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The Analysis of Coal Mining Impacts on West Virginia's Environment

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Authors' contributions

This work was carried out in collaboration between all authors. Author CEM designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Authors PI, JW and EN managed the analyses of the study. Authors CR and SF managed the literature searches. Authors SI and MC assisted with library searches. All authors read and approved the final manuscript.

Original Research Article

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ABSTRACT

Aims: The paper analyzes the impacts of coal mining activities on West Virginia's environment using GIS.
Study Design: Adopted a mixscale appoach.
Methodology: The aproach is applied to GIS and primary data connected to descriptive statistics by analyzing the impacts of mining with data collected at the state, county and watershed level.
Place and Duration of Study: The coal producing counties of West Virginia May 2010-December 2012.
Results: The study shows changes in coal production, and widespread degradation resulting in land loss and open space, impacts on mountain ecosystem and water quality decline in the head waters and human casualities.The spatial analysis revealed the dispersion of mining activities onto senstive environments comprising of streams and mountain ecosystems.

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Conclusions: The assessment of these trends and the capability of GIS in pinpointing them enhanced our research and understanding of ecosystem vulnerability in the face of recurrent degradation induced by mining. GIS also provided a framework for assessing ecosystem decline. To remedy the problems, the paper offered suggestions ranging from corporate code of ethics to improved data infrastructure and more use of GIS in environmental decision making.

Keywords: West virginia; coal mining impacts; environmental degradation; GIS; factors; mountain top clearance.

ABBREVIATIONS

WVMHST: West Virginia office of Mines' Health, Safety and Training.
NASA: National Aeronautics and Space Administration.
SMCRA: Surface Mining Control and Reclamation Act of 1997.
EPA: Environmental Protection Agency.
US: United States.
GIS: Geographic Information Systems.
MTR: Mountain Top Removal.
Geospatial Analysis: A comprehensive guide to principles, tools and techniques, including the full spectrum of spatial analysis techniques and GIS software.
Spatial Analysis: A study in depth of the patterns, lines, areas, and surfaces depicted on maps of some sort.

1. INTRODUCTION

1.1 Background

For over a century, coal stood as the major resource driiving the economy of West Virginia [1]. In the process coal mining generated jobs and a large part of the state's revenue [2,3]. Being a center piece of West Virginia's economy, in the 2010 fiscal year alone, the coal industry payed about $1.6 billion in salaries [4]. With its history, mining operations in the state accounted for the production of approximately13.4 billion tons of coal between 1880 to 2009. However, coal deposit in the state is now in constant decline with reccurent ecosystem degradation [4,5,6].These impacts on the ecosystem must be analyzed with GIS.

With 2,636 mountain top removal (MTR) permits distributed in the state between 1986 to 2001[7]. MTR and other types of mining built on machines and explosives continue to demolish mountainsides and the environment [8]. In 2007 alone in West Virginia, they accounted for 42 percent of all coal extracted. With much of the mining activities occurring adjacent to sensitive habitats for rare species, ecological externalities from mining degrade water quality and the surrounding ecosystem. Given the continual destruction of biodiversity rich Appalachian mountain peaks in the state by explosives and giant machines used by the industry. State officials in 2009 reported more than 16,000 safety violations that impacted the environment [6]. Consequently, West Virginia has about 4,391 abandoned mines with 1,180 of them linked with water degradation [2].

Notwithstanding the gravity of the issue, very little has been done to track the problems with Geographic Information Systems (GIS) in West Virginia. However,GIS has found widespread appeal in other studies on watershed degradation and landscape change over the years [9,10,11,12,13,14,15,16,17,18,19,20,21,22,23]. Similar studies along those lines by Bisaws [24], Prakash [25], Usery [26] and Khawlie [27] reinforce the essence of these themes.Seeing the benefits in the analysis of water quality issues, managers are using GIS to monitor various land uses in a watershed [28]. In realizing these benefits, scholars are channelling their GIS data management expertise towards the calibration of watershed and water quality models [26].

Many studies exist in the literature with focus on watershed protection using GIS. In implementing a framework for modelling the impact of land use practices on groundwater in watersheds, Almasri and Kaluarachichi used GIS to identify spatial dispersion of ground nitrogen sources and the resultant loadings [29]. Russell examined the role of GIS in selecting sites for riparian restoration based on hydrology and land use [30]. Elsewhere Liu developed a GIS interface that integrates soil and water assessment tool for estimating water quality benefits in watersheds [31]. Philippe combined cartographic modelling tool using GIS and statistics to measure the links between water quality, land use, and distance from stream on a watershed [32]. Furthermore, Davis focused on water issues and GIS analysis of land use composition in catchment areas [33]. Despite this array of studies, there is very little on the ecological impact analysis of coal mining in West Virginia using GIS.

With this void in the litterature, mining operations remain active in various areas of the state with growing threats that could be pinpointed for effective management using GIS (Fig. 1). This has generated concerns on the impacts of mining from the coal field sites of West Virginia. The effects ranged from non-point sources of pollution, impairment of stream and watershed quality, land loss and environmental health threats [34,35,36,37,38]. The problems of mining hazards do not operate in a vacuum; they emanate from many socio-economic elements. In light of current impacts of mining, this paper will fill that void in research.Accordingly, this paper analyzes the impacts of coal mining activities on West Virginia's environment using GIS. The emphasis is on the issues, factors fuelling the problems, environmental analysis, mitigation efforts and future actions. The paper has two objectives. The first aim focuses on the use of spatial technology in analyzing the effects of coal mining activities on the environemnt, while the second objective is to generate a tool for environmental management researchand decision making.The sections in the paper consist of the introduction, the materials and methods, the results, discussions and the conclusion.

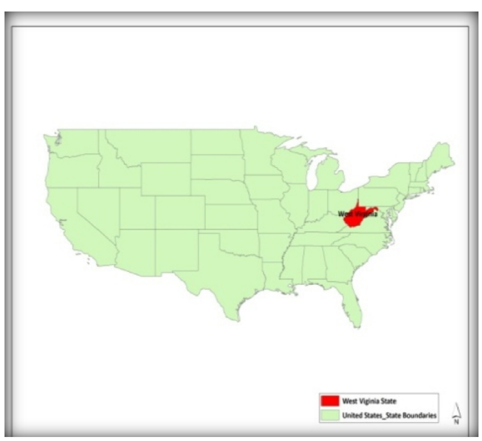

Fig. 1. The Study Area

2. MATERIALS AND METHODS

2.1The Study Area

West Virginia is located in the Applachian region of southern US with over 55 counties as well as many watersheds and wetlands Figs. 1-5. The state had a population of 1.8 million in 2009 and boosts of immense sceneries of sparkling water, fresh air and opulent green mountains and streams. West Virginia's northern panhandle contains the most diverse temperate hardwood forest. The hillsides provide habitats to many species in the southern Appalachian than any other area [35] but, biodiversity is being threatened by the impacts of coal mining Fig. 2 [38,39]. Being one of the major resources in West Virginia's economy [2,3] coal occurs in 53 of West Virginia’s 55 counties [6]. The economic benefits of the industry stems from tax revenue generation which stood at $684 million or 10 percent of the total in 2008 [4]. For more on the economic benefits of coal in the state, see Table 1.

