Potential landslides risk assessment based on remote sensing technique-a cause study from Dorset, southern England, United Kingdom

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Abstract. This paper presents a method of potential landslide risk assessment from the Dorset Southern England, United Kingdom. It concentrated on potential geological hazards and vulnerability to build a quantitative landslide risk framework in Dorset. In this study, the landslides risk assessment is centered on three components: identification of risks, calculation of risks, and evaluation of risks. Therefore, different natural environmental situations were collected using a large set of optical high-resolution satellite images and remote sensing to determine the probability of landslide occurrence and provide the quantitative model by combining the remote sensing technique. The result shows Dorset area risk level is high. The possibility of landslides mainly comes from natural conditions and human actions. The calculation of the possibility of potential landslides is based on the Bayes' theorem. Moreover, the limitation of the probability potential risk calculation is insensitivity. The challenge is related to the temporal resolution of precipitation information.

Keywords: risk assessment, remote sensing, landslide, geological hazards.

1. Introduction

Natural hazards are phenomena with a wide spatial dimension and impact [1]. The landslide is a typical natural risk with massive, instantaneous effects. When landslides occur, its instantaneous loss of life and injury to massive damage to buildings and public facilities. The resulting impact on both nature and society is irreversible. Consequently, people focus on researching the risk analysis for landside predictions. The limitations of the traditional technique of gathering data prior to landslides using drones include lengthy processing times and indistinct presentation of images. This results in risk estimate not being made even when mass casualties are caused. To surmount this limitation, remote sensing plays a vital role in data acquisition.

Remote sensing is a relatively crucial technique in conducting spatially explicit risk and vulnerability assessments because it has the most effective feature analysis techniques in data science, digital image processing [2], and analysis from the following aspects: optical and microwave wavelengths of satellites in addition to aircraft [3]. Therefore, it could provide contingency plans and risk maps to underestimate disasters in a faster time and to solve the limitations.

The aim of the study is trying to give a risk assessment by using the remote sensing technique for potential landslides in Dorset West Bay. It will focus on risk identification, calculation of potential disaster incidence and risk estimation. Remote sensing techniques are carried out mainly for environmental monitoring. By analyzing the DEM model and the vegetation change, The result shows the Dorset area risk level is high. By using the Bayes' theorem and multiple different elements to calculate the potential landslide probability is 0.22.

2. Regional overview

2.1.Geomorphology and geology for SW England

Dorset is typical geological research place due to the inimitable sedimentary structures. It is located in the Southwest England on the English Channel coast (Figure1).

Fig 1. The map represents the location of the Dorset West Bay in SW England.

The formation of the Dorset was by the plate tectonic setting. The process was the Cenozoic Alpine Orogeny results from the convergence and collision of Africa with Europe, closing the western part of the Tethys Ocean [4]. Therefore, as the result of the last glaciation, the region has been subjected to the powerful forces of coastal flooding and erosion and the occurrence of movements (Figure2). Alongside the outcropping geology, these processes have provided to create the almost vertical sea cliffs and left behind a legacy of unique, ever-changing features.

The area of Dorset covers a huge area of 2,653 square kilometers, which holds the unique geomorphology. For example, the barrier beach of Chesil Beach and the lagoon it encloses, the Fleet, classic erosional and coastal evolution features. On the other hand, the result of sea-level rise after the last glaciation.

