



Effect of Landscape and Climate for Water Sustainability

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Abstract— Climate changes and monitoring landscape is a better interpretation of water used for human life around the world. In order to maximize optimal water use, it is important to study future scenarios of weather conditions. This research assessed the impact of landscape and climate change on water sustainability in the study area. Landscape changes of selected areas from 1988 to 2018 were analyzed and climate changes and drought conditions of the study area were determined. Runoff and groundwater changes were estimated using the Soil Conservation Services curve number. The landscape results show that in the study area between 1988 and 2018, barren land and built-up land increased while water bodies and vegetation cover decreased. The Mann-Kendall test shows a continuously decreasing trend in precipitation, indicates an increase in drought periods, caused more severe and extreme droughts in the last decade (2008-2018).

Keywords— Landscape, sustainability, precipitation, drought, Barren land.

I. INTRODUCTION

In recent decades, the Earth's landscape has obviously and continuously changed as a result of anthropogenic activities and periodic extreme natural processes. Increasing urbanization and deforestation have led to drastic changes in the global environment, such as insecurity in rainfall, increased flooding, frequent droughts, rising temperatures, soil degradation, declining crop yields, and water scarcity [1]. According to a study by [2], population growth, land development, and landscape changes lead to critical problems such as unpredictable rainfall, soil degradation frequent droughts, and water scarcity. Therefore, the landscape development caused by anthropogenic activities and natural factors is of significant importance in the field of water sustainability. Landscape change is one of the major drivers of climate change at regional local and global scales [3], [4] because it alters the climate system by altering surface energy momentum, humidity, and land-atmospheric heat transport, with additional consequences for air movement, temperature rise, and lack of precipitation [5]. In the last three decades, climate changes such as precipitation fluctuations and the increase in the average temperature of the

Lower Dir district have greatly affected the water resources of the area [6].

In recent years, the increase in paved and sealed areas, overexploitation of groundwater, and urbanization have changed the quantitative balance of the hydrological system [7]. Climate change and landscape are adversely affecting groundwater and surface water around the world and most regions of Pakistan will suffer. Lower Dir District is one of the districts in Pakistan where the annual rainfall is sufficient for domestic and agricultural activities, but regular increases in urbanization, change in mean temperature and mean uncertainty of rainfall, and landscape changes have brought about serious changes over the past two decades Problem of surface and groundwater for the local community.

II. MATERIALS AND METHODOLOGY

A. Study area

For the research work, District Dir lower was selected as shown in Fig. 1. District Lower Dir is the lower part of the old District Dir, which lies at a latitude of 34.9161N and a longitude of 71.8097E. Dir Lower is located on the northwest side of Khyber Pakhtunkhwa [8].

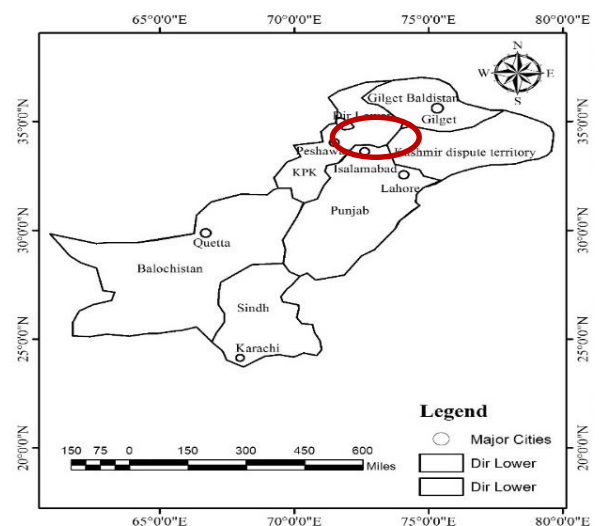


Figure 1: Map of the study area

B. Climate Data

Three types of data sets were used in the study, including landscape images data; Landsat-5 TM for years 1988 and 1998, Landsat-7 ETM+ for the year 2008, and Landsat-8 OLI TIRE for the year 2018 of band color multispectral and path/row 151/036 of 30 m resolution (from USGS), climate data (rainfall and temperature from Meteorology Department) and hydrological data (runoff and water table).

C. Image Processing and Classification

Before any changes were detected, the satellite imagery was reprocessed and the imagery was geo-referenced and processed in ArcGIS for mosaicking and sub-tuning for the area of interest. The delimited classes were vegetation, wasteland, built-up area, and water Table 1.

Table 1: Supervised classification of landscape classes are delineated

S. No	Class name	Description
1	Barren land	Landslide, bare soil
2	Built-up area	Earthen road, residential area,
3	Water bodies	water channel reservoirs, ponds, and rivers
4	Vegetation	Dense trees, green shrubs, grass, and cropland

D. The Mann-Kendall Test

The Mann-Kendall test was used to find the trend of precipitation data in the 30-year data [9], [10]. Ordered data of time series values are evaluated and compared to each data value to form sequence data values. Mann-Kendall S statistic, initial value not to trend, if the value in the latest period statistical data is higher than a statistical data value from an initial period, S is increased by one value from an initial period, S is incremented by one value. Similarly, if the value of the statistic from an end period is less than an initially tested data value, S is decremented by one value. The value of the final S statistic depends on the result of decrementing and incrementing data.