Fig. 2. Image of Moutaintop Removal Mining.
Source: SOCM.org, 2013

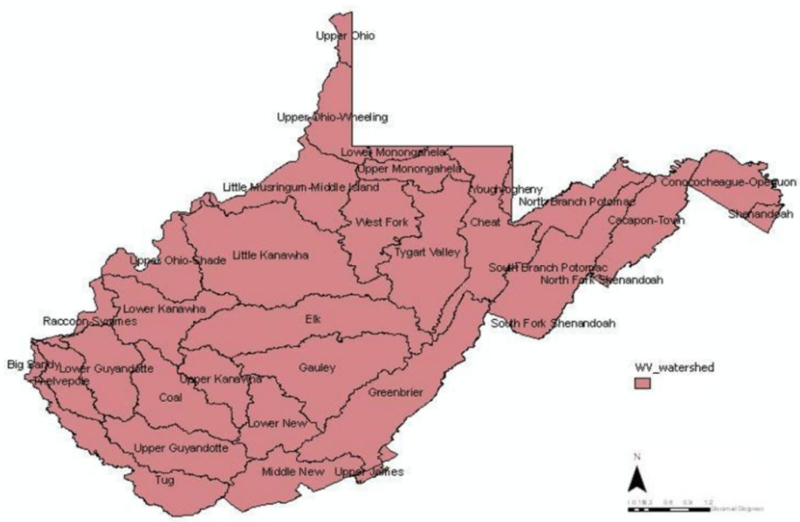

Fig. 3. Watersheds of West Virginia. Source: West Virginia GIS technical Center, 2009

In the last decades, mining safety and ecological concerns have emerged among the challenges facing the state. The environmental impacts of coal production has become so pronounced that there are now large presence of heavy metals in surface and ground water as well as watersheds adjacent to mining fields Fig. 3 [34]. To understand the impacts of mining on water bodies in West Virginia, let us not forget the presence of mining sites close to streams and the vulnerability of wetlands. From the geographic distribution of the mine sites in Fig. 4. It is evident they are visible in the northern and southern part of the state. Their presence alongside sensitive water bodies imply risks to stream ecology than the areas where mining activities are less diffused.

Table 1. The Economic Importance of Coal in West Virginia in 2008

Economic Impact of Coal Mining NAICIS 2121 In The West Virginia Economy 2008. (2008 Dollars)			
Variables	**Direct**	**Indirect and Induced**	**Total**
Best Volume sales, Billions $	$7.45	$12,30	$19.78
Total Value Added billions $	$4.06	$1.87	$5.93
Employee Compensation	$1.95	$0.87	$2.82
Employment jobs	20,500	25,600	46,000

Source: The Bureau of Business and Economics Research, 2010. West Virginia University

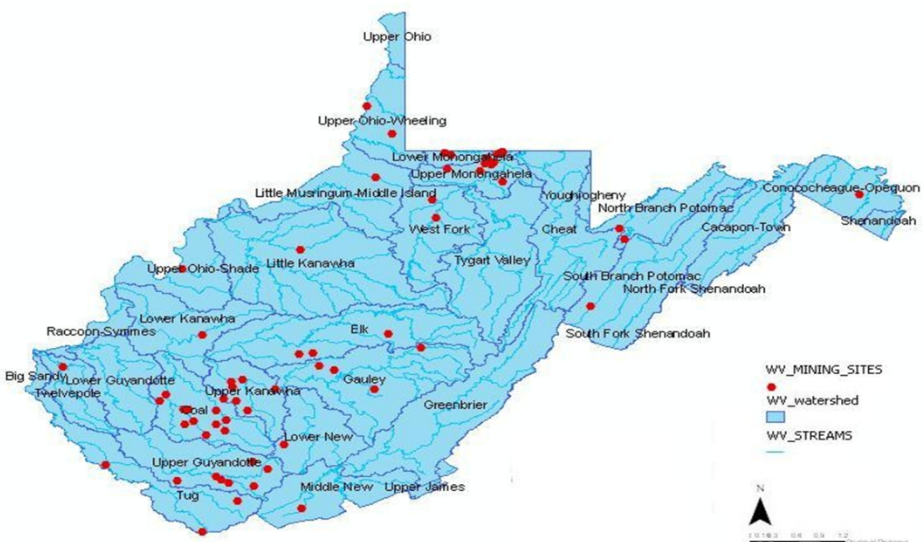

Fig. 4. The Locations of West Virginia's Mining Sites. Source: EPA 2009

Notwithstanding their sensitivity to degradation, wetlands locations as shown in Fig. 5. are essentail in the life of most communities.Over the years in West Virginia, these ecological features are being degraded regularly due to the by-products of mining including heavy metals and others. With very little understanding of the gravity of accumulated impacts, GIS anlysis provides a tool for understanding the spatial patterns of mining impacts on fragile waterbodies including watersheds and the environment.

Fig. 5. Wetlands of West Virginia. Source: West Virginia GIS technical Center, 2009

2.2 Methodology

The paper uses a mix scale approach involving descriptive statistics and primary data connected to GIS. The spatial information for the research was obtained from the West Virginia On line Technical Data, the National Aeronautic and Space Administration (NASA), West Virginia GIS Clearing House, The Governemnt of West Virginia, the West Virginia Department of Natural Resources office and the EPA. The West Virgina office of Mines' Health, Safety and Training (WVMHST) provided coal data for the periods of 1996-2010. Federal geographic identifier codes for the counties were used to geo-code the information contained in the data sets. This information was analyzed with basic descriptive statistics, and GIS, with particular attention to the temporal-spatial trends at the county and watershed level. The relevant procedures consist of two stages.

2.2.1 Stage 1: Identification of variables, data gathering and study design

The first step involves the identification of variables needed to assess degradation in areas adjacent to coal mines. The variables consist of number of mining sites, number of watersheds, impaired water bodies, cathegories of pollutants like biological elements, pH, metals, and percentages of pollutants. Others are coal shipment and consumption, land, acres of MTR, species richness, degraded habitats and deaths from mining. Additionally, access to databases that are available within the Federal and state archives in West Virginia and other agancies quickened the search process see Tables 1-4. The process continued with the design of data matrices for socio-economic and land use (environmental) variables covering the periods from 1980, 1996 to 2010, 1950 and 1976, 1969 and 2009 to 2012. The design of spatial data for the GIS analysis required the delineation of county and watershed boundary lines and species habitats. With boundary lines unchanged, a common geographic identifier code was assigned to each of the units to ensure analytical coherency.

2.2.2 Stage 2: Step 2: data analysis and gis mapping

In the second stage, descriptive statistics and spatial analysis were employed to transform the original socio-economic and land-use data into relative measures (percentages/ratios). This process generated the parameters for establishing degradation and change on the landscape in areas devoted to mining. This was facilitated by measurements and comparisons of the trends over time. While this approach allows for change detection, the tables highlight stressors, indicators of degradation, coal use and deaths. The remaining steps involve spatial analysis and output (maps-tables-text) covering the study period, using ARCVIEW 9. The spatial units of analysis consist of coal mining counties of the state and their watersheds. The geographic data for West Virginia which covered its watersheds and counties, also includes pollution and ecological data of land cover files of wetlands, watersheds, paper and digital maps from 1996-2004 as well as NASA Satelite images of 1984 to 2012. These Satelite images are only for an abbreviated analysis and illustration of change in Hobet 21 mines. There is no attempt here to describe the processing of the photo images. The outputs of the spatial data were mapped and compared to see the dispersion of stressors and the socio-economic factors fuelling environmental degradation.

3. RESULTS AND DISCUSSIONS

This section presents the results and discussions. There is an initial focus on the analysis of coal use, land use impacts, percentage of change and pollution analysis. This is followed by the human hazards of mining, factors, efforts and spatial analysis.

3.1 Results

3.2.1 Coal use 1996 to 2010

The temporal profile of coal use based on total tonnage, total shipments, local consumption and the rates of declines over the years is provided herein. In looking at the table, one notices that all three cathegories from total tonnage to used tonnage declined in West Virgina from 1996 to 2010. During that period, the state saw its quantity of coal production, the amount distributed and the tonnages consumed change from 174, 008, 217 to 172, 762, 769 and 356, 852 to 158, 835, 504, 147, 719, 307 and 342, 1054. This represents a change of 75%, 87%, to 54% repectively. From the period of 2008, note that the production of coal dropped from 1996 levelts to 162, 750, 817 Table 2.