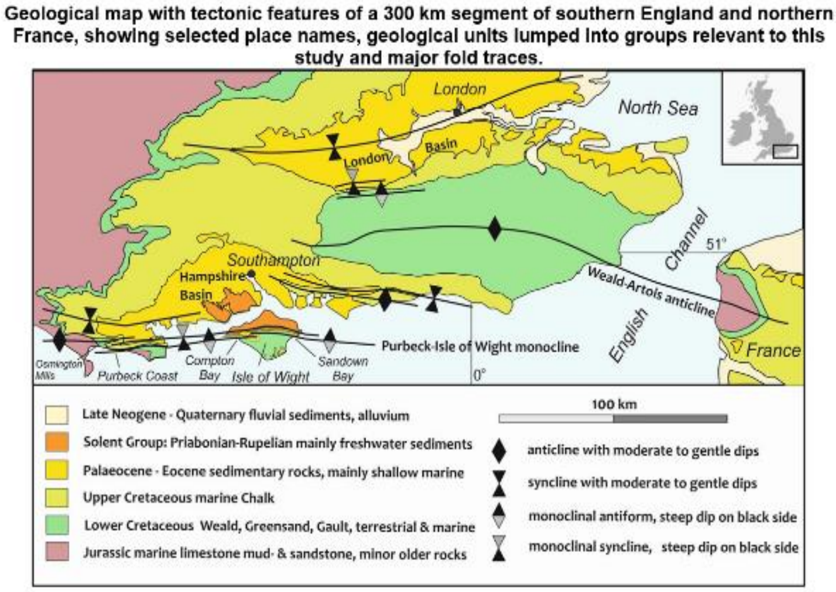

Fig 2. The Figure shows the formation of the Dorset formation by tectonic motion.

The area of Dorset covers a huge area of 2,653 square kilometers, which holds the unique geomorphology (Figure.3). For example, the barrier beach of Chesil Beach and the lagoon it encloses, the Fleet, classic erosional and coastal evolution features. On the other hand, the result of sea-level rise after the last glaciation.

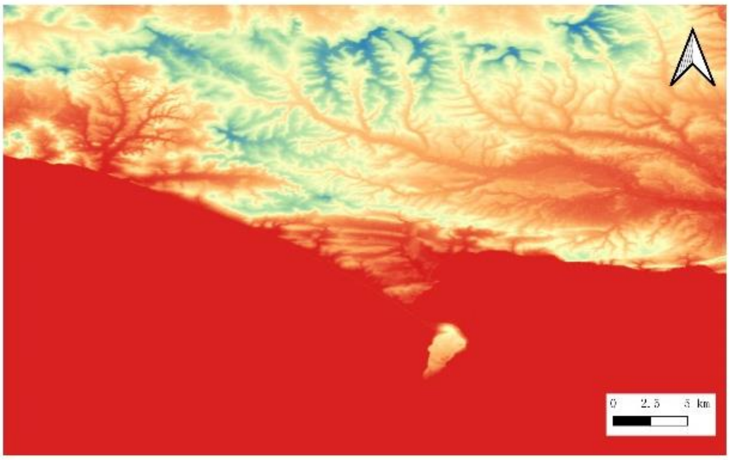

Fig 3. The Figure displays the DEM of psedcolor in West Bay area. The red part in the image mainly shows the sea region and the coastline with low sea-level. Morever the Dorset zone is located at a relatively high altitude inland.Hence, The cliff structures have been produced because of the difference in terrain.

2.2.Case study in Dorset West Bay

Landslides are defined as the failure and movement of material by sliding along a rupture or slip surface, normally through the activation of existing planes of weakness in the slope. The Dorset is the representative coastal environment (Figure 4), in the environment various process acts to destabilize sea cliff and initiated mass movements including weathering, rainwater and human activities.

Fig 4. The figure provides the satellite image using the true color with band (2,3,4).

As well as attacking the surface of cliffs through weathering, rainwater also destabilizes slopes by percolating through the subsurface and accumulation between rock layers. When rock or the soil is saturated, the water fills the pore spaces between grains, increasing pore pressure. This acts to reduce the material’s shear strength. On the other hand, lower the friction along bedding planes, resulting in the encouraging slip failure.

There are an increased number of landslip events in the Dorset. Consequently, this is the major hazard to coastal communities, with the cliff retreat and slope failure in particular threatening people, property, infrastructure, and business. The majority of landslides occur at West Bay (Figure 5). Hence, this study will be based on a multidimensional data collection around this area which then be processed and give an implementable risks assessment.

Fig 5. Photograph shows the geological rock of the West Bay.

3. Methods

3.1.Potential landslides risk concept

The potential landslide risk is related the probability of landslides and possibility of negative outcome of landslides. As a result, it can be explained as:

$$r = f(p, c) = p \times c \tag{1}$$

r: potential landslides risk.

p: probability of landslides.

c： negative outcome of landslides.

This formula summarizes the relationships existing between natural conditions and social behaviors of humans in landslide hazards.

3.2.Identification of risks

Identify risks primary centralize on the conditions of social behavior and natural influences leading to landslides and the aim for find the identification of the landslides mainly concentrated on the geology rocks, land slope and weathering.

The probability of landslide geological hazards including the natural conditions leading to landslides and modifying factors affecting the occurrence of landslides (Figure 6).

