The DRAM shown in Figure 9 provides the overall magnitude of drought risk across the Karachi city that integrates assessment indicators including hazard, exposure, and vulnerability. This map shows that populated areas are at higher risk of drought events. The northeast and northwest part are free from the drought events. The urban area is mainly characterized by high drought risk. Most of the area is having low drought risk expect the southwest and south coastal areas. The central, south, and east region of Karachi has severe drought risk. The high values of drought risk are linked with high vulnerability and exposure of these regions to drought as in

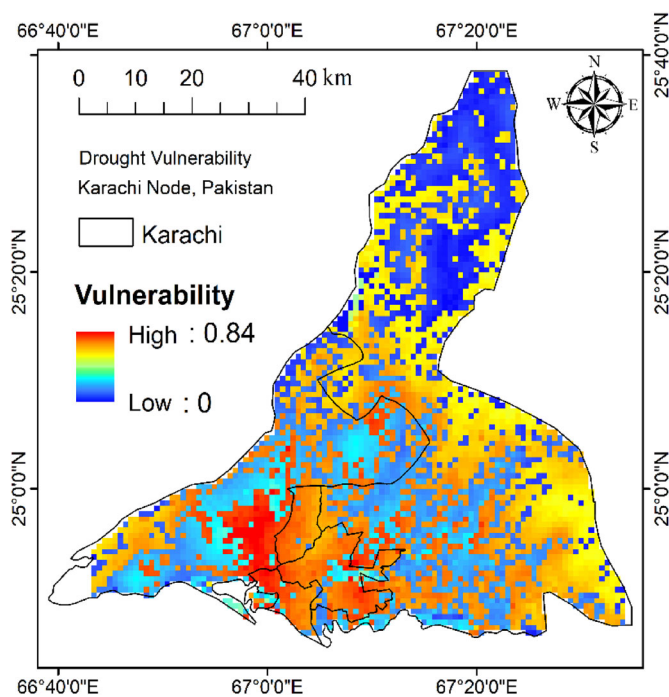


Figure 8. Drought vulnerability map for Karachi, Pakistan.

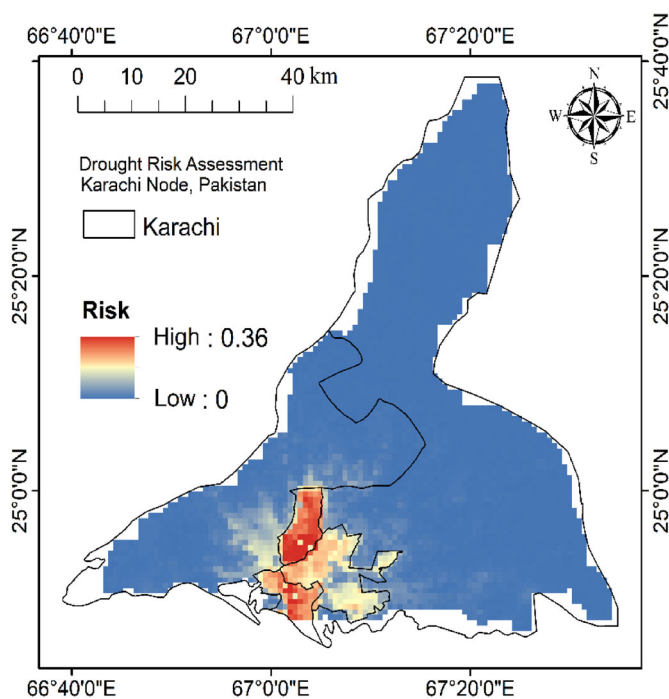


Figure 9. Drought risk map for Karachi, Pakistan.