Another important point worthy of note in 2010 touches on the reccurent drops in coal production, the amount distributed and those consumed internally in West Virginia. During the 2010 period, the declines in the tonnages of coal produced, distributed and cosumed went from 142, 944, 106, 122, 880, 676 to 886, 867 tons. Notwitstanding the fact that the state's production levels and export totals of 180, 794, 012 to 169, 918, 795 in 1998 exceeded the other years, the people of West Virginia only used 22, 460 tons of coal, the lowest in the entire periods. While this is lower than the 2002 period when local use reached its highest level of 12, 503, 110 tones, coal demand in West Virginia fluctuated regularly Table 2.

Table 2. Sumary of Coal Production and Distribution

Year	Coal Production and Usage In West Virginia 1996-2010		
	Tonal Tonage	**Total tonage shipped**	**Total used locally**
1996	174,008,217	172,762,769	356,852
1998	180,794,012	169,918,795	22,460
2000	169,370,602	155,902,023	399,034
2002	163,896,890,	153,597,899	12,503,110
2004	151,683,473	146,648,726	5,936,098
2006	158,835,504	147,719,307	3,421,054
2008	162,750,817	154,753,525	984,673
2009	144,017,758	130,332,049	1,025,080
2010	142,944,106	122,880,676	886,867

Source: WVMHST, 2010

3.2.2 Land use impacts from mining

To understand ways in which mounting top removal mining has impacted West Virginia's environment, consider the available land use statistics from 1950, 1976 and 2002. The temporal distribution of land use trend covers five different land types: developed, agricultural, open space, forest land area and disturbed areas with some mining. From the trends, it is clear that land for development in 1950, grew from 42, 533 acres to 135, 566 in 1976 until it climbed further to 154, 966 acres in 2002. From the data, open farmland in the area fell from the all-time high of 950, 135 acres in 1950 to 188, 363 in 1976, 246 and 082 in 2002. During this period, forest size jumped from 3, 873, 619 to 4, 450 and 580 only to drop by 4, 284 and 141. The size of disturbed land areas also grew from 3, 015 acres to 85, 598 and 73, 502 in 2002 Table 3.

Table 3. Summary of Land Use Statistics for West Virginia Mountain Top Removal Region

Land Use	Area (acres)			Percentage Changes		
	1950	**1976**	**2002**	**1950-1976**	**1976-2002**	**1950-2002**
Developed	42,533	135,566	154,966	218	14.3	264
Agricultural/ Open	950,135	188,363	246,082	-80.5	30.6	-74.1
Forest	3,873,619	4,450,580	4,284,141	14.8	-3.73	10.5
Disturbed (some mining)	3,015	85,598	73,502	2739	-14.1	2337

On the percentages of change, developed land grew by double digits with an exception in 1976-2002 when it stood at 14.3%. In the other periods, farmland and open space dropped by 80.5 to 74.1% but only to grow by 30.6% in 1976-2002. While forest area showed signs of identical gains of 14.8 to 10.5%, there was a notable decline of 3.73%. This was followed by significant growth rates for disturbed areas most of the time Table 3. Regarding the actual land use changes, during the periods of 1950-976, 1976-2002 and 1950–2002, the changes in the size of developed land stood at 93, 033, 19, 400, and 112, 433 acres respectively. At the same time, agricultural land loss reached -761, 772 acres, and continued with a gain of 57, 719 and further declines estimated at -704, 053 acres. In all those years, the MTR coal region posted slight increases (of 576, 961, 410, 522 acres) followed by losses totalling -166, 439 acres. The disturbed land areas which were initially valued at 84, 583 acres in 1950 -1976, fell to -12, 096 in 1976 –2002. Between 1950 to 2002, the size of disturbed land areas climbed to 70,487 acres Table 4.

Table 4. The Land Use Changes In West Virginia

Land Use Changes	Area (acres)		
	1950-1976	1976- 2002	1950-2002
Developed	93,033	19,400	112,433
Agricultural Open	-761,772	57,719	-704,053
Forest	576,961	-166,439	410,522
Disturbed (some mining)	82,583	-12,096	70,487

3.2.3 Mountain top removal mining and impacts

The impact of MTR among the four coal producing states in the Appalachian region adds another dimension to the analysis herein. The table containing three ecological indicators of size, number of mountains impacted and the percentages shows a troubling trend on the health of mountain top ecosystem and the threats to biodiversity found in the area. The total size of disturbed areas based on the table indicates Kentucky and West Virginia had 574,000 to 352,000 acres. The fact that these numbers surpassed the 156,000 to 78,000 acres cleared in Virginia and Tennessee shows the first two states as the most active places in MTR practice in the region. In the context of the study area, the entire region alone lost 1,160,000 acres covering about 501 mountains Table 5. Of the overall acres of mountain tops removed, the states of West Virginia and Kentucky accounted for almost 80% percent combined compared to 20% for both Tennessee and Virginia. The interesting point is that West Virginia ranked second in every statistical category of MTR practices in the region.

Table 5. The Distribution of Mountain Top Removal Acreage

Mountaintop removal mining impact study results by state				
Rank	State	Size	Number of Mountains Impacted	The Percentages
1	Kentucky	574,000 acres	293 mountains	49.51
2	West Virginia	352,000 acres	135 mountains	30.34
3	Virginia	156,000 acres	67 mountains	13.44
4	Tennessee	78,000 acres	6 mountains	6.72
Total		1,160,000 acres	501 mountains	100.00

Source: Appalachian Voices. 2012 c

Considering the risks to adjoining ecosystems, there are problems with air pollution resulting from the airborne movement of dusts, exposure to radioactive contaminants and geological residues. Other threats come from the damage to natural areas providing the life support system essential for the survival of different species. The vast clearance of mountain top habitats and forests also trigger biodiversity loss and the disppearance of rare species of flora and fauna. It has been estimated that since 2003, about 1.2 million hectares of land were lost to MTR [36]. In fact in May 2009, Mingo county and communities adjacent to south West Virginia coal mines witnessed one of the most deadliest floods.In the absence of trees in these circumstances to hold water and to act as a barrier, flash flooding in the adjoining communities becomes very life threatening [35]. With MTR mining waste known to hold chemical compounds usually found in coal and rock. Runoffs containing heavy metals such as lead, aluminum, chromium, manganese, selenium and inpure water from the slurry pools that wound up downstream, inflict further damage by polluting aquatic environments. This is compunded by the presence of abandoned mines and fragile impoundments containing toxic residues on MTR sites.

3.2.4 The pollution impacts on the watersheds

To understand pollution among the watersheds, one must consider the totals, the number of mining sites, the main pollutants and the number of impaired streams over time from 1996-2004. The most common types of pollutants in the area consists of biological, pH and metals Table 6. Their presence as indicated in the table are in the order of 9 for biological pollutants, 7 for pH and 4 for metals. Seeing that the total number of mining sites from which the pollutants originate stood at 65 during the periods of 1996, 1998, 2002 and 2004. The cases of impaired streams rose from the initial value of 1586, in 1996 to 2676 in 1998. Between 2002 to 2004, the numbers jumped further to 5389 and 4924 Table 6. The breakdown of the trends point to the presence of biological pollutants along the upper Monogahele watershed. Being the area with major mining sites estimated at 13, Monogahele saw its number of impaired streams from biological pollutants which stood at 56 in 1996 grow to 128 in 1998, and 182 in 2002 to 2004. At the same time, metals remained quite rampant in four other watersheds (the Upper Kanwaha, Coal, Upper Guyandatte and Twelvepole). The estimated number of mining sites in these watersheds were in the order of 7, 11, 1 and 7 respectively. Along the Upper Kanwaha watershed, the number of impaired streams between 1996 to 1998 grew from 250 to 319 and continued in the next periods. At Coal watershed, the number of impaired streams with metals remained high Table 6. See Appendix A for more on watershed impairments.