The natural condition is made up of the following elements:

a) geology or rocks.

b) persistent rainfall.

c) land slope.

d) weathering.

e) the change of landscape

The modifying factors affecting the occurrence of landslides emphasis on human activities, and the existence of faults:

a) land use.

b)drainage measures.

c)anti-slip structural measures.

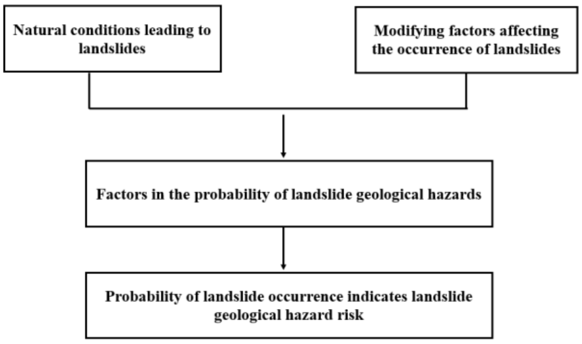

Fig 6. The flowchart exhibiting the mechanisms identification of risks.

3.2.1 The measurement of natural conditions in Dorset West Bay

Geology rock Measurement is measured in each bed thickness and observation. And the SI unit of the thickness is meter (m). Firstly, measuring the thickness of the rock bed. Secondly, repeat the procedure ten times with a tape recorder. In addition, find the average thickness by using following formula:

$$Thinkness = \frac{\sum tentime\ of\ thickness}{10} \tag{2}$$

Besides, use this primary data to construct a graphic log. Hence, by collecting the observations identify the rock type. Moreover, by using the graph to discuss the basic geomorphology of Dorset West Bay.

Slope measurement slope is measured using the inclinometer in degrees (θ). Measurements were made in specific areas that have not yet been dug in the landslide for the original slope (Figure.7). Repeat the measurements in the same area ten times(t)：

$$t = \frac{\sum tentimes\ \theta}{10} \tag{3}$$

And repeat the same procedure on ten distinct gradients(T):

$$T = \frac{\sum tentimes\ t}{10} \tag{4}$$

The measuring of persistent rainfall data is based on the website [5]. The figures were used to find the average monthly precipitation for Dorset West Bay region in the last ten years and the number of consecutive days of precipitation in the Dorset area in the last two years. Rainfall lasting more than two days may cause landslide hazards [6]. As a result, these data were processed, and the analysis obtained that the change in annual precipitation and the probability of landslides in Dorset zone

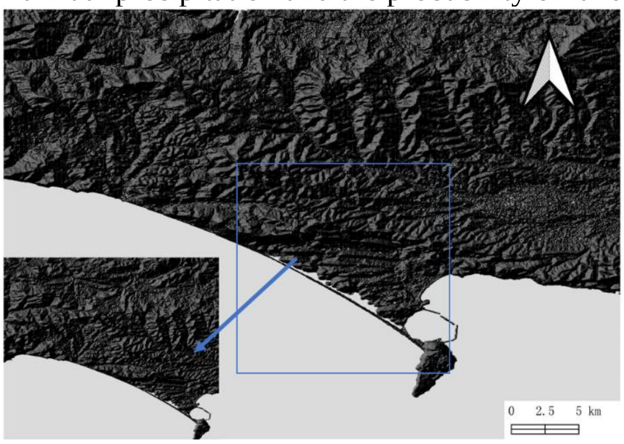

Fig 7. The DEM map of hillshade with 30°and it exhibits the measure slope degree’s area in Dorset West Bay area.

Landscape change is demonstrated through remote sensing techniques. The fundamental reasons for landscape alteration are ecological vulnerability. This identification of risks combined using the multitemporal remote sensing imagery combined with data collected from IKNOS [7] imagery combined. Besides, this process will link to the massive landslide in 2021 that occurred to find the impacts and recovery patterns of the exposed ecosystem and to have a deeper understanding of spatial characteristics of the Dorset (Huge landslide on Dorset coast [8].

In this process, the crucial point is searching for the changes in vegetation in the last decade. Based on the remote sensing technique, first did the classification of the vegetation to discriminate between the exposed area and the vegetated area. Then, by using the two-satellite imagery covering a common area from two periods in order to make the variations visualize and analyzed.

3.2.2. The measurement of modifying factors affecting the occurrence of landslides

An extensive collection of literature and other government information was used to find the types of landslide hazards that occur due to human activity.