E. Sen's Slope (Ss)

The magnitude of the slope can be obtained using the method of Sen's slope [11].

$$Y_{sen} = \text{Median} \frac{(X_i - X_j)}{(i - j)} \text{ for all } i > j \quad (1)$$

Where x_i are x_j are data points at i and j time, respectively

F. Normalized Difference Vegetation Index (NDVI)

This study uses the NDVI method to examine Landsat TM images from 1988 to 2018 at 30m resolution obtained from the

United States Geological Survey website Earth Explorer (<http://earthexplorer.usgs.gov/>). After registration in USGS, Landsat imagery was extracted from the (USGS) and geo-corrected. The NDVI index with a positive value relates to different types of vegetation rates, while a negative value indicates limited vegetation and a zero value of the NDVI indicates water bodies.

$$NDVI = \frac{(\text{Near infrared} - \text{Visible infrared})}{(\text{Near infrared} + \text{Visible infrared})} \quad (2)$$

G. Standardized Precipitation Index (SPI)

This study used a specialized software called DrinC (Drought Indices Calculator), which provides a simple interface to calculate drought severity. Therefore, to distinguish the drought period of the study area, the SPI technique was applied to a 3-month drought period.

$$f(x) = \frac{1}{\beta^\alpha \Gamma(\alpha)} x^{\alpha-1} e^{-x/\beta} \text{ for } x > 0 \quad (3)$$

For $\alpha > 0$ is a shape parameter, $\beta > 0$ is a scale parameter and $x > 0$ is amount of precipitation. Gamma function is $\Gamma(\alpha)$.

H. SCS-CN Method for Runoff Estimation

Over the past decade, it has been widely recognized that runoff has undergone significant changes due to the combined effects of landscape changes and climate variability [12]. In the ecological environment, these changes posed a major challenge for water resource managers and hydrologists [13]. Stormwater overestimation is one of the fundamental hydrological challenges faced by engineers and hydrologists [14]. For the estimation of excess water, the Natural Resources Soil Conservation Curve Number (NRCS-CN) (commonly Soil Conservation Service (SCS)-NC model) utmost commonly used by the researcher.

Table 2: Runoff curve number (AMC-II) for hydrological soil covers [15]

S. No.	Landscape Classification	Hydrological Soil Group			
		A	B	C	D
1	Double Crop	62	71	88	91
2	Plantation	45	53	67	72
3	Agriculture	72	81	88	91
4	Industrial	81	88	91	93
5	Commercial	89	92	94	95
6	Scrub forest	33	47	64	67
7	Urban area	89	92	94	95
8	Village	72	82	87	91
9	Canal	100	100	100	100
10	River	97	97	97	97
11	Quarry	71	77	89	91
12	Prosopis	61	70	74	78
13	Reservoir	100	100	100	100

III. RESULTS AND DISCUSSION

A. Validation and Classification of Landscape Maps

The landscape maps are generated using a maximum likelihood supervised classification and post-classification algorithm. The classified landscape maps of the study area from the years 1989, 1998, 2008, and 2018. The overall accuracy of the classified maps was 92.32%, 95.43%, 90.52%, and 94.73%, while the kappa statistic was 0.924, 0.951, 0.903, and 0.923 for the classification of the 1989, 1998, 2008 maps, respectively and 2018 respectively. Therefore, according to [15], the required overall classification accuracy of 90% via 0.90 and the statistical value of kappa of 0.90 were effectively achieved in the current study.

The classified summarized results of 1989, 1998, 2008, and 2018 are presented in Table 1. The results of the percentage classes show that landscape changes in the study area were observed in the years 1989, 1998, 2008, and 2018. The result shows that the water bodies in terms of area coverage in the study area show a significantly degraded part, while the vegetation area decreases, while the barren and built-up area also increases. The vegetation shrinks from 50% to 28% of the total area. Also, bodies of water that were considered the least classified area in 1988 continued to lose the cover, shrinking from 9% to 3% of the total area in 2018. The built-up area in 1988 is 20% of the total area, which is increasing tremendously and 43 % of the total area. Similarly, barren land was increased from 21% to 26% of the total area.

The results of each class from 1988, 1998, 2008, and 2018 showed that a noticeable landscape change was observed over the 30-year period. Similarly, the increase in built-up area from 1988 to 2018 in terms of percentage of covered area and increase in vegetation class in area by 26% and 43%, respectively, shows that major anthropogenic activities amplify landscape changes. Anthropogenic activity not only reduces deforestation but also the water bodies in the region. This shows that livelihoods, the sustainability of water resources in the region, are under severe threat.