Table 6. Environnmetal Pollution of Watersheds From Mining

Watershed	Mining sites Number	Pollutanat	Impaired streams 2004	Impaired streams 2002	Impaired streams 1998	Impaired streams 1996
Conocochegue	1	Biological	226	226	30	0
Northbranch	2	Biological	109	115	98	53
South branch	1	pH	191	191	128	27
Lower Monogahele	2	Biological	146	146	37	36
Upper Monogahele	13	Biological	182	182	128	56
West fork	2	pH	333	375	284	258
Upper ohio-wheeling	2	pH	287	287	112	37
Little Musringum middle island	1	Biological	118	118	16	14
Little Kanawha	1	pH	303	308	235	66
Upper Ohio-shade	2	pH	287	287	112	37
Elk	3	Biological	358	383	199	96
Gauley	4	pH	162	200	141	112
Upper Kanawha	7	Metals	402	417	319	250
Coal	11	Metals	671	729	133	80
Twelve pole	1	Metals	67	77	19	10
Tug	3	Biological	222	307	184	148
Upper Guyandatte	7	Metals	286	427	328	242
Middle New	1	Biological	292	310	38	29
Lower new	1	pH	228	228	94	28
Lower Kanawha	1	pH	67	89	65	33

3.2.5 Pollution analysis

Another dimension to the analysis is that of the 21 watersheds in the study area, metallic elements from 26 mining sites are discharged into adjacent stream habitats (Table 7). As mentioned before, such practices have far reaching consequences on the surrounding ecosystem. From the table, these numbers represent about 40% of all mining activities in the designated watersheds in the area. In terms of the percentage distribution of stream impairment, the four watersheds where metallic effluents are rampant accounted for 36.69% to 29.85% of impairment cases between 1996 to 1998. In other years, the percentage of impaired streams attributed to metals went from 30.61% in 2002 to 28.96% in 2004. Of all the watersheds Coal, Upper Kanwaha, and Upper Guyandatte emerged as the hotbeds of stream pollutions attributed to coal mining than the Twelve pole watershed. Their levels of toxicity are high enough to damage stream quality and habitats for marine organisms. With such frequency of pollution, iron and manganese concentration in water exceeded drinking water standards in 40% of wells in the Appalachian plateua and in 70% of wells adjacent to reclaimed surface mines [36]).The same can be said of nearby downstream waters where conductivity levels remained high due to cases of hardness and selenium presence as well.

Table 7. Comparative Pollution Aanalysis Metal Vs Other Pollutants

Watershed	Sites	Pollutant	Impaired stream 2004	Impaired stream 2002	Impaire stream 1998	Impaired stream 1996
Upper Kanawha	7	Metals	402	417	319	250
Coal	11	Metals	671	729	133	80
Twelve pole	1	Metals	67	77	19	10
Upper Guyandatte	7	Metals	286	427	328	242
Total	26	Metal pollutants	1426	1650	799	582
Overall Total	65	All pollutants	4924	5389	2676	1536
Total %	40	NA	28.96	30.61	29.85	36.69

3.2.6 The human hazzards of mining 1980-2010

The human costs of mining is a recurrent trend in West Virgina. This can be buttresed from the data on Table 8. Since the 1980s, West Virginia's coal producing counties have experinced reccurent hazards attributed to mining. This has resulted in the death of about 61 people in different locations of the state. Being incidents originating from coal producing companies, they involve gas explosions and other hazards leading to loss of lives. Aside from the single digit number of fatalities during the 1980s to the early 2000s, the state experienced double digit casualties numbering 12 to 29 deaths between January the 2nd in 2006 to April the 5th of 2010. No matter the size of these accidents, they impacted the natural and built environment through the emission of toxic chemicals and the loss of lives.

Table 8. The Hazzards From Mining In West Virginia 1980-2010

Date	Company	Mine	Location	Nature of Accident	Nube of Victims
Nov. 07, 1980	Westmoreland Coal Co.	Ferrell	Uneeda	Gas Explosion	5
Dec 03, 1981	Elk River Sewell	Sill House No. 1	Bergoo	Roof Fall	3
Feb 06, 1986	Consolidation Co	Love ridge No. 22	Fairview	Coal storage entrapment .	5
Mar 19, 1992	Consolidation Co	Blacksville No. 1	Wana	Explosion in Shaft	4
Jan 22, 2003	Central Cambria Drillling	Mcelroy Mine	Graysville	Explosion in Shaft	3
Jan 2, 2006	Anker WV Minning CO	Sago Mine	Tallmansville	Explosion and Entrapment	12
Apr 5, 2010	Performance	UbbmcMontcoal Eagle	Noama	Explosion	29
Total	Mining Accidents from Various Locations In West Virginia				61

Source: WVOMHST, 2010

3.3 Factors Influencing Degradation

The incidence of degradation from mining and the threats to watersheds do not operate in a vacuum. They emanate from socio-economic elements. This section identifies the factors fuelling degradation (See Appendix B). Notwithstanding the problems of degradation from coal mining in West Virginia, there are concerted efforts to minimize the impacts. Several initiatives ranging from the mobilization of environmental groups to land reclamation efforts are described briefly in Appendix C. For more on the factors and the efforts see sub sections 3.3-3.4 in Appendix B and C.

3.4 The Spatial Analysis

Aside from scatterd patches of impaired areas vissible from the northern to southern part of the state in 1996. The emergence of a broader thread of impaired streams at a much visiblescale compared to the north east and north west areas of the map raffirms current concerns. The spatial dispersion as shown in the map stretcthed through West Folk and Tygart Valley. Further along the lower and south central parts, one notices a gradual concentration of impaired streams on Upper Guyandatte and Upper Kanawha. Considering that the levels of impairment from mining are toxic enough to degrade water quality, watersheds in those areas are pushed beyond their carrying capacity Fig. 6. Knowing the nature of runoffs from their sources and the pace at which coal related pollution occur in the mining counties of West Virginia, the study area experienced a slight dispersion of impaired streams in 1998.

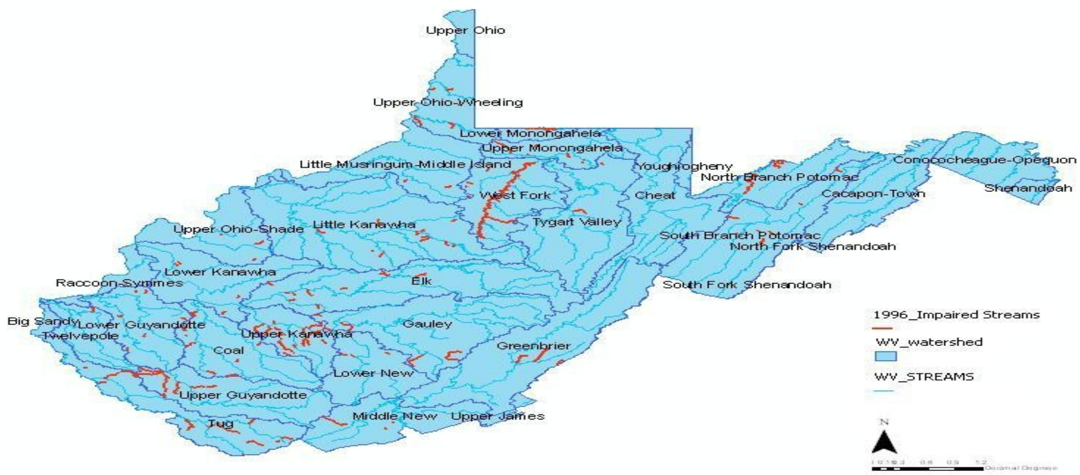

Fig. 6. Impaired Streams In West Virginia In 1996. Source: EPA 2009

With stream impairment apparent in areas where they were known to occur in the previous period of 1996, it is clear, degradation continued into areas where they did not occur previously. As a new entrant, Little Kanawha saw its share of impairment stretched deeper into the adjacent boundaries. The same can be said of Upper Kanawha and the northern areas including Upper Ohio, Upper Wheeling and Shenandoah where the head waters and streams experienced degradation from coal mining Fig. 7.