Data collection focused on the following three aspects including land use, drainage measures and numbers of anti-slip structural measures.

3.3.Calculation of risks probability

Because the basic probability calculation suffers from the interference of overlapping factors. Therefore, to further increase the landslide accuracy, it is carried out using Bayes' rule.
The probability of landslides risk developed from the formula:

$$p(total) = \sum P(M \cap N) = \frac{P(N|\mathrm{M}) \times P(M)}{p(N)} \tag{5}$$

P (total): probability of landslides

P(M): probability of modifying factors affecting the occurrence of landslides

P(N): probability of Natural conditions leading to landslides

Because there are multiple factors that cause landslides, the landslide potential probability can be either a single factor or a combination of various factors. There are the following three ways to undertake the possibility of a hazard occurring.

Based on the geometric conditions of landside generation (slope degree), and geotechnical conditions for probabilistic analysis.

By using the Hydrological information released by the Unite Kingdom Met Office to estimate the probability of landslide occurrence:

$$p = 1 - (1 - pr)(1 - pj) \tag{6}$$

p: probability of landslides

pr: probability of precipitation induced

pj: probability of landslides causing slides

The slip-inducing probability is a constant and it depend on reliability theory. The probability of precipitation induced determined based on total meteorological data and statistics for two consecutive days are determined in the same period.

Probabilistic analysis using existing disaster data.

Though the occurrence of landslide geological hazards is random in nature. However, the occurrence of independent random events always conforms to certain laws such as the Large Number Theorem, Central Limit Theorem.

The frequency of occurrence can be used as a proxy for probability, as it always has some stability. Instead of probability, and the frequency of occurrence can be obtained from historical disaster records. The frequency of occurrence can be obtained from historical disaster records.

3.4.Evaluation of risks

The assessment of landslide hazard risk combines two main dimensions. Firstly, landslide geological hazard risk is expressed in terms of the probability of a landslide, and secondly, landslide geological hazard risk is indicated by the annual value loss. The disaster loss factor is determined by measuring the occurrence of landslide geological hazards in a year resulting in loss of life and damage to asset resources. The value of assets is mainly measured in terms of the extent of local traffic damage, and damage to tourism (Figure 8).

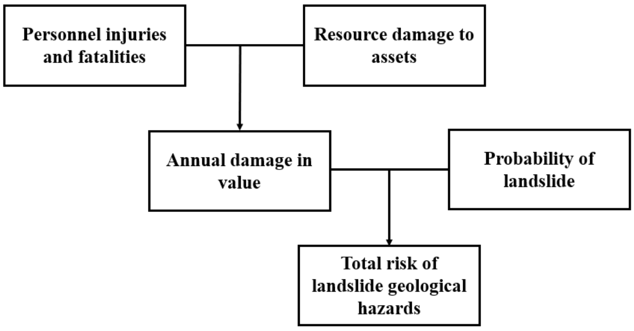

Fig 8. The Flow chart for determining landslide risk assessment

4. Results

4.1.Result of identify risks

4.1.1. The Geomorphology and geological hazards in Dorset West Bay

The root of landslides results from the angle of most cliffs being between 10°and 45°measured in the field (Figure 9). Hence, the unstable structure is continuously moving on the slope due to gravity. As a result, this may cause landslides.

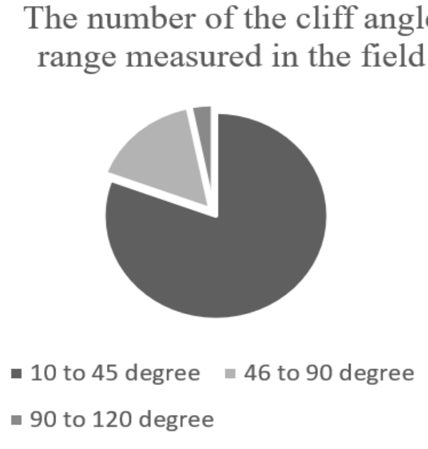

Fig 9. The diagram indicates that majority slopes lie between 46°and 90° found in field. In addition, the reason is that this measured area is nearly 1 km. Nearly a quarter of the cliff angle lies between 10 and 45 degrees, indicating the potential for landslides over a large area of this area.