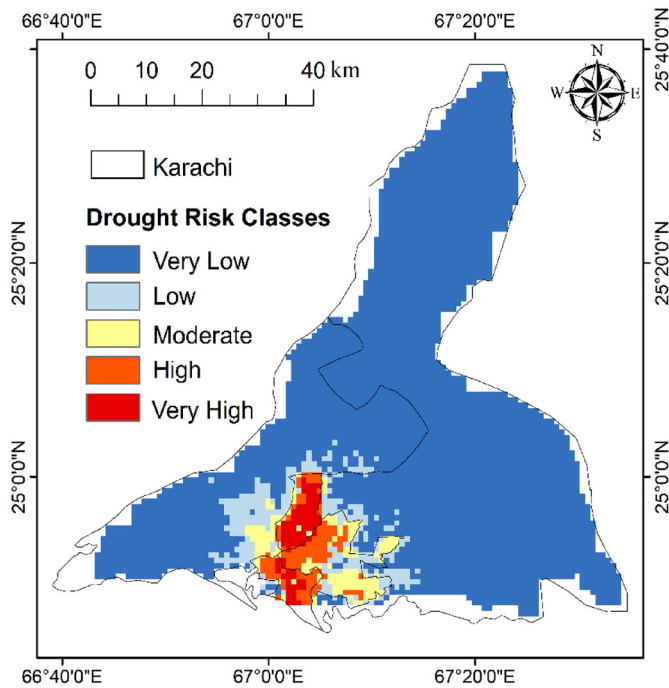


Figure 10. Map of drought risk classes for Karachi, Pakistan.

Figures 7 and 8. The coastal areas are highly active for the drought due to the high population, low groundwater table, and less soil moisture/precipitation. Furthermore, during national action plan for drought mitigation, Central, South, and East regions of Karachi require attention more compare to other regions as they are at high risk. Average DRAM shows that average risk is 0.18 while the maximum value is 0.36 and the minimum is 0. DRAM demonstrates that the region has least risk is the West and Milar regions less vulnerable, less exposed and suffered from hazard. The improving education level can be helpful to reduce drought vulnerability. According to the UNDP report, well-educated people have the potential to collaborate with the experts to deal with disaster risk and access information about hazards, preparedness, reduction, and adaptation (Pelling et al. 2004). Well educated people may be helpful to minimize the drought risks (Cardona et al. 2012).

3.5. Drought Risk analysis based on hazard, exposure, and vulnerability

The risk assessment has become more crucial since it serves as a link between adaptation and impacts. EDH, EDE, and EDV were estimated in this study using the socio-economic vulnerable factors and drought occurrence probability given in Figures 4, 5, and 6, respectively. The average EDH was 0.84, with minimum value 0.68 and a maximum value 1. Similarly, the average EDE (EDV) was 0.27 (0.42), with maximum value 0.55 (0.84) and a minimum value 0 (0). DRAM was classified into five classes, including very low, low, moderate, high, and very high risk as in Figure 10. The majority of Karachi has very low drought risk while the Central region at very high

risk. The southern part of the Pakistan crop water demand is high because of arid to extremely arid climate. The low rainfall, high temperature and evapotranspiration deplete the soil moisture and escalate the probability of severe drought (Adnan et al. 2017). A study by Adnan et al. (2015) found that most of area of Karachi is facing severe and extreme drought using SPI (Adnan et al. 2015). Although the key factors of drought risk in this area were climatic (LST/precipitation) and physiographic. Since the physiographic factors are important for the risk assessment in the present area it is necessary to take into account both climatic and physiographic factors in assessing the drought risk in order to make effective mitigation and management.

In Pakistan disaster managers do not adequately use of the most recent scientific methodologies, and tools for cost effective and sustainable interventions. Disaster risk can be reduced by adopting the spatial planning, but many of countries are having clear guidelines to deal with hazards and risk (Prevention 2004). The scientific literature makes cleared that Pakistan does not have in place appropriate spatial planning tools. The researchers have recognized that GIS and remote sensing in particular, and geospatial information in general, provide an effective plan for variable spatial resolution with multiplicity temporal scales (Wijitkosum and Sriburi 2019; Wijitkosum 2020). It is clearly evident that modern technologies can be helpful to monitor, forecast the devastating events and characterize their effects. In recent years, geospatial information and remote sensing tools and techniques such as modelling had considerably advanced (Joyce et al. 2009). The expected outcome of the current study is to support policy makers and technical personnel in identifying high drought risk region in Karachi and developing effective drought mitigation and adaptation strategies. It can be done by achieving the following objectives: selecting appropriate factors, quantification methodology for risk assessment; and to compute the drought risk maps for Karachi.