Fig. 7. Impaired Streams In West Virginia In 1998. Source: EPA 2009

As we move towards the 2002 period, there began to emerge a slightly different kind of pattern in the geographic diffusion of stream impairment linked to coal mining activities Fig. 8. The frequency of these patterns, did have profound effects on stream quality in the affected areas. From the 2002 map, there are four major clusters of streams with notable cases of impairment from mining. The waterbodies in question are in the high section of Upper Ohio, the North East Shenandoah and the adjoining streams and watersheds. Others in that cathegory include the upper north central streams of West Fork, Little Kanawha and the

Upper Ohio Shade and Elk. Stepping onto the deep southern part of the map, note the gradual manifestion of hightened impairment in lower Guyandotte, Coal, and Tug, Greenbrie, Middle new, and the Twelvepole streams. The presence of impairment cases in the study area occurred at levels much higher than the 1996 period Fig. 8.

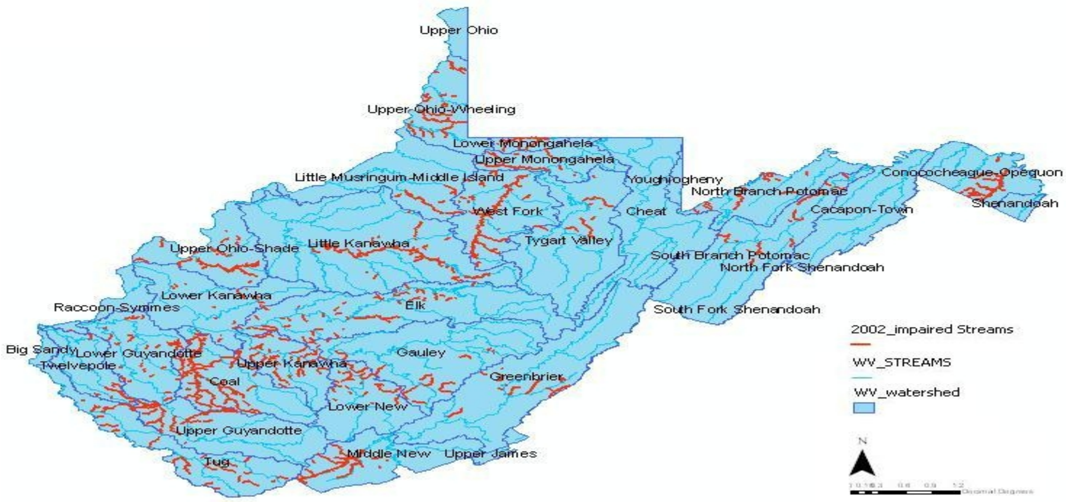

Fig. 8. Impaired Streams In West Virginia's In 2002. Source: EPA 2009

The details in Fig. 9 outlines the spatial dispersion of impaired streams in West Virginia. Despite some convergence in the patterns of degraded streams in 2002 and 2004, there are slight differences in the dispersion of impaired streams'locations in the study area. The minor divergence in patterns is evident in the lower south and central part of the map along Tug and Tygot valley. With impaired streams seemingly visible on many spots in a way similar to the previous period of 2002, a common trend in 2004 stems from the gradual disappreance of degradation in the two areas under a different pattern from the previous year. With the presence of impaired streams in space in 2004, let us not forget that most run-offs from mining sites empty into fragile streams and watersheds of the state Fig. 9

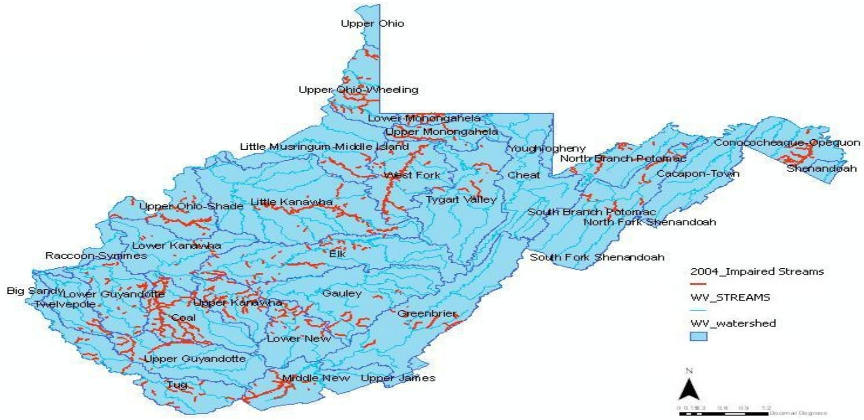

Fig. 9. Impaired Streams In West Virginia In 2004, Source: EPA 2009

From the maps, there seem to be a large scale stream impairment along the surrounding ecology of fragile watersheds adjacent to mining sites in the state between 1996 to 2004. Comparing the 1996 and 1998 maps, one notices slight diffusion of impairment into adjoining water systems in a manner not seen in the ensuing periods. Water impairment as a recurrent trend in the state assumed a much bigger scale as the years went by. During 2002-2004, the state experienced large scale levels of degradation. In this period, the extent of pollution known to threaten streams reached enormous proportions in the lower and upper part of the state. These impairments continue to threaten watersheds in the state.

Regarding the vulnerability of biodiversity, Fig. 10. Shows the distribution of habitats for diverse species in various areas of the state where mining activities are quite active. The data represents also the circulation and conservation status of biodiversity in the state. These areas contain different life forms made up of butterflies, amphibians, reptiles, birds and mammals. Inadequate safety measures during mining activities not only pose enormous threats to ecosystem health in these areas, but sensitive habitats for different life forms are also vulnerable. The species richness index calibrated at high and medium scales of red and yellow colors maintained a large presence in different areas adjacent to mining activities. With the proliferation of MTR, surface mining and the problems posed by abandoned and underground mine fires. It is evident that species richness across different areas on the map remained at risk all these years.

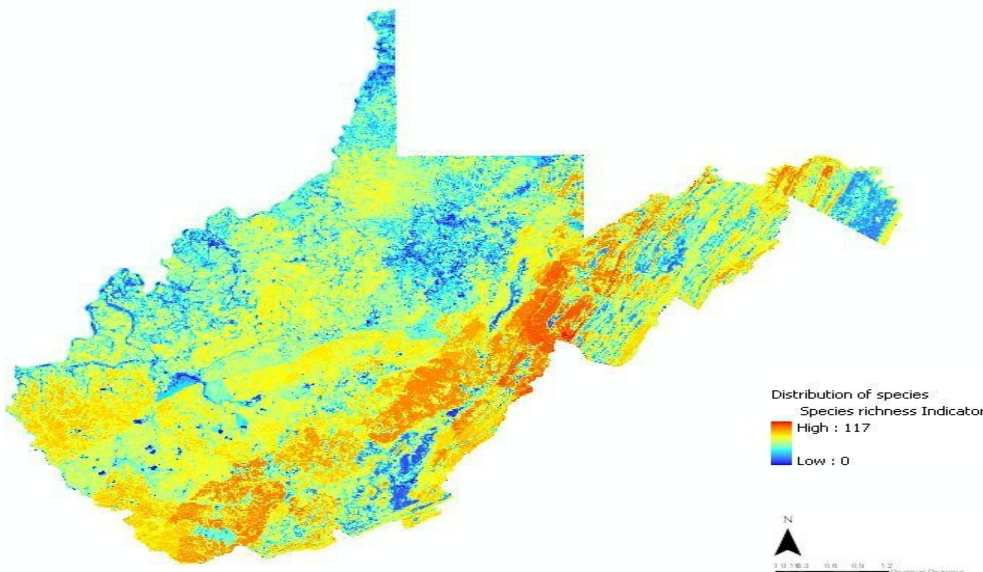

Fig. 10. Species Richness Source: Natural Resource Analysis Center, WV, 2002

3.5 Analysis of Green Space Degradation from Mountain Top Removal

Another evidence of degradation stems from the spatial dispersion of MTR impacts on Hobet 21 mine sites in West Virginia along the Mud River watershed. Analyzing these patterns of degradation on Hobet 21 mountain top mine requires multi temporal LANDSAT Satellite images from 1984, 1992 to 2012. The green and milky white colors on the maps represent indicators and stressors on the mountain top ecosystem. The green depicts open space in a mountain ecosystem, along with pipelines carrying mining residues into the tributaries, disturbed and restored areas and mining operations.