The Dorset West Bay is a typical coastal environment. The lithology structure consists of the Brid-port Sandstone and Liassic clay (Figure 10), and the vegetation cover is not sufficiently dense. As a result, there is enormous geology exposed on the cliff. Correspondingly, these layers slope gently down towards the sea. Making these materials easily to move.

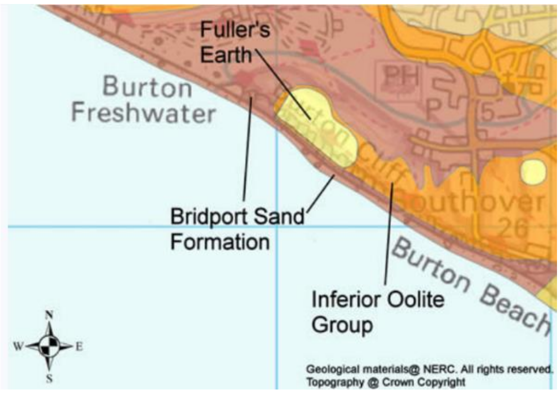

Fig 10. The image indicates the bridport Sandstone and Liassic clay dominated rock distribution in the area [9].

Consequently, the water storage capacity of sandstone is too small as the continuous rainfall (Figure11). Hence, the precipitation is. Incapable of penetrating the aquifer. Moreover, there are absent baseflow, and runoff can help perform triage. On the other hand, the exposed surfaces that have been strongly weathered are structurally unstable. As a result, it caused the landslide.

The change of the landscape main characteristic of the landscape change is detected in the transformation of the vegetation cover. In the West Bay, the dominant plant on this site is heather, and the root is the shallow roots (Figure12). Moreover, because of the strong weathering and the human activity. The distribution of the heather was reduced by 7% in ten years.

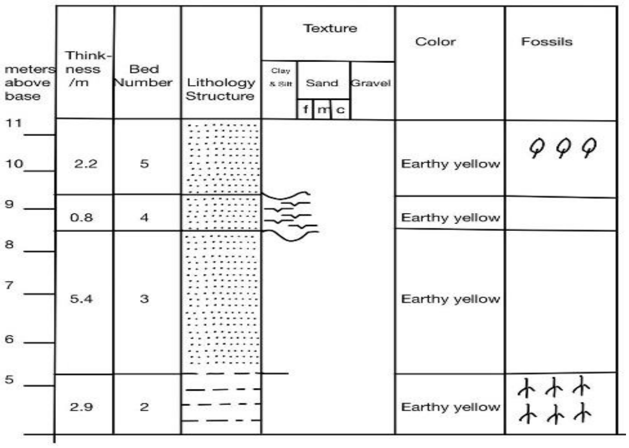

Fig 11. The graphic log graph in Dorset West Bay which shows the rock components of the cliffs, severity of weathering (curve bend) and vegetation cover.

The reduction in the vegetation cover carries several negative consequences. For instance, the reduced vegetation increases the exposure of the cliffs, while the soil structure becomes more diluted due to the lack of root mass. The possibility of landslides increases due to weathering effects.

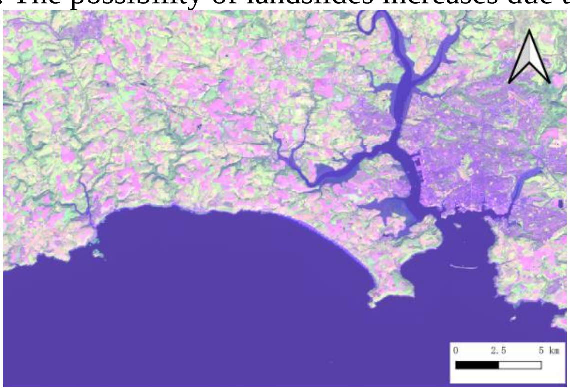

Fig 12. The picture shows the Vegetation distribution is less in Dorset West Bay coastal areas by using the satellite image in band (6,5,4).

4.1.2. The natural element affecting landslides and the probability of the potential landslide

In generally, Analysis was carried out by the UK Met Office. The number of extreme rainfall events in the UK will continue to ramp up in the future, and this is probably linked to climate change. As a result, the frequency of landslides will persistently occur (Figure13).