According to World Bank, drought risk and its three components hazard, exposure, and vulnerability, refer to the physical aspect of the drought occurrence (Bank 2019). On the other hand, exposure links to people, assets, and infrastructure in an area where drought hazards may occur, whereas drought vulnerability involves socio-economics and biophysical dimensions (González Tánago et al. 2016). The socio-economic aspects of vulnerability, refer to the social group which makes it susceptible to suffering the results of drought occurrence (Naumann et al. 2014; Carrão et al. 2016); whereas the biophysical aspects refer to environmental conditions such as river network, vegetation cover, soil characteristics and land surface temperature (Heydari Alamdarloo et al. 2020; Kim et al. 2021).

For the first time, a comprehensive drought risk analysis as proof of concept for Karachi is presented in this research by integrating the hazard and socio-economic conditions of the region, as well as use of PDSI for drought hazard assessment. The findings of the present study confirm the significant importance of socio-economic aspects in addition to physical hazard in the drought risk assessment. The proposed drought risk assessment overcomes the limitations of existing risk assessment methods used in Pakistan for drought hazard monitoring. As a result, the inappropriate and limited information about drought hazard would lead in inadequate mitigation strategies. As an example, the Central, South, and East region of Karachi have high

drought risk, while these regions are not on the top list of drought hazard. Water shortage is an important issue in the areas with higher risk and it needs to be strengthened water infrastructure in accordance with drought conditions (Zhao et al. 2020). The surface topography and subsurface geology are favourable to recharge the aquifers and store the water. The lack of rainfall and scarcity of groundwater recharge infrastructure have intensified the drought risk (Irfan et al. 2018). The rate of water loss is increased with low vegetation in urban areas (Fang et al. 2016). Additionally, the rainwater harvesting can reduce the drought risk while the water use efficiency in agriculture production can be by water saving technologies. The areas are showing high exposure are heavily populated. Certain measures can be taken for the areas with high vulnerability, by adjusting the industrial structure, reducing the dependency on agriculture etc. At the end, it is important to enhance water reservoir construction to ensure the timely irrigation. Reforestation is a main factor to reduce the drought risk and protect the environment whereas the link between forest and the drought is complicated due to structure of forest, local climate condition, and types of plants (McDowell et al. 2008; Parks et al. 2010).

Drought risk component (hazard, exposure, and vulnerability) are very important as the risk map and these layers allow for investigation of overall drought risk assessment and characteristics of each region under the influence of drought such as the adaptation capacity, the level of exposure, and the probability of drought hazard. It can be very helpful for the drought, technical managers make the suitable approach for the drought response region wise. The combined index for drought risk is an immensely recognized tool in drought management and it seems effective and easier for the public to show the composite indicators rather than to show a common trend of individual indicators.

4. Conclusions

This study concludes that drought risk assessment incorporating drought hazard, exposure, and vulnerability components was conducted for Karachi node, Pakistan uses a comprehensive approach. This analysis was carried out by using annual PDSI data for hazard map. The population density and GDP were included in the exposure domain, while the vulnerability domain used LST, NLT, LULC, Dis to water, and NDVI maps. Maps of drought hazard, exposure, vulnerability, and risk were produced in ArcGIS 10.3. The findings of the present study showed that the Central, South, and East regions, are at highest risk during drought events which are mainly populated areas. On the other hand, the North East and North regions were less influenced by the drought. This study contributes to a better understanding of the hazard, exposure, vulnerability and drought risks that the Karachi is currently facing. Therefore, we suggest that present methodology is a proper tool for accounting climatic and physiographic factors to explore the drought risk in drought prone regions. Current findings can be used to identify high risk areas and provide the actions for adaptation. Dense urban and populated areas suffered from high risk. Therefore, unplanned urban societies should be prohibited. Reforestation should be encouraged that maintain soil moist and precipitation rate. Constructing the small or medium

reservoirs within the city area is an effective way to enhance the moisture atmosphere and soil.

Thus, the current study provides a gateway to stakeholders, including food security planner, researchers, policymakers, and the government officials to improve adaptive capacity, socioeconomic development, and mitigation of drought challenges in the country. This case study examined the high drought risk in a specific region; future research should be extended this methodology for drought risk assessment for the whole country by incorporating the biophysical indicators such as high resolution soil moisture etc. It is suggested that the high risk drought areas must consider the following measure to cope the drought situation: strengthen the land use management; strengthen the water storage reservoirs; reduce dependence on single industry; and adopt the population control policies.

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