A close analysis of the images show the progression of the Hobet - 21 Mountain top mine along the Mud Rriver watershed of West Virginia Figs. 11-13. The images represent the expansion of the Hobet mine during the periods of 1984-2012. The usual background of the area showed shadowy green forested mountain containing tributaries and basins. At that time, the mountain features looked rancid-white, while areas under restoration with vegetation were defined by bright green colors.

Beginning in 1984, one notices partial presence of mining operations along the western portion of the Coal River. This was followed by more stretches on the south west of the mountain top Fig. 11. In 1992, mining activity extended onto the north side with vast presence of debris deposits evident with valley fills and earth dams. This is apparent with the flattening of the landscape and the development of mining areas in the northwest Fig. 12. While the area experienced a gradual emergence of green spaces and a reclaimed landscape in 2012, the images still point to the presence of mining activities in both the south west and northwest Fig. 13. Consequently, in almost three decades of MTR activities, landscape disturbance not only grew, but it impacted over 10,000 acres of land, the equivalent of 15.6 square miles.

Fig. 11. The Hobet Mine 21 In The Study Area, September 21 1984. Source: NASA

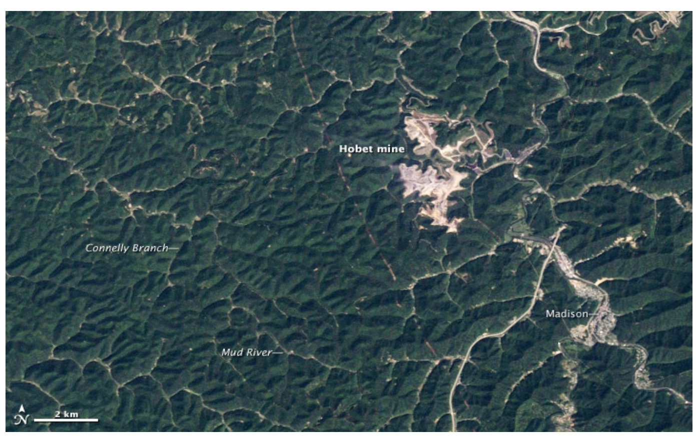

Fig. 12. The Hobet 21 Mine In The Study Area August 1992. Source: NASA

Fig. 13. The Hobet 21 Mine In The Study Area September 20, 2012. Source: NASA

4. DISCUSSIONS

From the analysis, the state of West Virginia is so heavily dependent on coal mining activities, that the sector provides jobs, income and tax revenues for the state. This is evident from the monetary contributions of the coal industry to the state. The environmental analysis of the trends showed that aside from the benefits of coal over the years, coal production in the state has been fluctuating with visible decline between 1998 through 2012. The drawback rests on the fact that much of the coal produced in the state are not all consumed there. In 1998, coal export and production exceeded other years when local consumption stood at only 22,460 tons. In the process, West Virginia not only carries the environmental burden of coal consumers outside the state, but it serves as a shadow ecology of those states at the expense of its own citizens.

Accordingly, the production of coal are not without impacts especially in the area of land use. From the analysis, the size of developed land in 1950 rose from 42,533 acreas to 135,566 in 1976. In the same period, the state saw its open farmland in mountain top coal producing areas drop to 188,303 in 1976. Within the same period, disturbed land areas rose from an initial value of 3,015 to 85,598 untill it reached 73,502 in 2002. Sizable acres of land were also consumed due to coal related activities over the years. Infact agricultural land loss went from 112,433 in 1950 to -716,000 over the years. The danger is that land disturbance of this nature impedes the welfare of the inhabitants. It leads to environmental degradation and loss of income from agriculture for those who depend on it and the state in general. The implication is that it amounts to deprivitaion of livelihood and ecosystem disturbance in a state where mining hazard has claimed over 60 lives between 1998 to 2010.

Notable threats from mining consists of ecosystem damage during MTR. As the paper showed, the state of West Virginia saw 352,000 acres of its mountain top land varnish from mining. This occurred on about 135 mountains representing 30.36% of the mountain top excosytems in the Appalachian region known for sediments, mud flow and run-offs from mining. There were also growing impairment of streams and watersheds attributed to different stressors. With evidence of biological contaminants, pH, and metals in streams and watersheds of the state, biological pollutants and metals continue to stretch the Upper Monogahele and four other watersheds (the Upper Kanawha, Coal, Upper Guyandatte and Twelve pole) beyond their carrying capacity respectively. Just as watershed analysis showed large concentration of stressors, MTR assessment identified landscape disturbance and ecosystem damages linked to mining. Seeing the vulnerability of natural areas, GIS as a tool pinpointed the enormity of risks faced by waterbodies and species' habitats adjacent to the coal fields of West Virginia. With socio-economic elements linked to degradation, mitigation efforts still have not adressed current concerns completely.

5. CONCLUSIONS

This part of the paper focuses on the closure with future lines of actions ranging from the need for corporate code of ethics to data infrastructure upgrade. See Appendix D for details of the recommendations. Essentially, this paper has explored the environmental impacts of mining using GIS with focus on West Virginia. The paper presented the issues with a profile of the study area and environmental analysis. The research also focused on the factors and efforts to stem degradation. With intense mining and the growing demands over the years, it is evident that coal production in West Virginia showed visible declines with impacts on the surrounding ecology and areas known for MTR activities. To analyze these issues, the paper used a mix-scale method of temporal-spatial analysis involving descriptive statistics and GIS. From the analysis, West Virginia boosts of substantial deposits of coal with economic benefits and growing impacts. While the techniques of mining (surface, underground, and MTR) threatens the ecosystem and the adjascent headwaters, between 1998-2010, mining hazards resulted in the death of 60 people in West Virginia.

Accordingly, the environmental impacts of mining continue to be felt in West Virginia with the disappearance of green cover, land loss, threats to mountain top biodiversity and water quality impairment. This is partly attributed to socio-economic variables of population, political factors, policy defects and favorable terrain for the industry. Notwithstanding the continual decline in the tonnage of coal over the years and the linkages between some socio-economic elements and environmental degradation, combined efforts among various entities to minimize degradation showed some promise. However, those initiatives have not eradicated degradation from mining completely. Compounding the matter is the absence of a mix scale analysis of mining of impacts on West Virginia's environment using GIS.

Of great importance is the mix-scale research approach of descriptive statistics and GIS in highlighting the severity of change induced by mining. In the geospatial analysis, the paper shows that while mining offers various benefits to West Virginia, it continues to impact nature with multiple cases of watershed impairment with greater concentration in different areas of the state. There were large spatial concentration of biological effluents, pH and metals in ecologically sensitive streams and the watersheds. Using GIS in that setting to track watershed impairment and the dispersion of pollutants, improves ourresearch and knowledge of the scale of ecosystem stress. This inturn provides a framework for analyzing ecosystems at risk. The usefulness of GIS in that circumstance stems from its capacity as a research and policy tool for pinpointing the threats of degradation across space.