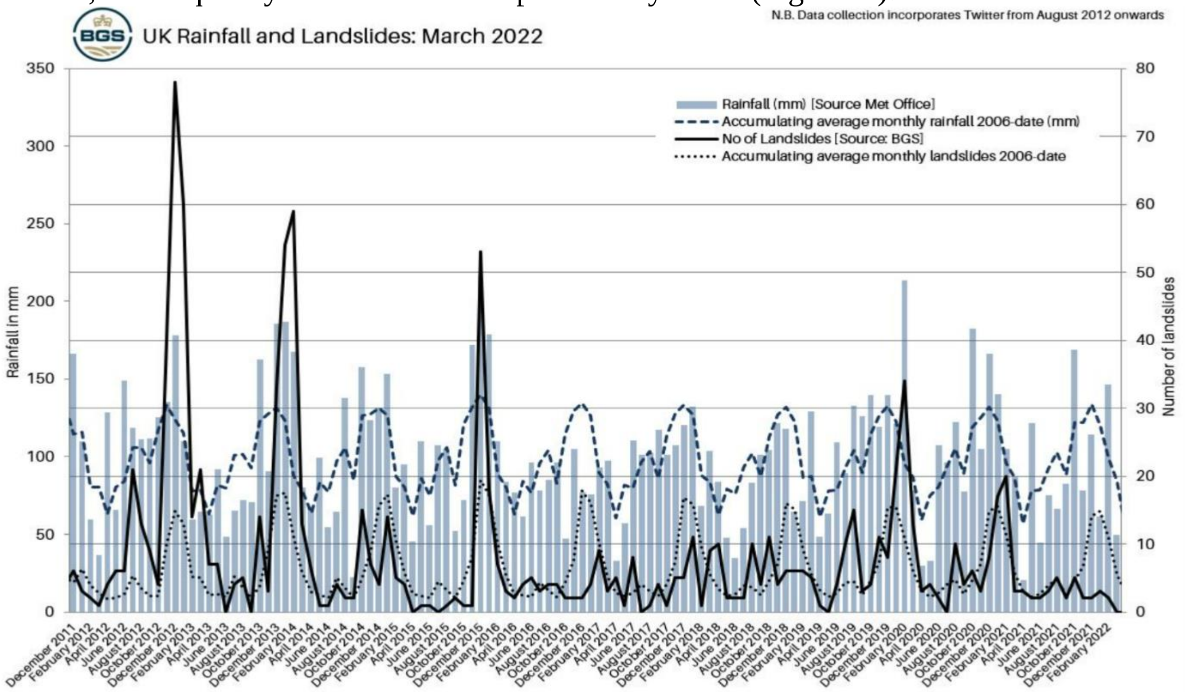

Fig 13. This chart counts the number of rainfall and landslides in the UK. The graph suggests that the higher the rainfall, the higher the number of landslides. UK rainfall (source: MetOffice) and landslides (source: BGS) in UK.

It can be clearly seen that the UK experienced several months of above-average rainfall from April 2012 to December 2012. In addition, this situation made it one of the wettest periods in the region since meteorological records began [10]. During this period, A significant improvement in the number of landslides occurred until early 2013, as recorded in the BGS, and winter 2015 saw another spike in the number of landslides due to extremely stormy weather. Increasing annual precipitation increases the probability of landslides occurrence. The annual precipitation increases by 9% from 2012 to 2022 (Figure 14) [11].

Statistics are taken over a specified period (three months). Weather marked with continuous greater-than-continuous rainfall is defined as weather that may cause landslides. The probability of potential landslide weather is approximately 30% [12]. The probability of landslides causing slides is 35%. Furthermore, bringing the data into the above formula, found that the probability of landslides is 0.54.

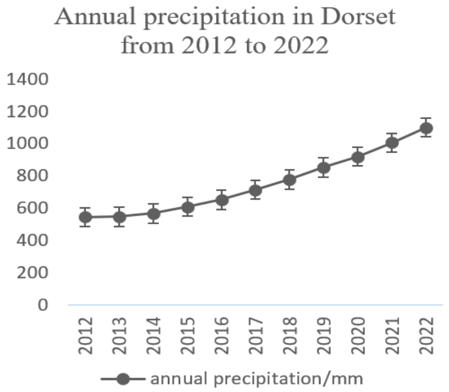

Fig 14. This figure denotes the sustained increase in precipitation in the area, and the rate of growth continues to increase (9%). This indicates the increasing likelihood of landslides.