The built-up area includes a residential area, a dirt road, a land-side vacant area, a school, a park, which has an area increase of 23% in terms of the total area coverage of the study area. This increase in built-up area indicates that built-up areas are undergoing extensive deforestation in the form of forest cover and crop degradation, leaving the land surface exposed and barren. Soil loss caused by anthropogenic activities results in less-yielding lands that were eventually maximized on crop yields by agronomists due to financial incompetence, resulting in a huge intensification of built-up area and fallow land. The statistics shown by the classification results showed that the water class coverage area decreased from 1988 to 2018. The reduction in the coverage percentage of the landscape-covered class was 72%. The water classes have been severely affected due to landscape changes observed over the last three decades of the study area. In addition, either barren land or compact surfaces affect easy water availability, as a result of which sustainable water depletion occurred in the study area. Another reason for the water reduction was the lack of plant roots, which

hold water and avoid an increased surface runoff. Most of the changes are due to agricultural intensification and human intervention. In addition, there was a lowering of the groundwater level in the study area due to the runoff effect.

Table 3: Landscape classes (1988-2018) proportionate area in percentages

Landscape classes	1988	1998	2008	2018
Barren land	21	23	24	26
Vegetation	50	45	37	28
Water bodies	9	8	6	3
Built up area	20	25	33	43

B. Rainfall Trend on Seasonal and Annual Scale

To find the annual and seasonal trends of precipitation, monotonic trends are not suitable for detecting changes. Analogous to monotonic, a nonparametric test that depends on time series data while not specific to the hypothesis that the probability distribution belongs to arbitrary data is useful.

C. Annual Rainfall Trend Analysis

The 30-year average annual precipitation trend were calculated, which shows that the total annual maximum precipitation (1761.3 mm) was recorded in 2005, while the total minimum annual precipitation (569 mm) was recorded in 2016 during 30 years. The average annual rainfall of 30 years is 1175 mm. The positive value of Z and Sens slope (Q statistic) showed that there is a decreasing trend with decreasing precipitation tendency on an annual basis. Mann-Kendall statistics $S=269$ indicate a decreasing trend in annual precipitation data, with the absolute value of $ZMK=4.78$, which is greater than $Z=196$ at 5% of the significance level. Therefore, the null hypothesis is rejected at 95% of the confidence level, identifying a gradually decreasing trend in the annual mean precipitation data. The Sens slope $Q = 2.86$ mm data size, indicating that there was a 2.86 mm decrease in precipitation each year

D. Normalized Difference in Vegetation Index

Landscape activities mostly change land cover spatially and temporally. The main feature responsible for changing the landscape is due to increased agricultural intensification and overpopulation to meet growing human food needs, clearing of natural landscape covers for commercial activities, and forests for settlement. The change in the landscape also disturbs other natural components such as soil erosion, soil fertility, biodiversity, ecology, water balance, and air quality of the disturbed area. Concerns about the landscape change received significant attention after recognizing the impact of the change on the area's ecosystem and climate. In this study, four images (1988, 1998, 2008, and 2018) were classified based on the Normalized Difference Vegetation Index (NDVI).

E. Drought detection using Standardized Precipitation Index

The SPI for drought detection is a widely used index in different parts of the world and is considered to be the most appropriate and most accurate in the Asian region [16]. In the study area, the maximum precipitation occurs in the winter season and the monsoon season, showing high seasonal variability from each month. In this study, drought indices were calculated in 3 months, since a lack of rainfall in this month is a common climate feature and a time step for determining a month does not adequately describe the situation of a drought period. To understand the severity of drought events, calculating the drought index value helps to better represent the drought situation.

Annual average precipitation and annual SPI results are compared with the statistical data. Therefore, the results are analyzed linearly, finding R2 values of 0.6322 for the annual mean precipitation (mm) and 0.6331 for the annual SPI result. Therefore, the R2 values for both annual mean precipitation and annual SPI are nearly the same, indicating that the SPI technique can be successfully used to monitor drought conditions in the area. Similarly, the actual precipitation and SPI values of different years were analyzed and the precipitation deviation from the normal precipitation distribution in the study area was determined. The first decade of the study area has a lower number of droughts than the second, while the last decade is the worst in terms of an exceptional number of droughts. Overall, the comparative analysis of the precipitation and SPI results shows that the SPI index can provide a better indicator of the drought situation than the precipitation variance method.

F. Runoff of the study area

The characteristics of the landscape in an area influence all these activities, the proportion of precipitation affecting each of these activities varies depending on the landscape change. Increased urbanization, reduction in vegetation, and increase in sealed strata reduce bare ground exposure and result in increases in runoff water. In the investigation area calculation, the landscape change and its influence on the surface runoff is determined using the soil protection service method.

CONCLUSION

This study examined the landscape and climatological variability of Lower Dir District, Pakistan based on landscape classification, normalized differential vegetation index (NDVI), and standardized precipitation index (SPI) using precipitation data associated with temperature. Based on the NDVI assessment, dense forest and agricultural area is decreasing. Using the Mann-Kendall statistic, the precipitation trend decreases when the absolute value of $ZMK = 4.78$, which is greater than $Z = 1.96$ at 5% of the significance level. The Sens Slope value $Q = 2.86$ mm shows that precipitation decreases by about 2.86 mm each year. This reduces the outflow.

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