Furthermore, the spatial analysis using GIS identified a cluster of areas in West Virginia where coal mining activities and the resulting run offs threaten stream habitat quality. From the analysis, the ecosystem was not only threatened, but there were a growing number of impaired water bodies. The assessment of these trends and the capability of GIS in pinpointing them enhanced our research and understanding of ecosystem vulnerability in the face of recurrent degradation induced by mining. GIS also provided a framework for assessing ecosystem declines attributed to coal mining activities and the mechanisms for mitigation. Finally, in the last decades the spatial dispersion of pollutants triggered by mining continues to erode sensitive environments adjacent to the coal fields of West Virginia. To remedy the problem, the paper offered suggestions ranging from the need to formulate a corporate code of ethics for the industry, the upgrade of data infrastructure and the continuity of GIS to sustain environmental decision making.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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APPENDIX- A

3.2.4 Watershed Impairments (Continued)

Among the watersheds adjacent to 1 to 2 mining sites, Conocochegue, South Branch, West Fork and North Branch seem to stand out. Of this group of watersheds most notably Conocochegue and North Branch, biological contaminants stood out as the core stressors with impairments numbering 226, 109, to 155 from 2002 through 2004. Looking at the other class of watersheds like Upper Ohio wheeling and Little Kanawha, pH impairements were distributed over the periods of 1996,1998 and 2002-2004 with numbers totalling 37, 112, 287 and 66, 235, 308 to 303 cases. Of the other set of lower tier watersheds (Middle new, Lower new, and Lower Kanawha) an interesting scenario emerges. At middle new watereshed, cases of biological impairment occurred in 29 to 38 streams between 1996 and 1998. The trend extended further into the 2002-2004 periods with 310 to 296 water bodies classified as impaired. This was a bit similar to the Lower new watershed, already dealing with high pH content reported in 28 to 94 streams and additional cases numbering 228 between 1996 to 2004. At Lower Kanawha, stream degradation from coal mining stayed on the rise with 33 to 65 incidents from 1996-1998. The trend continued in 2002 to 2004 with more cases.

APPENDIX- B

3.3 Factors Responsible For the Problems

As mentioned earlier, the prevalence of ecological degradation from mining does not operate in a vacuum. They are linked to socio-economic elements of politics, policy defects and demography.These factors are listed in detail on the following paragraphs.

3.3.1 Economic factors

West Virginia would not be in the current ecological morass without the lust for coal products. The demand for mountain top coal has grown the past years due to rising costs of fossil fuel and the demand for non-renewable extractive resources. This is attributed to the essence of coal as the economic engine driving the daily lives of US citizens and the emerging economies of China and India. Accordingly, the cost of coal products in the mid Appalachian region in serving those needs has increased threefold above the 2006 levels. In taking advantage of such a turn around, Virginia-based Massey Energy, in charge of several of the Appalachian's MTR activities, is committed to coal exports to China. Growing requests in this case lead to MTR which the industry views as the most gainful method. In the state where MTR and other kinds of mining represented 42% of coal production in 2007, the gains from global market access trigger externalities that disrupt ecosystems hence the linkage.

3.3.2 Political factors

From what transpired in West Virginia where coal is intertwined with politics, one notices a disregard for human lives and the ecosystem by the industry. Such inter-linkage is an indication of the power of coal industry in the political economy of the state in which degradations from coal happen while elected officials looked elsewhere. While this stems from the political and economic influence of the coal lobby. It reinforces the deep entrenchment of politics into the nature-economy interface debate in the state. Given the significance, it is political suicide for office holders to denounce safety violations. West Virginia's political elite has been firm in its backing of the coal sector. This mutual rapport is displayed yearly during the state's coal symposium, when elected officials and the coal sector socialize. This is compounded by the state government and congressional delegates who prefer softer regulations to accountability. In the absence of that support, MTR might not be permissible [40].

3.3.3 Policy defects

Stronger policies supported by the executive branch and the other regulatory agencies are crucial for attaining compliance in the mining sector [41]. Under a command and control mechanism in those rules and the "polluter pay" sanctions, violators who pay hefty fines would not want to be repeat offenders. However, in the case of West Virginia, the mining industry was offered a safe haven in 2002 when the Bush administration amended the regulation central to MTR waste in a ploy to circumvent the lawful ban on valley fills [40]. In fact, sanctions against clean water act violations prompts criticism by industry insiders who often decry stringent regulations as a hindrance to free enterprise. This is because much of West Virginia's land belongs to private landholding operators who rent the land and the rights to minerals to the coal industry. While this stifles public oversight on mountain top projects in private hands, it is hard to regulate in those circumstances.

3.3.4 Favorable terrain for the mining sector

The socio-cultural setting of West Virginia favors the industry. The state has the 2nd to lowest GDP per capita and 2nd lowest median household income. It also ranks 6th among states where citizens live below the poverty level [42]. Seeing that the state ranks poorly in most socio-economic indicators, it comes as no surprise that only a small number of businesses with the exception of coal mining are attracted to towns lacking basic necessities where infrastructures are under the worst conditions. Without steady revenues to provide services, impoverished counties turn to revenues generated from MTR. Mining operators, who capitalize on public misery, exploit those conditions at the expense of clean environment. In such a terrain, it is hard to survive politically in mining counties where those who back it thrive at the ballot box with huge rewards in campaign donations compared to challengers.

3.3.5 Geographic dimensions of economic elements

In terms of other economic factors, the geography of over dependence on revenues from mining in a fiscally challenged state such as West Virginia should not be overlooked. This can be buttressed from Fig. 14. where a few counties account for the largest concentration of income.Tougher regulations in those settings, could be seen as taking jobs away in economically depressed areas where citizens need jobs for survival, hence the tendency in the state to soften regulations in favour of the mining industry. The other thing is that being a less affluent state, there is a minor concentration of higher income brackets in a few areas of the state compared to the other cathegories in yellow and brown. Under that scenario, there is a always a tendency in space to support mining activities at every cost in order to generate wealth no matter the impacts on the surrounding ecology of the area.

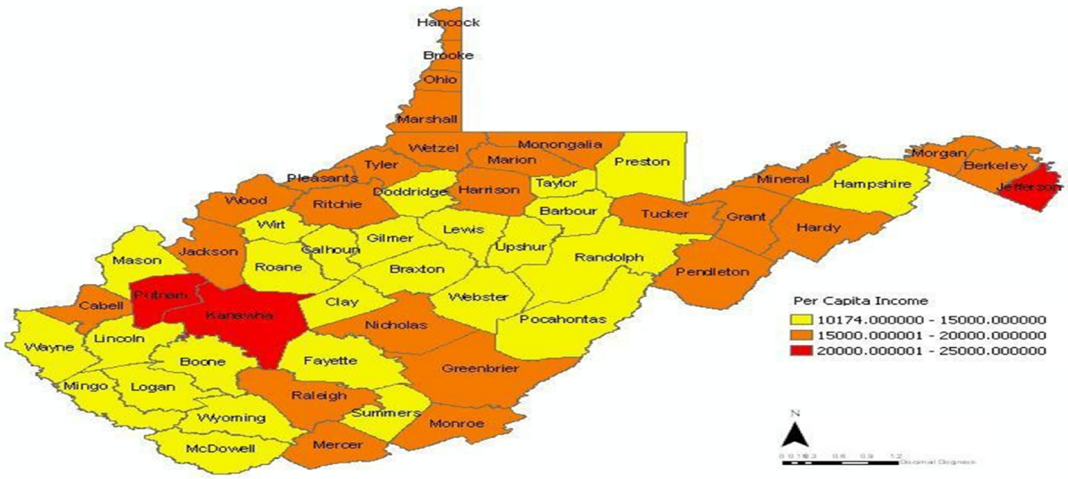

Fig. 14. Percapita Income Distribution. Source: US Census.gov, 2000

3.3.6 The spatial distribution of population

The distribution of populations in West Virginia from the map shows multiple classes with the highest identified as the blue and the medium ones in light blue and light green Fig. 15. This is followed by the low classes of population presence in orange and red. The problem is that regardless of location, size and the the number of people, built and natural environments in high and low density areas are always at risk. The severity of air and water pollution from mining would equally be damaging in counties represented in red and orange. The concern here centers on the vicinity of these communities to the mining sites of the state. Looking at these sites and the adjacent streams, one notices their vicinity to built environments. Such proximity raises the level of risks to built and natural areas.