4.1.3. The human behavior element affecting landslides and the probability of the potential landslide

Human behavior primary effect on the land use, drainage measures and anti-slip structural measures. The land use in Dorset coast is coastal area, recreation tourism farming and industry (Figure15) [13].

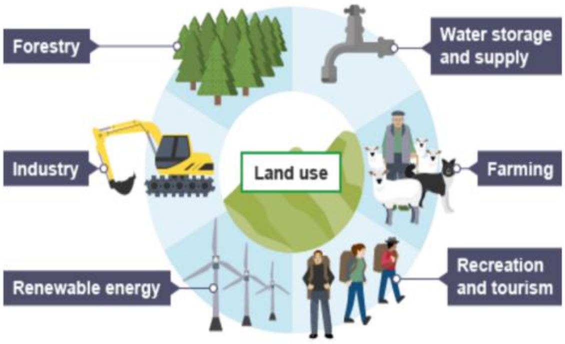

Fig 15. The five of land uses in Dorset mainly increase the potential landslide of risks due to exposed area on cliff.

Between 2012 to 2022 the land use increased to 8% [14]. Simultaneous growth in the frequency of landslides [15]. Natural England was afraid the landslide would cause the casualties and building damage. They collaborated with the government to build drainage measures and anti-slip structural measures [16]. Categorizing landslides caused by historical anthropogenic activities, the probability of anthropogenic activities causing landslides is 0.31.

4.1.4. Calculation landslide risks probability

Both human activity elements and natural facts that impact the landslide is precipitation (0.25). The probability of landslide risk in Dorset area is 0.22. This result shows the main issue caused by the natural elements. In order to decrease the value of the probability of the landslide should decrease the land use and switch to planting more plants instead.

4.1.5. The limitation of the calculation landslide probability

The limitations about this modelling mainly arise from the precipitation uncertainty. It is based on cumulative event rainfall and the intensity of rainfall. Therefore, it is not conducive to establishing an early warning system [17]. The reason is that a change in one of these parameters can cause a disaster to occur. For instance, because precipitation is influenced by the monsoon.

In addition, Due to the unique climatic conditions in southern England, the climate is wet in summer. Precipitation becomes more frequent. This causes the error of the module to become large. In further study, researchers could mainly study the Two-Dimensional Bayesian Probability in the disaster alert. It is important to the combine probability of any two variables or a range. These are principally referenced to the implications of the combination of rainfall intensity, duration, event rainfall and predicted rainfall on the incidence of landslides.

4.2.Evaluation of risks

The disaster risk of the area is expressed in terms of annual value losses. The annual value focuses mainly on loss of life and damage to asset resources. As an example, in 2012, two people died as a result of landslides. A tunnel collapsed. Approximately £2 million of property damage was caused [18].

Risk evaluation table based on differences in annual expected losses and unit risk values (Table.1) [19]. In conclusion, the figures collected will be evaluated by means of a graph. The landslides in the Dorset West Bay have a high-risk level. Furthermore, the government should strengthen environmental management and rationalize land use. Reduce the incidence of landslides through human intervention.

Table.1 Table shows the risk evaluation table. and applies it to the measurement of risk levels.

Risk level	Very high	High	Medium	Low
Average Annual Deaths	>100	<10,>1	0	0
Economic loss (million yuan/year)	>10	<100,>10	<10,>1	<1
Unit Risk	>=0.1	<0.1,>=0.5	<0.05,>=0.02	<0.02

5. Conclusion

Landslides can be regarded as among the most devastating natural disasters because of their reoccurrence, economic costs, and destruction of human lives. In the Dorset area landslides occur depending on the natural elements and human activities.

The result shows that Dorset West Bay have a high-risk level for landslide. In the Dorset region, the main cause of landslides is precipitation. Among the precipitation contains is heavy and slow and continuous rainfall. Furthermore, the methodology used the Bayes' theorem to find the probability of the potential landslide is 0.22. However, Limitations of satellite estimates of rainfall, particularly in resolving the accumulation of peak rainfall, affect the detection of rainfall-triggered landslide events, thus reducing the validity of intensity-time curves. In other side, the model for this prediction is based on cumulative event precipitation and precipitation intensity with statistics of short-term rainfall. Therefore, it is not conducive to an early warning system. Scholars can use the Two-Dimensional Bayesian Probability with more factors in the disaster prediction field in the future study. Moreover, the government should plan the land use in the future and decrease the probability of potential landslide risks caused by human activity.

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