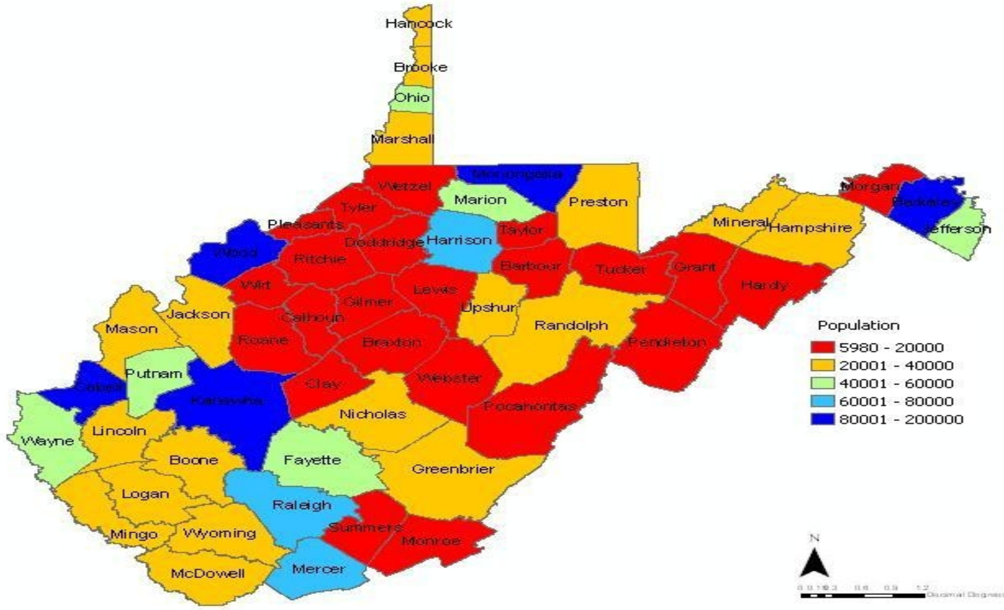

Fig. 15. Total population in the WV counties. Source: US Census.gov, 2006

APPENDIX- C

3.4 Efforts to Deal with the Problems

Within the study area, there are ongoing efforts to contain the environmental impacts of coal mining. Those initiatives ranging from the mobilization of environmental groups to land reclamation efforts are described briefly below.

3.4.1The active mobilization of environmental groups and legal actions

The impact of mining helped mobilize green groups in their support of communities faced with ecosystem damages in the state. Different forms of support made up of capacity building, trainings, legal and financial assistance were instrumental in acquainting impacted communities with their rights under existing policies. Since the late 1990s, environmental NGOs and residents of coalfield communities have initiated lawsuits against coal operators and regulatory agencies over these mines. The cases involved the illegality of streams as landfill for mining waste in accordance with the Clean Water Act and the use of valley fills in violation of the 1977 Surface Mining Control and Reclamation Act which require mining operators to return sites to their pre-land use form.

3.4.2 Federal guidance on mining

To deal with the problems associated with mining, the U.S. EPA has been active in the past in charting a new course towards effective monitoring. In the process, the agency devised a path on Appalachian mining aimed at a more reliable assessment of surface mining permits in line with the Clean Water Act and other laws. The proposed guideline drew heavily from the current advances in research and development that integrates feedback from the public. In furnishing EPA's local branches with up-to-date data on the present standards, the policy assists them to collaborate with states, the U.S. Army Corps of Engineers, mining companies, and the citizens in arriving at an acceptable method that shields communities from the hazards originating from coal mining. The expectation is that the EPA will enforce the policy amenably, in line with the common experience of individual sites.

3.4.3 Growing coordination among federal agencies

Recently the Obama Administration officials stated they are taking measures to diminish the impacts of MTR in the six Appalachian states including West Virginia under a synchronized model with the EPA, Department of Interior and Army Corps of Engineers. Building on a joint agreement reached by the agencies and the US Interior Department, the Administration implemented an Interagency Action Plan focused on MTR to minimize the negative impacts through interim measures finalized in 2009. Other aspects of the plan involved long range initiatives to strengthen guidelines on MTR and collaborations among agencies with tougher environmental assessments and rigorous scrutiny of permit requests in line with the Clean Water Act (CWA) and the Surface Mining Control and Reclamation Act (SMCRA) of 1997.

3.4.4 Reclamation and reforestation initiatives involving the private sector

Having seen the role of mining in degrading areas adjacent to coal fields, elements in the industry have taken it upon themselves to restore and reclaim degraded ecosystems. Knowing the complex process involved, coal entities are now restoring previously degraded

MRT sites. Being a difficult initiative requiring a decade for implementation, the process involves valley fills and new hilltops of crushed rock covered with topsoil to hold tree roots. Just as the recovery demands effective land management which coalfields lack, the lasting benefits remain unclear due to the sheer number of policy obstacles out there to overcome.

APPENDIX- D

4.1 Recommendations

4.1.1 Institute a corporate environmental code of ethics for the mining sector

There is a mutual relationship between humans and nature, yet industry critics forget that doing away with the ecosystem in any form under the pretext of development does more harm than good to communities facing the daily ordeal of degradation. Seeing that every decision made in the corporate board rooms of mining in West Virginia impacts nature and the wellbeing of communities, there is an ethical obligation which must be addressed through strict adherence to a corporate code of ethics by the sector. Because there is something intrinsically good about people and the different life forms in counties close to coal fields, it is pertinent that those values be observed by the industry. Thus there is an urgent need for a corporate body of norms to hold the industry accountable for the good stewardship of nature.

4.1.2 Subject the mining sector to tougher reviews

The regulation of MTR practices need not be grounded solely on the belief that the laws are always functional when crafted. In the case of water pollution from mining, the scanty oversight of its ecological impacts may not always solve it. Environmental policy without effective enforcement mechanisms like reviews not only risks losing its appeal, but there is a danger of being branded out of touch with the very issue it ought to be addressing. Rolling back laws in this way diminishes the use of federal regulators in addressing the impacts of mining. Seeing the degradation of natural areas adjacent to West Virginia coal fields known for MTR, stringent assessments with standards are indispensable in ensuring the quality of sensitive streams and for bringing the industry in compliance with the Clean Water Act.

4.1.3 Support reforestation and reclamation

The need for reclamation of degraded landscape in the study area after many years of mining is central to ecological regeneration of communities known to have experienced disturbance. This is vital considering the gravity of accumulated degradation in counties near West Virginia's coal fields. Even though the regulation requires MTR site be restored to its pre- land use form at the end of activities, most landscapes remain in ruins. Accordingly, reforestation is barely given a serious thought. Knowing the abundance of biodiversity in the study area, abandoned mines and habitats which should have been reclaimed to ensure species richness languish. In that light, the paper calls for the reforestation and reclamation of degraded areas in order to restore landscapes to their previous forms in affected counties.

4.1.4Improve data infrastructure and design regional ecological information system

During this study, there was no centralized data clearing house on the impacts of mining in West Virginia. The available facts on mining impacts were scatterred in diffferent places. To improve the situation, it is suggested that West Virginia improve existing environmental technologies and strengthen public access to data on degradation. This would enhance the ability to carry out impact assessment and reviews of coal fields activities in the state. There is also a need for more geospatial data on mining impacts. Without access to a spatially referenced system, decision makers and mining operations would not know the location and severity of degradation in the ecosystem. This would sharpen the readiness of regulators in reviewing policy violations while ensuring compliance with GIS as a tool in future endeavors.

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